Trend Analysis for Temperature and Precipitation Extreme Events over the Headwater of Upper Blue Nile, Ethiopia

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Abstract

Purpose: Increased trends in extreme climate events such as prolonged hot or cold days and intensively rainy days or consecutive dry days have greater negative impacts on society. While studies are conducted on climate variability and impacts most of them focus on the mean climatologies. Extrem events of Tempertaure and preciptation however have profound effect on human health and the environment. The present study aims to examine the spatial and temporal characteristics of means and extremes of temperature and precipitation events in the Tana-Beles Sub-basin for the 1980-2015 periods.

Methodology: Daily temperature and preciptaion time series was collected from the Ethiopian meteorological institute covering the 1980-2015. From the daily climate variables 22 daily extreme climate indices are calculated based on the Expert Team on Sector-specific Climate Indices (ET-SCI) definitions.

Findings: The Monthly, seasonal and annual temperatures show mostly increasing trends. The mean annual maximum and minimum temperatures increased slightly, respectively, by 0.047 and 0.014 ^{o}C/yr. The frequency of cold days/nights has reduced by 33/38 days/nights annually; whereas, the frequency of warm days/nights has increased by 91/83 days/nights. The mean monthly, seasonal and annual precipitations also show mostly increasing trends.Among the selected precipitation indices the number of very heavy rain days (R20mm), Simple Daily Intensity Index (SDII), very wet days exceeding the 95th percentile (R95p), and annual total wet days precipitation (RCPTOT) shows increasing trend; whereas, only the maximum 1-day precipitation (Rx1day), show an insignificant decreasing trend. Precipitation during the study period shows high variability spatially and temporally.

Unique Contribution to Theory, Policy and Practice: The study reveals increasing in number of hot days and vraible prciptation events, hence measures must be taken to reduce risks of extreme tempertures such as direct effect and indirect malaria distributions to new areas that have been cold before, and agricultural advised forming is also suggested to cope with the variabilities of prciptation.

Keywords: Climate trends; extremes climate events; Temperature and rainfall; and Tana-Beles Sub basins.

1. Introduction

Changes in extreme weather and climate events could have a profound negative impact on society and the environment severely than the changes in climatological means [1], [2]. An extremely hot or cold temperature event can increase human mortality, energy utilization, as well as environmental damage [3], [4]. Similarly, unusually heavy rainfall can lead to widespread flooding and significant drought can be caused by prolonged dry conditions [5]. Consequently, information about whether the weather or climate is becoming variable or more extreme is of greater interest to meteorologists, climatologists, and the public as well. Many studies have revealed that significant changes in some climatological extremes have taken place in many regions of the world over the last decades [4], [6], [7]. For instance analysis of extreme temperature and rainfall trends by [7] in western Thailand from 1961 to 2002 reveals a significant increase of warm days and warm nights, and the number of dry days was also increased, whereas, the number of wet days was decreased along most of the studied basins.

Tropical East Africa is considered as an important region where such analysis is lacking due to various issues such as poor data availability, quality, and consistency. However, owing to the community's highly direct dependence on the natural environment for livelihood, high levels of Poverty, rainfall variability due to Elnino Southern Oscillation (ENSO), and high population density; the region is highly vulnerable to impacts of extreme events [8], [9]. Recent studies in East Africa suggest that the region is facing various extreme events such as frequent droughts and excessive rainfalls [10]–[12] and left millions of people in need of humanitarian assistance. Moreover, different global and regional climate projection models indicate considerable trends in the climate and warming temperature in the region that exacerbate the existing extreme events such as heavy rainstorms, floods, fires, hurricanes, and tropical storms [13].

Ethiopia is a country located in the Tropical East Africa region where temperature differences are strongly modulated by elevation [14]. In other words, though Ethiopia is found within the tropic, is not a hot country since its altitudinal climate-controlling effect is significantly higher than its latitudinal controlling effect [15]. Analysis of mean climate time series in many parts of the country shows an increasing trend in temperature and a steady decline in precipitation [16]–[18]. This increase and variability of temperature and rainfall deficit determines crop suitability and cropping calendars of a certain area by affecting the evaporation rates and soil moisture [19], [20]. [21] reported no trend in annual and seasonal rainfall totals or the number of rainy days over central, northern, and northwestern Ethiopia, while, a decline in rainfall totals was detected in the eastern, southwestern, and southern parts. While average monthly observations capture the general climatic conditions and climate change well, extremes are best expressed by regular observations [22].

To address these and related problems, the Expert Team on Climate Change Detection and Indices (ETCCDI) has developed climate indices to provide information on daily climate extremes at regional and local scales. Although it was difficult to achieve common definitions of extreme climate indices approved by the international community until 1900 [23]; The ETCCDI is a statistically robust, globally accepted extreme climate index designed to define characteristics such as the amplitude, persistence, and frequency of extreme daily precipitation and temperature and to help explain whether the climate is more extreme or variable [6], [24], [25].

Little is however known about trends in extreme temperature or rainfall in Ethiopia in general and the North Central parts in particular; whereas, many areas of the country are particularly vulnerable to changes in climate extremes because of the population increase, dependence on a climate-sensitive sector (Agriculture) and ragged topography. In addition to this, the strong link between Ethiopian climate and ENSO is an important source of climate variability and extremes in many parts of the country [16], [26], [27].

The main objective of the present study is therefore to assess spatial and temporal trends in means and extreme temperature and precipitation events across the Tana-Beles Subbasins for the 1980-2015 study periods. Since the study area is considered as one of the growth corridors in Ethiopia where large-scale development projects such as the Tana-Beles hydropower plant (Operational), the Ethiopian Grand Renaissance Dam (EGRD), and the Tana-Beles sugar factory are underway; the information on climate means and extremes in the area can help manage the sedimentation and evaporation rates and water availability of the dam and the other projects. The area generally is the emerging place of the Blue Nile River hence, leveled as headwater.

2. Methodology

2.1 Study Area

The Tana and Beles sub-basins, totaling some 28,655 km^2, are sub-basins of the Abbay (Blue Nile) river in the northern highlands of Ethiopia (**Figure 1**). The sub-basins are geographically located between 10.20^o–12.78^o N and 35.00^o–38.25^o E in the western part of the upper Blue Nile basin. Lake Tana, the largest lake in Ethiopia and the third largest in Africa is located in these sub-basins. The Lake is the source of the Blue Nile River. The mean elevation of the Tana basin is 2025 masl, with the highest elevations reaching some 4,038 masl in the north-eastern part of the basin, and the mean elevation of the Beles basin is 1190 masl, with the highest point is 2,725 masl around the water divide between the Tana and Beles subbasins [28].

The climate of the TBSB is highly correlated with the seasonal propagation of the Inter-tropical Convergence Zone (ITCZ). The climate zone of the area dominantly falls under weinadega (sub-humid) and kola (semi-arid) agro climates. The mean annual rainfall varies from about 950-2000 mm, with a significant annual variation. Generally, the region is characterized by a monomodal rainfall regime, receiving most of the rain (70% to 90%) in one season (June to September); however, in the southern parts of the Tana sub-basin, the months of April to May are also an intermediate season where minor rains often occur. Similarly, the mean annual Temperature in the TBSB ranges from 6^{o}C to higher than 27^{o}C. The Mean annual temperature increases from North (the mountainous region) to South (The lower parts of Beles river).

The soils in most of the Tana basin are derived from the weathered basalt profiles, and are highly variable [29], [30]. In the Beles catchment soils have largely been derived from basalts and the basement rocks (source: MoWR). These soils generally are characterized from well to highly fertile for agricultural practices; however, the runoff associated with the complex topography makes it less productive in some parts. Most rural inhabitants of the TBSB are farmers employed in rain-fed subsistence agriculture. Crop production and livestock raising are closely integrated into the agricultural system.

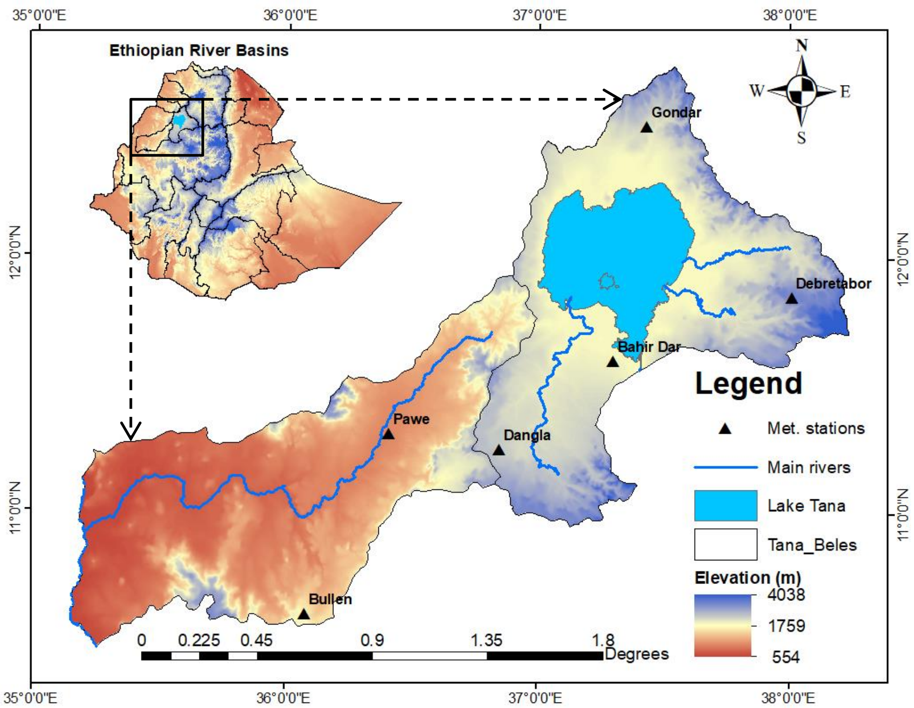

Figure 1 Location Map of the Tana-Beles Sub-basin and the Meteorological Stations Used in This Study.

2.2 Data and Quality Control

Time Series of daily minimum Temperature (T-min), daily maximum temperature (T-max), and daily precipitation (P) data for the period 1980 to 2015 for six meteorological stations were obtained from the National Meteorological Agency (NMA) of Ethiopia. The data record for the stations was not uniform; while few stations such as Bahir dar and Gondar have long-term records back to the 1960s; most of these data set experience uncertainties and too much missing data. However, the modern organized distribution of meteorological stations has been established since 1980. Quality data with little missing values for many meteorological stations in the country can be obtained from this period to date. Yet, most of the stations had only registered a short time or had several discontinuities for a brief time. Hence, the criteria for the selection of stations for extreme climate analysis were based on representativeness of different agro climate zones with feasible geographical distributions to cover the study area, length of record period, and the lowest proportion of missing data.

For robust results of trend analysis; a particular station must be considered to have 80% complete time-series data [31], [32]. Accordingly, after conducting exhaustive data quality checks, stations with less than 20% of missing data were qualified for further analysis in the present study. Moreover, routine quality checks were done by plotting the time series data and outliers such as negative values of rainfall as well as minimum temperature values greater than the maximum temperature values in a particular day were replaced by -99.9 or taken as a missing data which will later be recognized by the software for calculation of indices. While typographical errors such as minimum temperature typed as 115.5 ^{o}C during the first of June, 2008 for Bahir Dar were corrected to 15.5 ^{o}C by contacting the experts in the Meteorology Office.

In addition to data quality control, inhomogeneity is a further problem that theoretically affects data quality. Any time-series data may experience discontinuities or inhomogeneity due to various causes such as; urbanization, changes in location, exposure, instrumentation, and observation practice, and also from missing data. It is important to conduct homogeneity tests for the robust analysis of climate trends and variability of the time series [22], [31], [33]. For this reason, the RHtestsV4 tests software package embedded in the R software has been utilized to test the data inhomogeneity and further adjustments. The RHtests technique is based on the penalized maximal t (PMT) or F test (PMF) [34]. While the t-test needs the use of neighboring stations for comparison; the F-test can be used as an absolute method [35]. The present study uses the latter approach to detect potential non-climatic changes in the precipitation and temperature time series.

Finally, after conducting the necessary quality checks and adjustments to inhomogeneity; the daily time series data were subjected to further classifications into monthly, seasonal and annual time series. The seasons of Ethiopia are classified into three; Winter (ONDJ), Spring (FMAM), and Summer (JJAS) based on the climatological means of rainfall and temperatures [36],[37].

3.2 Extreme climate indices

Indices derived from daily data are an attempt to extract information critically from daily weather observations to address questions about aspects of the climate system affecting many human and natural systems, with a particular focus on extremes. The Expert Team on Climate Change Detection and Indices (ETCCDI) has therefore established a globally organized set of core climate indices consisting of 27 descriptive indices for moderate extremes to detect changes in extreme climatic conditions [1], [38]. Later, the ET-SCI developed a set of core and non-core indices by the World meteorology Organization (WMO) Technical Commission for Climatology for better support sector-specific adaptation. The ET-SCI indices are developed along with software called ClimPACT2 which is run on an R software package; which is used to construct time series of the indices and for the user to create their index based on absolute thresholds.

The extreme climate indices calculated are based on two approaches; the relative threshold which is based on an absolute threshold (summer days (SU), Number of days when TX > 25 °C or consecutive dry days (CDD), Maximum number of consecutive dry days, when PR < 1.0 mm) and percentiles (hot days (TX90p), Percentage of days when TX > 90th percentile and heavy rains (R95P), Annual sum of daily PR > 95th percentile) approaches [4]. The percentile weather indicators were calculated by summing the number of days for which daily values exceed a time-of-year dependent percentile. In the present study, a total of 22 extreme climate indices of the Expert Team on Sector-specific Climate Indices (ET-SCI); 12 extreme temperatures and 10 extreme precipitations were utilized to calculate the changes in extreme events **(Table 1)**. Since TBSB is located in the warm tropical area of the northern hemisphere, it is not possible to obtain values for indices such as Frost Days (FD) and Ice Days (ID) for most years of the study period; hence, they are not included in our research.

The study used twenty years (1981-2000) averages of each station as a baseline for the extraction of an anomaly in the time series by adapting procedures of [22]. The inter-annual anomalies of the selected parameters are also calculated using this reference period. While the standard base period recommended by WMO to calculate climate indices is 1971-2000; in lack of data record that covers the standard base period, users can specify the climatological base period which is most suitable for their data [1], [22].

Table 1 Definition of the Selected Extreme Temperature and Precipitation Indices.

Index	Indicator name	Long definition	Units	Sector
TXx	Max TX	Warmest daily TX: Hottest day	ºC	AFS
TNn	Min TN	Coldest daily TN: Coldest night	ºC	AFS
TNx	Max TN	Warmest daily TN: Hottest night	ºC	---
TXn	Min TX	Coldest daily TX: Coldest day	ºC	---
DTR	Diurnal temperature range	Monthly mean difference between TX and TN; Average range of maximum and minimum temperature	ºC	---
SU	Summer days	Number of days when TX > 25 °C : Days when maximum temperature exceeds 25 °C	days	H
WSDI	Warm spell duration indicator	Annual number of days contributing to events where 6 or more consecutive days experience TX > 90th percentile: Number of days contributing to a warm period (where the period has to be at least 6 days long)	days	H, AFS, WRH
CSDI	Cold spell duration indicator	Annual number of days contributing to events where 6 or more consecutive days experience TN < 10th percentile: Number of days contributing to a cold period (where the period has to be at least 6 days long)	days	---
TX10p	cool days	Percentage of days when TX < 10th percentile: Fraction of days with cool day time temperatures	%	---
TX90p	hot days	Percentage of days when TX > 90th percentile: Fraction of days with hot day time temperatures	%	---
TN10p	Cold nights	Percentage of days when TN < 10th percentile: Fraction of days with cold nighttime temperatures	%	---
TN90p	warm nights	Percentage of days when TN > 90th percentile: Fraction of days with warm nighttime temperatures	%	---
CDD	Consecutive Dry Days	Maximum number of consecutive dry days (when PR < 1.0 mm): Longest dry spell	days	H, AFS, WRH
CWD	Consecutive Wet Days	Maximum annual number of consecutive wet days (when PR≥1.0 mm):	days	---
R10mm	Number of very heavy rain days	Number of days when PR ≥ 10 mm: Days when rainfall is at least 10 mm	days	AFS, WRH
R20mm	Number of very heavy rain days	Number of days when PR ≥ 20 mm: Days when rainfall is at least 20 mm	days	AFS, WRH
SDII	Daily PR intensity	Annual total PR divided by the number of wet days (when total PR ≥ 1.0 mm): Average daily wet-day rainfall intensity	mm/day	---
Rx1day	Max 1-day PR	Maximum 1-day PR total: Maximum amount of rain that falls in one day	mm	---
Rx5day	Max 5-day PR	Maximum 5-day PR total: Maximum amount of rain that falls in five consecutive days	mm	---
R95p	Total annual PR from heavy rain days	Annual sum of daily PR > 95th percentile: Amount of rainfall from very wet days	mm	AFS, WRH
R99p	Total annual PR from very heavy rain days	Annual sum of daily PR > 99th percentile: Amount of rainfall from extremely wet days	mm	AFS, WRH
PRCPTOT	Annual total wet-day PR	Sum of daily PR ≥ 1.0 mm: Total wet-day rainfall	mm	AFS, WRH

2.4 Trend analysis of Rainfall and Temperature

Using least square likelihood techniques, the linear trends in the time series of selected indexes at each weather station and averaged over the six stations for the study period are extracted. The Kendall-tau test, which is a non-parametric approach to determine the pattern of extreme climate events effectively, [39], [40], was used to test the significance of the trend. The linear trends with a significance of p-value less than 0.05 (~95% confidence level) were considered as significant, and the "*" symbol in the tables and graphs represents trends that are statistically significant at ($p \leq 0.05$). The regional trend analysis provides a clear picture of the spatial variation in the direction of trends and their statistical significance. To this end, the magnitude of trend and statistical significance for the regional averages were mapped by using the Geographic Information System (ArcGIS 10.2). Moreover, the inverse distance waiting (IDW) interpolation method, which is suggested for sparse distribution of data, was used to interpolate each data points into spatial patterns. The direction of the arrows in the spatial plots of the trend indicates; an upward arrow for positive trend and a downward arrow for negative trend. Similarly, the significances are represented by colors as; red color for significant positive trend, blue color for significant negative trend, and black color for trends that are not significant.

4 Results and Discussions

3.1 Trends in mean temperatures

Table 2 summarizes the monthly trends of maximum and minimum temperatures for the selected stations and the regional averages during 1980-2015. The trend analysis of the mean monthly maximum temperatures shows a statistically significant increasing trend for most of the months at all stations; particularly at Bahir dar and Pawe, trends are significant in eleven months. However, the months April through November show a decreasing trend which is not significant, at few stations. The areal average trend of maximum temperature shows a significant increasing trend in all months. On the contrary, the mean monthly minimum temperature shows both increasing and decreasing trends. The increasing trend is significant in all months at Pawe. Conversely, the decreasing trends for some months are also significant at Dangila and Debretabor. The highest regional significant increase in monthly minimum temperature is 0.030 °C/year and is observed in September. The seasonal and annual temperatures also show trends that are mostly positive and significant at most stations and the whole TBSB as well **(The seasonal** and annual time series linear trends for the anomaly of maximum and minimum temperatures are illustrated in **Figure 2**. From the figure, it can be noted that the increase in maximum temperature is steeper than that of minimum temperature among all time scales. In addition to that, the maximum and minimum temperatures show an abrupt increase during recent years indicating that extreme temperatures are accelerating and forcing the climatological means particularly in the latter part of the study period.

Table 3**)**. Maximum temperature shows significant (except at one station: Bullen) increasing trends, particularly during the spring season. Significant decreasing trends were also observed for the seasonal and annual timescales at few stations. On the other hand, the seasonal and annual minimum temperature shows a significant increasing trend at Gondar and Pawe. Significant decreasing trends were also recorded at Dangila and Debretabor during the winter and spring seasons. The areal average minimum temperature shows an increasing trend in all seasons and the annual times, and trends are significant for summer (0.024°C/year) and annual (0.014°C/year) time scales.

Table 2 Linear Trends (°C/year) for Monthly Maximum and Minimum Temperatures in Individual Stations and the TBSB for 1980-2015.

	Station	J	F	M	A	M	J	J	A	S	O	N	D
Maximum Temperature	Bahir dar	0.023*	0.073*	0.040*	0.041*	0.039*	0.063*	0.033*	0.034*	0.027*	0.023*	0.020*	0.018
	Bullen	0.029	0.058*	0.029*	-0.04	-0.027	-0.038*	-0.031*	-0.030*	-0.016	-0.039*	-0.018	0.012
	Dangila	0.046*	0.086*	0.049*	0.025	0.005	0.008	0.023	0..014	0.026*	0.009	0.011	0.033*
	Debretabor	0.058*	0.094*	0.079	0.057*	-0.024	0.017	0.041*	0.058*	0.070*	0.078*	0.067*	0.020
	Gondar	0.027	0.069*	0.043*	0.045*	0.059*	0.020	0.030	0.029*	0.039*	0.058*	0.057*	0.044*
	Pawe	0.186*	0.221*	0.204*	0.183*	0.141	0.120*	0.122*	0.106*	0.112*	0.087*	0.112*	0.157*
	TBSB	0.063*	0.102*	0.075*	0.059*	0.034*	0.033*	0.037*	0.035*	0.044*	0.037*	0.042*	0.046*
Minimum Temperature	Bahir dar	-0.021	-0.019	-0.032	0.005	0.001	-0.042	-0.001	-0.003	-0.004	0.035*	0.017	-0.021
	Bullen	-0.015	0.013	0.013	0.003	-0.005	-0.015*	-0.014*	-0.002	-0.006	-0.021*	-0.039*	-0.017
	Dangila	-0.079*	-0.064*	-0.076*	-0.042	-0.027	0.005	0.023	0.015	0.033	-0.001	-0.030	-0.061*
	Debretabo r	-0.084*	-0.049*	-0.036*	-0.040*	-0.040	-0.016	0.024*	0.030	0.013	-0.015	-0.033*	-0.065
	Gondar	0.028	0.055*	0.027	0.030	0.041*	0.033*	0.044*	0.046*	0.040*	0.045*	0.034*	0.031
	Pawe	0.057*	0.111*	0.105*	0.118*	0.081*	0.122*	0.095*	0.087*	0.105*	0.097*	0.062*	0.035*
	TBSB	-0.003	0.019	-0.001	0.023	0.016	0.021*	0.023*	0.023*	0.030*	0.026*	0.005	-0.017

The seasonal and annual time series linear trends for the anomaly of maximum and minimum temperatures are illustrated in **Figure 2**. From the figure, it can be noted that the increase in maximum temperature is steeper than that of minimum temperature among all time scales. In addition to that, the maximum and minimum temperatures show an abrupt increase during recent years indicating that extreme temperatures are accelerating and forcing the climatological means particularly in the latter part of the study period.

Table 3 Linear Trends (°C/year) in the Seasonal and Annual Maximum and Minimum Temperatures in Individual Stations and the TBSB, 1980-2015.

Station	Maximum Temperature				Minimum Temperature			
	Winter	Spring	Summer	Annual	Winter	Spring	Summer	Annual
Bahir dar	0.021*	0.048*	0.039*	0.036*	0.003	-0.001	-0.013	-0.007
Bullen	-0.007	0.014	-0.029*	-0.007	0.023*	-0.001	-0.014*	-0.013
Dangila	0.025*	0.042*	0.018*	0.028	-0.043*	-0.052*	0.019	-0.025
Debretabor	0.056*	0.052*	0.046*	0.051*	-0.049*	-0.041*	0.013	-0.026*
Gondar	0.046*	0.054*	0.030	0.043*	0.035*	0.038*	0.041*	0.038*
Pawe	0.136*	0.0187*	0.115*	0.146*	0.063*	0.104*	0.102*	0.090*
TBSB	0.047*	0.067*	0.037*	0.050*	0.003	0.015	0.024*	0.014*

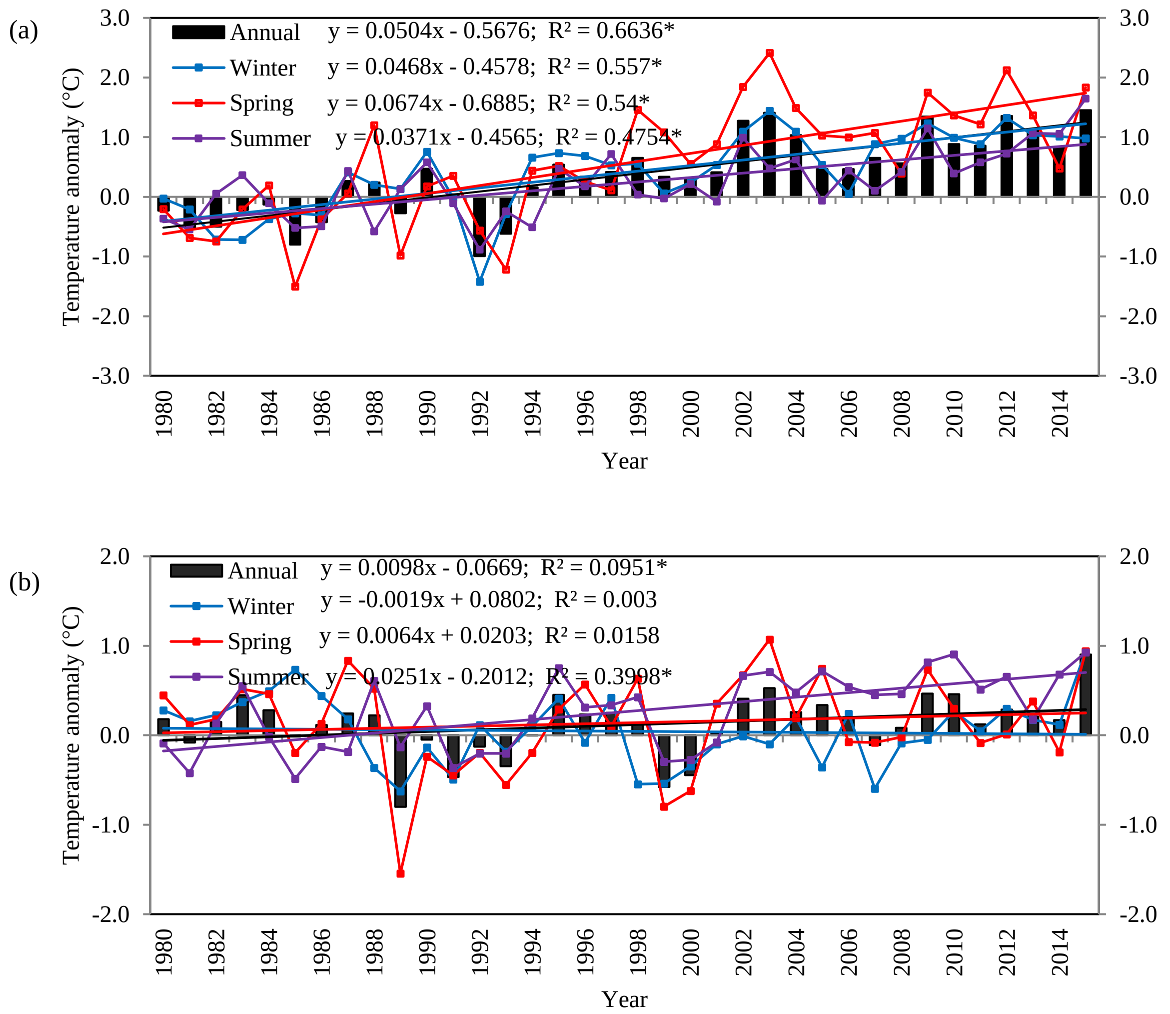

Figure 2 Seasonal and Annual Changes of the Maximum (a) and Minimum (b) Temperatures Averaged Over the TBSB for the 1980-2015 Study Periods.

3.2 Trends in extreme temperatures

The trends of various temperature indices for each selected station and regional averages are summarized in Table 4. Accordingly, the indices Max Tmax (TXx) and min Tmax (TXn) show an increasing trend in most of the stations. The Max Tmax (TXx) shows a significant increase at five stations (Bahir dar, Bullen, Dangila, Gondar, and Pawe) among the six selected stations, while a decreasing trend not significant at Debretabor. The rate of significant increase of Max Tmax (TXx) during the study period includes 0.090, 0.082, and 0.044 ^{o}C/yr; recorded at Bullen, Pawe, and Gondar, respectively among the others. Similarly, the Min Tmax (TXn) shows an increasing trend in five stations (Bahir dar, Bullen, Debretabor, Gondar, and pawe), and a decreasing trend in one (Dangila). However, neither the observed increase nor the decrease in the Min Tmax (TXn) is significant at all stations. When comparing the results of Max Tmax (TXx) with Min Tmax (TXn), we note that almost all stations show relatively stronger positive or weaker negative trends for the Max Tmax (TXx). Regarding the Max Tmin (TNx) and Min Tmin (TNn); the Max Tmin (TNx) shows an increasing trend in four stations of which only at Pawe with a significant increase of 0.065 ^{o}C/yr, whereas the other two stations (Bahir dar and Debretabor) show a decreasing trend which is not significant. Similarly, the Min Tmin (TNn) shows the same pattern of a trend as the Max Tmin (TNx) counterpart. However, the negative trend is significant at Debretabor (-0.074 ^{o}C/yr) for the Min Tmin (TNn). The set of indices (TXn, TNx, and TNn) shows comparatively weaker trends; only a few stations show significant change. Because, as these indices are calculated based on a single event in a year, there is more inter-annual variability than the other indices. The trend results are generally consistent with previous results in many parts of Ethiopia. For example, [41], found a significant increasing trend in Max Tmax (TXx) of about 2.4 ^{o}C for the whole country.

Other analyzed extreme weather indices include diurnal temperature range (DTR), summer days (SU), an indicator of cold spell period (CSDI), and an indicator of warm spell duration (WSDI). The diurnal temperature range (DTR) shows an increasing trend in all stations except two (Bullen and Dangila) which are located in the lower half of the sub-basins. However, the rate of increase/decrease in DTR is significant in none of the selected meteorological stations. While most of the temperature indices are affected by either of the daily maximum or daily minimum temperatures; the DTR is affected by both of these parameters. Hence, the result of these differential changes is the narrowing of the diurnal temperature range (DTR) (Easterling et al. 1997). Summer days (SU) show an increase in all of the analyzed stations; the significant increases are 1.527, 1.345, 1.253, and 1.234

days/yr which are recorded at Debretabor, Bahirdar, Pawe, and Gondar stations respectively. The CDSI shows a decreasing trend in five statins which is significant only at Dangila (-0.743 days/yr); whereas, the WSDI shows an increasing trend which is significant at Bahir dar (1.105 days/yr) and a decreasing trend that is not significant at Debretabor. It can be generally noted that while the increase in Max Tmax (TXx) and Max Tmin (TNx) is accompanied by the increase in WSDI; the decrease in Min Tmin (TNn); and min Tmax (TXn) is accompanied by a decrease in CSDI.

Table 4 Annual Trends in Extreme Temperature Indicators for the Selected Meteorological Stations and the TBSB.

Station	Indexes											
	TXx	TXn	TNx	TNn	DTR	SU	CSDI	WSDI	TX10p	TX90p	TN10p	TN90p
Bahirdar	0.011	0.009	-0.013	-0.027	0.037*	1.345*	0.480	1.105*	-0.249*	0.596*	0.115	0.088
Bullen	0.090*	0.010	0.153*	0.032	-0.041	1.935	-0.468	0.117	-0.317	0.318	-0.419*	0.778*
Dangila	0.039*	-0.037	0.065	0.028	-0.060	0.217	-0.743*	0.042	-0.338*	-0.170	-0.578*	0.249
Debretabor	-0.012	0.007	-0.019	-0.076*	0.074*	1.527*	-0.364	-0.190	-0.451*	0.282	0.042	-0.465*
Gondar	0.044*	0.024	0.025	0.001	0.018	1.234*	-0.025	1.364*	-0.261	0.812*	-0.219	0.298*
Pawe	0.082*	0.017	0.065*	0.010	0.039	1.253*	-0.542	0.520	-0.430*	0.390*	-0.338	0.446
TBSB	0.069*	-0.008	0.047*	-0.021	0.015	1.422*	-0.432*	2.209*	-0.325	0.911	-0.381*	0.830*

The set of percentile-based indices: warm days (TX90p) and cool days (TX10p) Warm nights (TN90p) and Cool nights (TN10p) also show trends. Generally, the warm indices show an increasing trend in most of the selected stations whereas the cold indices mostly show a decreasing trend. Warm days (TX90p) show a significant increase at Bahir dar (0.596 days/yr), Gondar (0.282 days/yr), and Pawe (0.812 days/yr) and decreasing trend which is not significant at Dangila. Similarly, the Warm nights (TN90p) shows a significant increase/decrease at Bullen (0.778 days/yr) and Gondar (0.298 days/yr)/ Debretabor (0.465 days/ yr) respectively. on the contrary, the cool days (TX10p) show a decreasing trend at all stations that is significant at three stations; namely, Bahir dar, Dangla, and Pawe; with a rate of decrease of 0.249, 0.338, and 0.430 days/yr respectively. Whereas, the Cool nights (TN10p) shows a decreasing trend in four stations while two stations show an increase that is not significant. The significant decreasing trend is recorded at Bullen (0.419 days/yr) and Dangila (0.578 days/yr).

More comprehensive information on how the extent of the rate of change in extreme climate events varies from one weather station to another is given by spatial distribution maps of patterns in extreme climate indices at individual stations [4]. For this reason, the spatial distribution pattern of trends for selected temperature indices is presented in **Figure 3**. Generally, while the cold indices cold days (TX10) and cold nights (TN10) show a decreasing trend; the pattern of warm extremes; warm days (TX90p), and warm nights (TN90p) show an increasing distribution except in Dangila and Debretabor for the former and latter cases respectively. The decreasing pattern in warm nights (TN90p) in Debretabor is significant; this could be related to the location of the station which is situated to the highest mountain (Mount Guna) of around 4038m. Because spatial and temporal temperature trends are complex in mountainous countries due to both regional synoptic-scale and landscape-scale physiographic climate system controls [17], [42].

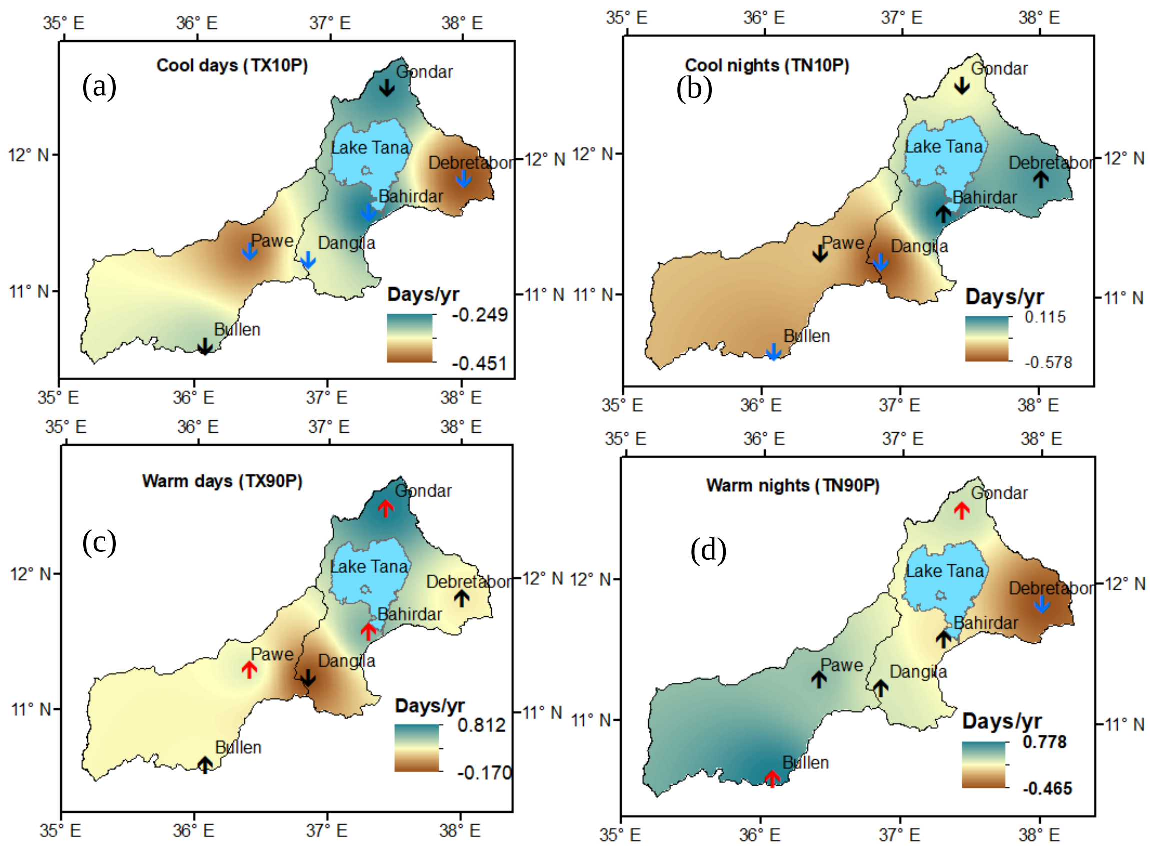

Figure 3 Spatial Patterns of Trends (Days/Year) in percentile-based Annual Extreme Temperature Events at Six Individual Weather Stations Across the TBSB, 1980–2015: for (a) Cool Days (TX10P); (b) Cool Nights (TN10P); (c) Warm Days (TX90P) and (d) Warm Nights (TN90P). The Direction of Arrows Indicates the Signs of Trend, Colored Arrows (Red/Blue) Represent Statistically Significant (p=0.05) Trends of (Increase/Decrease).

The results of the trend analysis for the regional temperature indices are also illustrated in **Figure 4** (for selected indices). It can be noted that an increase in the number of hot days and warm nights and a decline in the numbers of cold days and cool nights with some evidence of year-to-year variation particularly after 1995. In the last year 2015, there was a similar increase in hot days and warm nights and a decrease in cold days and cool nights throughout the region; coinciding with the hottest year (2015/2016) in the history of instrumental records before the current study[43][43][43][43]. Generally, the numbers of cool nights and cool days have been reduced annually by a factor of 38.1 and 32.5 days/yr respectively, while the numbers of hot days and warm nights have increased by a factor of about 91.1 and 84.2 days/yr respectively, as compared to the base period of the data series (1981-2000). This implies that the warming during recent decades can be related to the increase in warm extremes than a decrease in cold extremes.

(a)

(b)

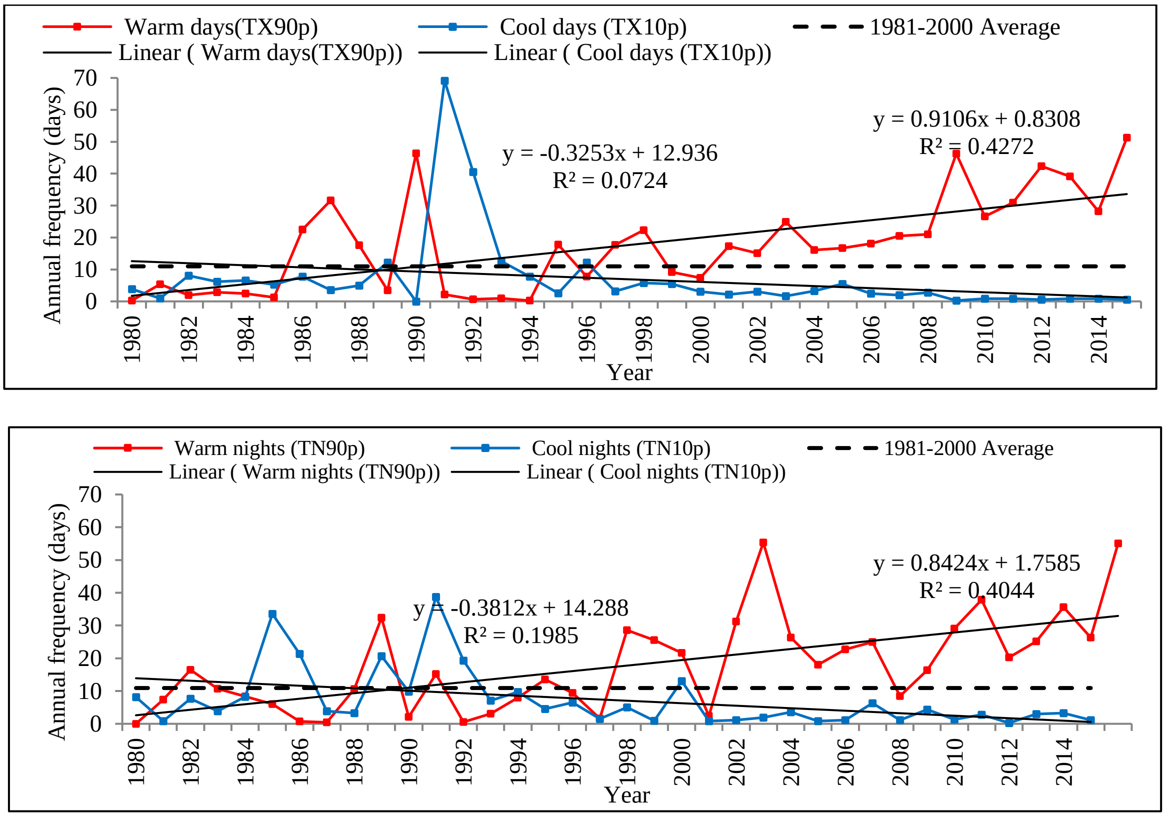

Figure 4 Regional Average Change in; (a) Warm Days (TX90P) and Cool Days (TX10P), and (b) Warm Nights (TN90P) and Cool Nights (TN10P), Averaged Across the Six Meteorological Stations, 1980-2015.

The results found in the present study are consistent with previous results conducted at various places; for example, in Africa, the temperature had significantly increased by more than 0.5^{o}C in the last 50-100 years (Senegal et al., 2014; Gan et al., 2016). The studies also show a positive trend of maximum and minimum temperatures in Africa during the last decades (Senegal et al., 2014; Adhikari et al., 2015; Mengistu & Lal, 2014); and, statistically significant positive trends since the 1980s [47]. In Ethiopia, reports of the NMA on maximum and minimum temperatures show an increase by 0.1 and 0.25–0.37 ^{o}C per decade respectively. McSweeney et al., (2008), revealed that mean annual temperature had increased by about 0.28 ^{o}C per decade; differing among various seasons he observed the higher magnitude of change of about 0.32 ^{o}C per decade during summer. Moreover, the studies report an increase in the frequency of warm extremes and a decrease in the frequency of cold extremes. In 2010 a study by, McSweeney et al., (2010) show an increase in the number of warm days (TX90p) and warm nights (TN90p).

A relatively recent study Over East Shoa Zone, Ethiopia by Mequanint et al., (2016), which cover approximate observation period to the current study, also show a significant ($p<0.05$) increasing trend of TN90P, TX90P, TXx, and TNx indicators in most of the stations examined. Likewise, a study in three eco-environments of Ethiopia by Mekasha & Duncan, (2013), found positive trends of warm extremes; TXx, TX90p, TN90p, and WSDI at seven out of eleven examined stations and negative trends of cold extremes; TX10p, TN10p, and the CSDI at eight statins; negative trends being significant at four stations. However, in the present study, the spatial coherence within and among the temperature indices was weaker; this could be related to the complex topography of the study area in which some stations are located at about 550 masl and others at about 4038 masl.

3.3 Trends in mean precipitation

Similar to temperature, the trend and variability results of precipitation are also presented for the monthly, seasonal and annual time scales. The monthly rainfall shows both increasing and decreasing trends, however, only a few months at some stations show a significant rising trend **(Table 5)**. The regional average monthly precipitation shows a significant trend of 1.577 mm/year only during September. The highest monthly decreasing trend which is not significant is 2.484 mm/yr which was observed during May at Pawe station. Due to the erratic events in the months, rainfall events during the period from October to May are sporadic and bring about a considerably small amount of rainfall. On the other hand, since the TBSB receives most of its rainfall during the main rain months (June-September), any significant change in these months may later lead to long-term change in summer and annual trends and the occurrence of extreme events (i.e., storms and floods).

Similarly, the seasonal and annual rainfall shows both positive and negative trends dominated by positive trends **(Table 6)**. The significant rising trends are observed during the winter and summer seasons and the annual time scale, and the corresponding amounts of rising are 3.198, 3.857, and 5.796 mm/year recorded at the stations Pawe, Gondar, and Bahirdar respectively. The negative trends are seen in the winter and spring seasons only. The regional average precipitation shows a positive trend in all seasons and the annual timescale. However, the trend is significant only for the annual time scale which is 5.012 mm/year. The patterns of change in the annual rainfall revealed by this study are consistent with changes observed in many parts of Ethiopia. Trend analysis by McSweeney et al., (2008) indicates that annual precipitation decreased during the 1980s in many parts of Ethiopia, and recovered during the 1990s and 2000s except 2002–2003 where the country was under the worst drought period.

Table 5 Linear Trends (mm/year) for Monthly Precipitation in Individual Stations and the TBSB, 1980-2015.

Station	J	F	M	A	M	J	J	A	S	O	N	D
Bahir dar	0.026	-0.044	0.342	-0.214	0.679	0.410	1.156	1.864	0.963	0.458	0.012	0.0142
Bullen	-0.011	-0.025	0.089	0.144	-0.124	1.602	-0.443	1.422	3.980*	1.608	0.155	-0.052
Dangila	0.013	0.016	0.043	0.262	2.143	0.741	-0.975	-0.748	1.251	1.017	1.139*	-0.016
Debretabor	0.197	-0.118	0.590	0.344	1.510	1.159	-0.384	-0.059	1.095	-0.774	-0.280	0.049
Gondar	0.063	0.003	0.211	-0.466	-0.227	0.693	0.250	2.681*	0.233	-0.050	0.159	0.126
Pawe	-0.084	-0.035	0.085	-0.156	0.261	-2.484	-0.402	1.696	1.003	0.893	0.277	1.734*
TBSB	0.024	-0.029	0.235	0.099	0.578	0.330	-0.430	1.520	1.577*	0.497	0.271	0.338

Table 6 Linear Trends (mm/year) for the Seasonal and Annual Precipitation at Individual Stations and the TBSB, 1980-2015.

Station	Winter	Spring	Summer	Annual
Bahir dar	0.639	0.764	4.393	5.796*
Bullen	1.700	0.083	6.561	8.344
Dangila	2.153	2.463	0.270	4.886
Debretabor	-0.808	2.326	1.811	3.329

Gondar	0.298	-0.478	3.857*	3.677
Pawe	3.198*	-0.155	1.293	4.336
TBSB	1.131	0.883	2.997	5.012

Analysis of rainfall variability is also important for many sectors for early warning and preparation purposes. For example for the Agricultural sector; it is important to know the seasonal variation of rainfall for accurate assessment of crop water requirements [39]. To this end, high regional rainfall variability was observed in the monthly, seasonal and annual time scales during 1980-2015 (**Figure 5**).

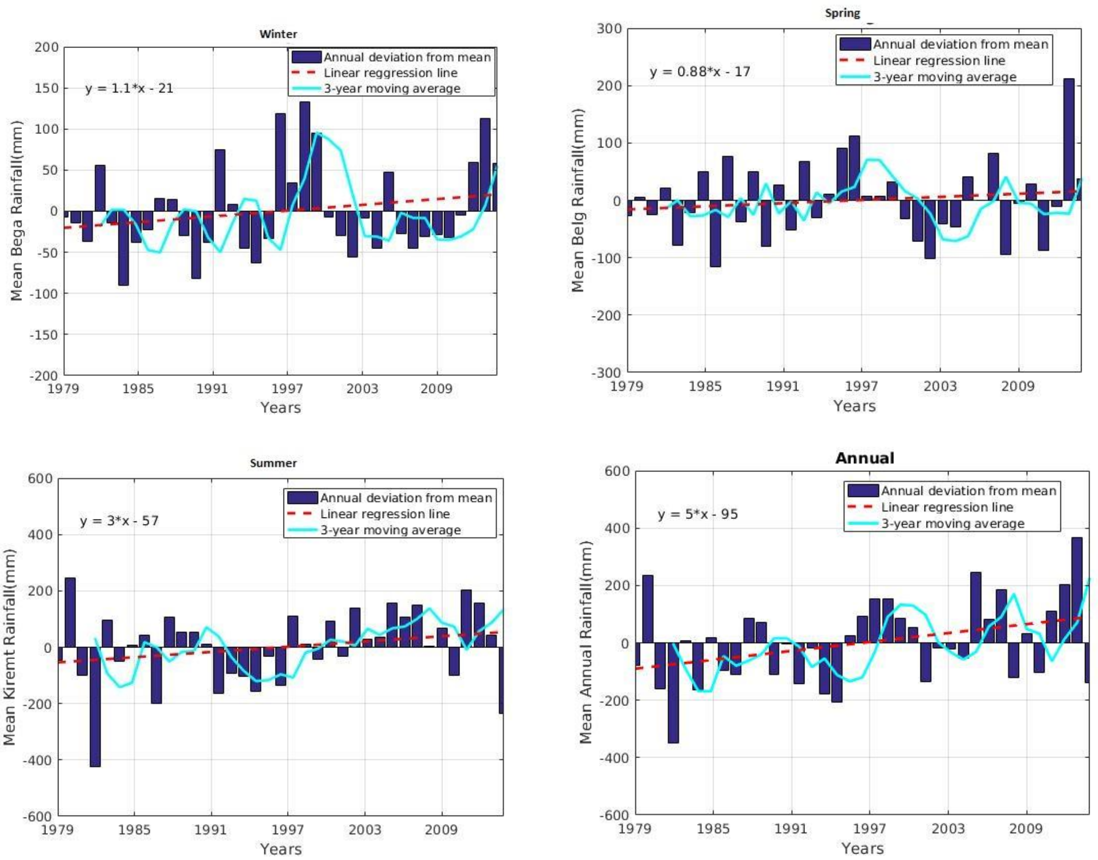

Figure 5 Mean Seasonal and Annual Precipitations, Equivalent Linear Regression Trend Line, and Three Year Moving Average Line of the TBSB.

3.4 Trends in extreme precipitation

In the computation of annual trends in extreme precipitation indices, we found several positive and negative trends that are statistically significant and insignificant **(Table 7)**. The CDD show an increasing trend in four out of the six stations, two showing a decreasing trend. However, neither of these events is significant for the CDD. Similarly, the CWD shows an increase in four and decrease in two stations but the trends are

significant at some stations for both cases. A significantly increasing number of days with perception >1 mm (CWD) are recorded at Dangla (0.63 days/yr) and Bahir dar (0.29 days/yr); while the significant negative trend of 0.39 days/yr is observed at Bullen. The R10mm and R20mm also show both increasing and decreasing trends that are similar in direction and significance for each station. The same significant trend was also recorded at Dangila and Gondar stations for both cases; the largest positive trends being recorded at Dangila. The SDII shows a positive trend in most of the stations being significant at two stations. On the other hand, two stations show a negative trend of which is significant at one station. The significant positive trend is recorded at the stations Dangila (0.06 days/yr) and Gondar (0.03 days/yr); the significant negative trend is at Debretabor (0.06 days/yr).
Similarly, the Maximum 1-day and 5-day precipitation (Rx1day and Rx5Dday) also show trends that are increasing in most of the selected stations. However, the increasing trend is significant only at Gondar for the latter with an annual increase of 0.78 mm. The number of very wet days and extremely wet days (R95p and R99p) also show negative and positive trends; however, only the positive trends at Dangila (2.23 mm/yr) and Gondar (2.83 mm/yr) for the R95p and R99p respectively are significant. Finally, the Annual wet day's precipitation (PRCPTOT) shows an increasing trend at all of the analyzed stations except Debretabor which shows an insignificant decreasing trend of 6.14 mm/yr. The significant increasing trend recorded in PRCPTOT ranges from 5.35 to 12.06 mm/yr. Since the topography of the study area is generally ragged the magnitude and direction of trend experienced may differ from one station to the other. For this reason, we have summarized the spatial patterns of trends for selected precipitation extremes spatially (throughout the TBSB) in **Figure 6**.

Table 7 Annual Trends in Extreme Precipitation Indicators for each Meteorological Station and as Averaged over the TBSB.

Station	Indexes									
	CDD	CWD	R10mm	R20mm	SDII	Rx1day	Rx5day	R95p	R99p	PRCPTOT
Bahirdar	0.619	0.293*	0.114	0.093	0.025	0.341	0.704	2.098	1.913	5.450
Bullen	0.433	-0.391*	-0.345	-0.073	-0.034	0.134	-0.879	-0.715	0.714	-6.144
Dangila	0.229	0.628*	0.398*	0.299*	0.056*	0.003	1.010	7.546*	2.272	12.062*
Debretabor	-0.392	0.165	-0.008	-0.083	-0.056*	0.449	0.198	-0.762	2.239	1.524
Gondar	-0.196	0.053	0.146	0.101*	0.024	0.338	0.708*	1.863	2.514*	3.863*
Pawe	0.645	-0.065	0.180	0.182	0.069	-0.243	-0.058	6.462	-0.203	7.434
TBSB	0.387	0.111	0.235	0.090*	0.030*	-0.039	0.309	2.976*	1.197	4.149*

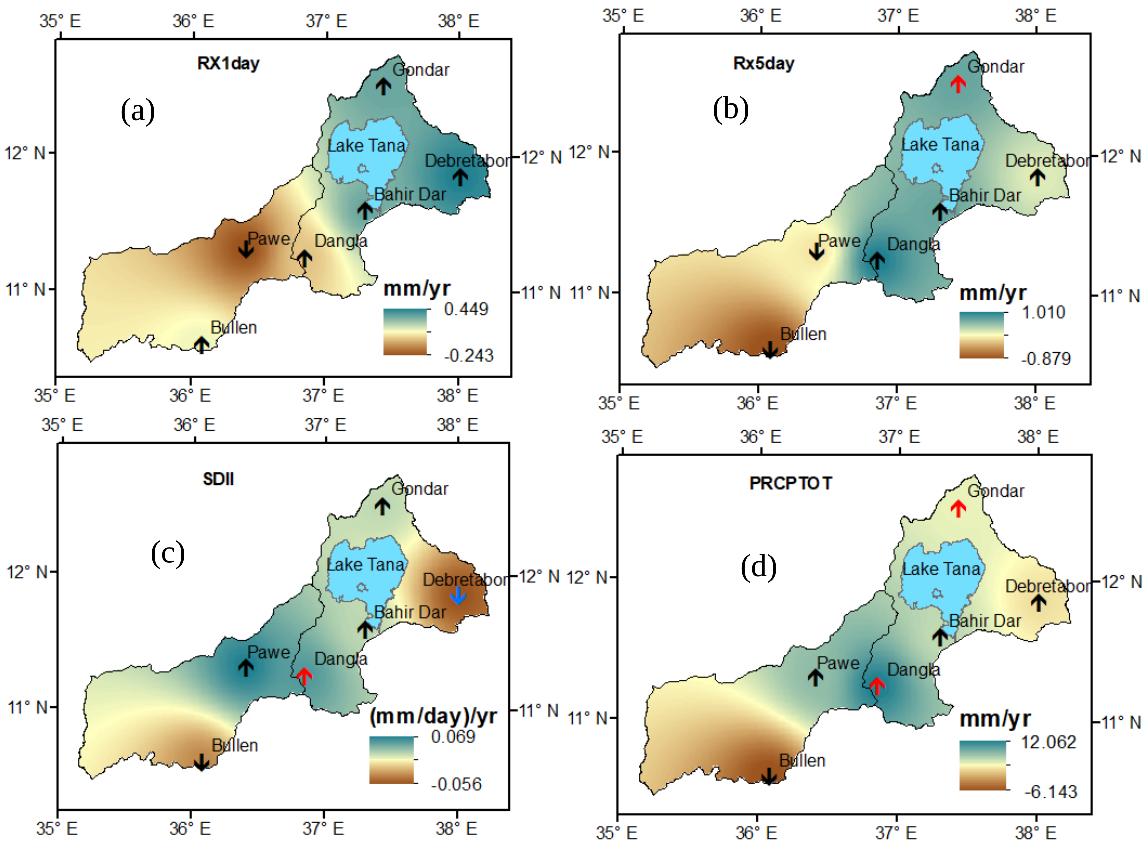

Figure 6 Same as **Figure 3** but for Extreme Precipitation, (a) Rx1DAY (mm/yr); (b) Rx5DAY (mm/yr); (c) SDII (mm/day/yr) and (d) PRCPTOT (mm/yr).

Generally, in many parts of Ethiopia rainfall is often erratic and unreliable; and rainfall variability and associated droughts have historically been major causes of food shortages and famines [49], [50]. Similarly, according to World Bank [51] report, in Ethiopia droughts and floods are endemic, with significant events occurring every 3–5 years. From the precipitation time series, it is possible also to trace the pattern of large-scale factors like the El Nino Southern Oscillation (ENSO) which occurs in about 2-7 years and affects rainfall in the study area positively or negatively. For instance, a study by Diro et al., (2010) summarizes summer rainfall over the Ethiopian highlands is positively correlated with the equatorial East Pacific sea-level pressure and the southern oscillation index and negatively correlated with SST over the tropical eastern Pacific Ocean. A recent drought in many parts of Ethiopia in 2015 due to failure in the summer and annual rainfall, which is related to the positive ENSO event (ELNINO), is also another example. Moreover, the correlation of rainfall in the study area to such large-scale events can be formulated by tracing the event track during the study scope of the present study.

4. Conclusion

In the present study, the trends in climate means and extreme events on the temporal and spatial aspects of temperature and rainfall over the Tana Beles sub-basins were analyzed for the 1980-2015 study period. The study finds that the climatic factors, rainfall, and temperature of the TBSB are changing.

The results reveal monthly, seasonal and annual temperatures show positive trends in most of the examined stations and averaged over the study area in both the maximum and minimum parameters. Higher positive and significant trends were observed for maximum temperature (for all seasons and the annual) than the minimum temperature over all time scales. Similarly, a general increase was observed in the extreme temperature events. While the warm extremes such as TXx, TX90p, TN90p, and WSDI show an increasing trend; the cold extremes, TX10p, TN10p, and the CSDI show negative trends at most stations and the whole TBSB. The frequency of warm days/nights had increased; while the frequency of cold days/nights had reduced. The significant increase/decrease in warm days/nights is an implication that climate change is becoming a health threat around the study area and vicinity. Abrupt changes in the warm extremes when compared to the 1981-2000 base period were also observed in recent decades particularly 1995 to 2015; implying the warming in recent decades could be as a result of the rising in warm extremes than the decreasing of cold extremes.

The monthly rainfall shows a positive trend in most of the selected stations and the areal average. Rainfall at all the analyzed stations and averaged over the study area show a positive trend in September; with a significant increase in the regional rainfall of 1.577 mm/yr. This could be an implication in the shift of the main rain season towards the end of the months and the beginning of winter. The seasonal and annual rainfall also shows positive trends at most of the stations, with only a few stations showing negative trends. However, the rate of change in the seasonal and annual rainfalls was not statistically significant. On the other hand, among the selected ten indices only the Rx1day shows a negative trend for the study region. The analysis also reveals spatial incoherence in consecutive 1-day and 5-days rainfall (Rx1day and Rx5day). While the former shows a decreasing trend, the latter shows an increasing trend which is significant at some stations. Spatially coherent results for the number of days with rainfall of more than 10 and 20 mm (R10 and R20) were also obtained. This could be since, over a semi-arid and humid region like the current study area; about 10-20 mm precipitation can be experienced in many years of the period over most climatic types of the region. Despite the decreasing trend in very wet days (R95p) at some stations, we generally found an increasing trend of very wet days (R95p) and extremely wet days (R99p) at many stations of the TBSB. Moreover the wet-day precipitation PRCPTOT overall the study area had shown an increase of 4.149 mm/yr. However, the observed changes in extreme precipitation indices were spatially not coherent and temporally asymmetric. This suggests that large rainfall variability was observed spatially and temporally during the 1980-2015 study period.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

The authors wish to acknowledge the National Meteorological Agency (NMA) of Ethiopia and its experts for kindly providing the weather data of the studied stations.

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