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Trend Analysis of Climate Change-Induced Extreme Events in Drought-Prone Areas: A Case of Legambo District in South Wollo Zone of Amhara National Regional State, North Central Ethiopia

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ABSTRACT

Ethiopia is among the most vulnerable countries to the adverse effects of climate change, which are manifested in recurrent droughts, extreme temperatures, and erratic rainfall, affecting agriculture and food security. This study examines the trend of climate change-induced extreme events over Legambo district using indices from Expert Team on Climate Change Detection and Indices (ETCCDI) for the period 1979-2019. Trend analysis was based on daily records of precipitation and temperature data obtained from Koninklijk Nederlands Meteorologish Instituut (KNMI) climate explorer, mainly from Climate Hazard Groups Infrared Precipitation with Stations (CHIRPS 2.0 Africa) at 0.05 by 0.05-degree resolution and Climate Research Unit (CRU TS 4.07) at 0.5^0 resolutions respectively. Data analysis was done using R-Studio (RClimDex) software. We employed Mann-Kendall's trend tests and a non-parametric Sen's slope estimator to detect the statistical significance and magnitude of changes in extreme climate, respectively. The findings found a statistically significant ($P<0.05$) positive trend in temperature-related indices such as monthly maximum of daily maximum temperature (TXx) (0.08^0C per year); monthly maximum of daily minimum temperature (TNx) (0.065^0C per year), warm days (TX90p) (5.4 per century), warm nights (TN90p) (5 days per century), warm spell duration indicator (WSDI) (2.81 days per decade) and hot days (SU) (14.92 days per decade). A negative trend was observed in temperature extremes of the number of cool nights (TN10p) (-3.05^0C per decade), cool days (TX10p), and cold spell duration indicator (CSDI) (-2.2 days per decade). A statistically significant ($P<0.05$) decreasing trend was observed in most precipitation-related indices like total precipitation (-10.305mm/year), simple daily intensity index (-0.024 mm/day), maximum one-day precipitation (-0.5mm/year), maximum five-day precipitation (-0.56mm/year), very heavy precipitation with greater than 20mm per day (-1.89 days/decade), very wet days (-5.537mm/year) and extremely wet days (-1.534mm/year). With the high variability of indices and the fact that farmers live in a business-as-usual scenario, the vulnerability of smallholder farmers will be further exacerbated. Therefore, it is highly recommended that the government design appropriate adaptation strategies for farmers to cope with these variability**.**

Key words: Climate change, Extreme events, Trend, Legambo district

INTRODUCTION

As greenhouse gas concentrations rise, catastrophic events linked to climate change will occur more frequently and with greater intensity (Planton *et al.*, 2008; IPCC, 2022). The world has to face the reality of climate variability and its associated extreme events, and in many parts of the world, this has

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manifested in an increase in the frequency and intensity of extreme weather events (IPCC, 2007; Eckstein *et al.*, 2018; IPCC, 2022). Plants experience stress due to prolonged periods of excessive or no rainfall or high or low temperatures (Gray *et al.*, 2006). Besides extreme weather events also affects animals (Alho and Silva, 2012) and humans (Smith *et al.*, 2013). According to Teshome and Zhang (2019), there is a continuous reduction in the number of heavy rainy days observed over the Greater Horn of Africa, including Ethiopia. Beyond their immediate physical effects, climate variability and extreme events have cascading effects that impact Sub-Saharan Africa. There is a severe compromise to livelihoods, especially for those reliant on rain-fed agriculture (Mintenbeck *et al*., 2011). This may result in food insecurity, migration, and poverty (Serdeczny *et al*., 2016). Furthermore, these occurrences can worsen existing social inequalities (UNDP, 2016) where developing countries like Ethiopia are disproportionality affected.

In Ethiopia, while consecutive rainy days have shown a declining tendency, consecutive dry days show an increasing trend, which is a phenomenon that is conducive to the occurrence of drought. However, spatial and temporal patterns and the intensity of extreme events differ from region to region. Crop pests, livestock epidemics, hailstorms, drought, and floods become Ethiopia's most dominant and frequently occurring climate-related shocks (Misganaw *et al.*, 2014). According to a study conducted in the Amhara national regional state by Ayalew *et al.* (2012), there has been an occasional fluctuation in the number of wet and dry years, and the length of the growing season has shortened recently due to early rainfall cessation. This study indicates that rainfall in the *belg*-dependent regions contributes significantly to the annual total rainfall and has been trending toward less consistency. A study by Weldegerima *et al*. (2023) in the Amhara region showed a clear upward trend for warm temperature events and a downward trend for cold temperature events. This study also reported high spatiotemporal variability of precipitation.

Rosel and Holmer (2015) reported a decline in belg rainfall in South Wollo since 1996, when droughts became recurrent, while erratic rainfall became more predominant. Similarly, Mekonen and Birlie (2020) found an extremely high variability of belg rainfall in south Wollo, where a statistically significant decreasing trend in belg and annual rainfall was reported. According to a Kahsay (2013) study, the farming system and production in South Wollo are impacted by irregular rainfall, a delayed onset and early cessation, and poor belg performance. In the Woleka sub-basin of the South Wollo administrative zone, Asfaw *et al*. (2018) found a decreasing trend for the primary rainy season, an increasing trend for meteorological drought episodes, highly variable belg rain, and an increasing trend for temperature. Subsistence farmers in Legambo District have suffered from recurrent drought and famine due to climate change-induced extreme events leading to erratic rainfall, frost hazards, flooding, and hailstorms (Cafer and Rikoon, 2017). The magnitude and implications of climate variability are not adequately examined in Ethiopia. For substance agriculture, occurrences and frequencies of climate extremes and variabilities are equally affecting as of mean annual changes. Thus, reliable information is essential in designing appropriate adaptation strategies in the agricultural sector.

Moreover, Ethiopia has a varied and complex rainfall pattern, which urges further context-specific detail investigations into the variability and trend of extreme events, thereby designing local adaptation interventions accordingly (Mohammed *et al*., 2018). In recent decades, extreme climatic and weather conditions have become increasingly common and costly in Ethiopia. The geographic coverage, intensity, and frequency of drought have increased recently (Emerta, 2013). Since rainfall is a significant component in forecasting and risk assessment, it is crucial to comprehend the frequency of extreme weather events while making decisions. The repercussions of extreme weather occurrences are expected to be greater than those of the average climate. Since extreme events brought on by climate change have a disastrous effect on agriculture and other sectors, predicting the trend of these events is crucial for planning and managing water resources. It has numerous real-world applications in Ethiopia's smallholder agriculture. Designing response strategies that improve readiness and early warning systems, as well as long-term planning for effective adaptation to lower associated risks, depends on an understanding of the characteristics of climate extremes at the regional and local levels (Teshome and Zhang, 2019; Worku *et al*., 2019; IPCC, 2022). Research on rainfall variability and trends is crucial for assessing the adverse impacts of climate change and extreme events on regional and local scales. Designing effective adaptation strategies requires precise quantification of severe factors' variability, trends, and frequency not represented by slight variations in the long-term mean. Most climate variability studies (Hadgu *et al*., 2013; Mengistu *et al*., 2014; Gebrechorkos *et al*., 2018; Esayas *et al*., 2018 and Berhane *et al*., 2020) in Ethiopia in general and the study area in particular focus on long-term mean changes while little has been research on the magnitude of change of extreme events and their resultant effects. There was inadequate monitoring of the study area's climate and weather variability. These days, the frequency and occurrence of extreme events have a more significant influence than the mean value of climate elements. Research on the variability and trends of rainfall amounts and extreme events at regional and local scales is vital for assessing climate change impacts. Accurate quantification of extreme events' variability, trends, and frequency, not captured by small changes in the long-term mean, is paramount in designing appropriate adaptation strategies (Mohammed *et al*., 2018).

Variability of Meteorological Variables in Ethiopia: Empirical Evidence

Historically, Ethiopia is prone to extreme weather events where rainfall is highly erratic, with high rainfall intensity and extreme spatial and temporal variability (World Bank, 2010). Since Ethiopia's agriculture is substance- and rain-fed dependent, the amount, incidences of extreme events and temporal variation seriously affect its productivity (Evangelista *et al*., 2013). A study by Funk *et al*. (2012) revealed that rainfall amounts have declined by 15-20 percent in some areas of Ethiopia from the long-term mean since the mid-1970s, mainly in the southern and south-eastern parts of the country, which have adversely affected crop yields and pasture conditions. The dryness might be further exacerbated due to the warming tendency of the temperature in the country. Such rainfall variability and high incidences of extreme events impeded the farming system (Leulseged *et al*., 2013). Rains are delayed by several weeks or may start and stop unexpectedly during critical germination periods that impact the overall productivity of the agriculture sector (Evangelista *et al*., 2013). The quantification and characterization of the intra-annual and inter-annual spatial and temporal variability of meteorological variables (like rainfall and temperature) in a climate that is changing (especially in nations where rain-fed agriculture is predominant) is crucial to assess climate-induced changes and suggest appropriate future water resources management strategies and agricultural practices in a highly agrarian community like Ethiopia, where the population's livelihood and the nation's gross domestic product are almost entirely dependent upon rain-fed agricultural production (Wagesho *et al*., 2013; Hadgu *et al*., 2013). A study by Mengistu *et al*. (2014) revealed a statistically significant increasing trend of both minimum and maximum temperatures. Nevertheless, for Tesso *et al.* (2012), the rate of change for the maximum temperature is higher than the minimum one. Another study by Hadgu *et al*. (2013), Ayalew *et al*. (2012), and Addisu *et al*. (2015) found that though rainfall in Ethiopia is highly variable with a non-significant decreasing trend, there is a significant change in trends of rainfall events like onset date (late onset in most cases), cessation date (early cessation), contraction of the length of the growing period, and incidence of dry spell periods, which have a paramount effect on agricultural activities. A study by Addisu *et al*. (2015) in the Lake Tana sub-basin (Ethiopia) revealed a statistically significant decreasing trend in summer rainfall.

A study conducted by Worku *et al*. (2019) in Jemma sub-basin (Ethiopia) confirmed increased rainfall extreme events in most stations and a warming trend of annual maximum and minimum temperature and extreme temperature indices. In this study, an increasing trend in annual total wet-day rainfall (PRECPTOT), very wet days (R95p), and extremely wet days (R99p) were reported. Similarly, significant warming trends were demonstrated in the intensity of temperature extreme indices (TXx, TXn, TNx, and TNn) and frequency of temperature extreme indices (TN10p, TX10p, TN90p, and TX90p). In contrast, a decreasing trend of cold extreme indices (TN10p and TX10p) was observed. It was observed that warm extremes at night were increasing while cold extremes at night decreased more strongly than other indices. A study by Teshome and Zhang (2019) reported a decreasing trend in total annual precipitation (PRCPTOT), consecutive wet days (CWD), and the number of heavy precipitation days (R10), while an increasing trend in consecutive dry days (CDD), tropical nights (TR20), and daily minimum and maximum temperatures. A study in Southern Ethiopia by (Esayas *et al*., 2018) also found a statistically significant increasing trend in the daily temperature range, the number of very wet days, and a decreasing trend in the cold spell duration. The study further added that the annual number of occurrences of warm nights (TN90p), the warmest night (TNx), and the occurrence of warm days (TX90p) show a significant warming trend. In contrast, warm nights (TN90p) have significantly increased. However, cool nights (TN10p) showed a consistently decreasing trend. A study in Western Tigray (Ethiopia) by Berhane *et al*. (2020) found that the number of heavy rainy days, very heavy rainy days, very wet days, extremely wet days, maximum 5 days of precipitation, and total rainfall showed a negative trend. On the other hand, the monthly maximum and minimum value of minimum temperature, the minimum value of maximum temperature and the monthly maximum value of maximum, hot nights and hot days revealed positive trends throughout the study areas. Mohammed *et al*. (2018) examined the variability and trend of extreme rainfall events in the northeast highlands of Ethiopia. They found a statistically significant decreasing trend in the mean annual consecutive dry days, whereas consecutive wet days significantly increased. A study in the Upper Blue Nile of Ethiopia by Weldegerima *et al*. (2023) revealed a decreasing trend of cold temperature events and a markedly increasing trend of warm temperature events. The frequency of cold days/nights has decreased by 33/38 days/nights annually, whereas the frequency of warm days/nights has increased by 91/83 days/nights. 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) showed an increasing trend. From the continuing debate, we can infer that the results are inconclusive and that context-based trend analysis on extreme events is crucial. As a result, this research offers insightful data on the frequency and variability of extreme rainfall events, which has implications for efficient water resource management and climate risk reduction. Furthermore, the work adds to the scant body of knowledge already available regarding changes in climatic extremes at the local scale.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Legambo district, part of the South Wollo Zone in Amhara National Regional State, Ethiopia. The absolute location of the district lies at 10^{0} 43' 00" N to 11^{0} 00' 00" N latitude and 38^{0} 52' 00" E to 39^{0} 26' 00" E longitude (see Figure 1). The district covers an area of 1001.4 km^2 of land, and the elevation ranges from 1472-4202 meters above sea level. Most of the district is well known for its undulating topography (Legambo District Plan Commission (LDPC, 2021). The vast majority of the district, covering 68.54%, has temperate (*Dega)* agroecology, and the next largest share is alpine (*Wurch)*, sharing 29.53%. The remaining 1.93% and 0.0016% of the area coverage in the district have subtropical (*Woinadega)* and tropical (*Qolla)* agroecology, respectively. The mean annual precipitation amount is 920 mm. The district has two rainy seasons: *kiremt* or summer (primary rainy season including June, July, and August) and *belg* (short rainy season including February, March, and April) (Mohammed *et al*., 2018).

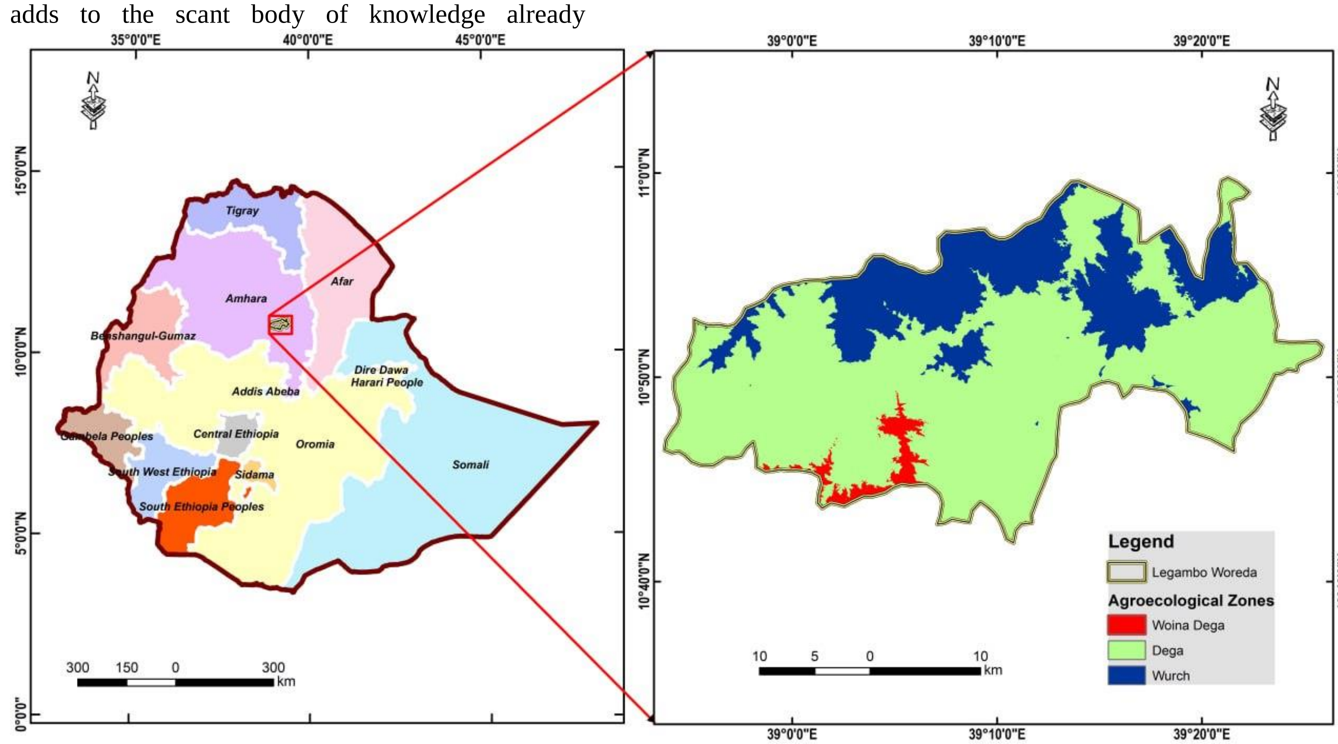

Figure 1: Location of the Study Area
Source: Ethio GIS, 2022

Legambo district had a total population of 203,535 in 2020 (49.08% were male) (LDPC), 2021). The district's economic activity is predominantly rain-fed subsistence agriculture (98%), and the major farming system is a mixed cereal-livestock type (Mohammed *et al*., 2018). However, the district is known for its humanitarian aid reception from international and local aid organizations, where 30.75% of the total population (2019) received emergency and Productive Safety Net Program (PSNP) aid (LDPC, 2021). The study area is under the bimodal rainfall regime, enabling two harvesting seasons. However, the *belg* rainy season, essential for belg-dependent areas like the study area, has become erratic and has frequently failed, hampering belg harvesting (Rosell, 2011; Ayalew *et al.,* 2012). A study by Asfaw *et al.* (2018) in the Woleka sub-basin (where our study area is part of it) showed an increasing tendency in meteorological drought events, a decreasing trend in the primary rainy season, extremely unpredictable *belg* rain, and an increasing trend in temperature. The farming system and productivity are impacted by irregular rainfall patterns, delayed onset and early cessation, and poor *belg* performance (Kahsay, 2013). Due to these factors, the study area is considered among the country's most food-deficient and drought-stricken areas, where most of the population depends on food aid for survival (Bantider *et al*., 2011). Cafer and Rikoon (2017) labeled the area as the "famine belt of Ethiopia."

Research Design

We employed a longitudinal research design to estimate the extent of changes of weather extreme events triangulated with key informant interview output. Scholars (Dinku *et al*., 2011; Dubache *et al*., 2021; Getaneh and Getachew, 2021; Hordofa *et al*., 2021; Ageet *et al*., 2022) recommend using gridded satellite data in countries like Ethiopia where weather stations are few, unevenly distributed, have a missing data problem, and have a short observation period. The most recommended gridded data sources for Ethiopia and Horn of Africa include CenTrend (Philips *et al*., 2015), Global Precipitation Climatology Centre (GPCC) (Asfaw *et al*., 2018; Degefu *et al*., 2022), Global Precipitation Measurement Integrated Multi-SatellitE Retrieval (GPM-IMERG) (Hordofa *et al*., 2021), Climate Research Unit (CRU) (Asfaw *et al*., 2018), Climate and Climate Hazard Groups Infrared Precipitation with Stations (CHIRPS) (Philips *et al*., 2015; Ayehu *et al*., 2018; Tesfamariam *et al*., 2019; Dubache *et al*., 2021; Hordofa *et al*., 2021; Degefu *et al*., 2022, Gebretsadkan *et al*., 2023). Validation studies (see, for instance, Funk *et al*., 2015; Tote *et al*., 2015; Ayehu *et al*., 2018; Lemma *et al*., 2019; Nawaz *et al.*, 2020; Dubache *et al*., 2021; Hordofa *et al*., 2021; Edris *et al*., 2021; Degefu *et al*., 2022), conducted to validate existing gauge station data with satellite gridded data using correlation Coefficient, Mean Error (ME), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and graphic method, found that the precipitation data from CHIRPS closely matches with the gauge station data in both parameters than other satellite sources. Besides, CHIRPS has a high spatial resolution and is available at the lowest temporal level (daily), that makes it as suitable data source for analyzing extreme variables in small geographical areas (Funk *et al*., 2015 and Degefu *et al*., 2022).. Furthermore, Funk *et al*. (2015) recommended CHIRPS for East Africa because it is a combination of in-situ station data with satellite imagery, and available with a high-resolution since 1981. As a result, we obtained gridded daily precipitation data from CHIRPS2.0 Africa at 0.05 by 0.05-degree resolution for the period of 1979-2019 (downloaded from Koninklijk Nederlands Meteorologisch Instituut (KNMI) climate explorer. We obtained gridded daily maximum and minimum temperature data from CRU TS 4.07 at 0.5^0 resolution based on the recommendation of Asfaw *et al*. (2018) and Tefera *et al*. (2019) from KNMI. Data analysis was done using R-Studio (RClimDex) software developed by Zhang and Yang (2004) at the Canadian Meteorological Service to obtain the climatic extreme indices using the methodologies of Zhang *et al.* (2005). RClimDex provides 27 indices. It provides a friendly graphical user interface to compute climate change indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI). Only 21 indices (see Table 1 and 2) that can better explain the study area have been given due attention. Indices like ice days, tropical nights, and ice days, less critical in our study area, were excluded from the analysis). Trend analysis computation was supported with MAKESENS, Sens' Slope estimate, and the XLSTAT software. Ten farmers were purposefully selected for interviews, and their views are triangulated with the trend analysis results.

Table 1: Temperature-related extreme event indices

ID	Indicator Name	Definitions	Units
SU	Summer days	Annual count when TX (daily maximum) >25°C	Days
TXx	Max Tmax	The monthly maximum value of the daily maximum temp	°C
TNn	Min Tmin	The monthly minimum value of the daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN<10th percentile	%

TX10p	Cool days	Percentage of days when TX<10th percentile	%
TN90p	Warm nights	Percentage of days when TN>90th percentile	%
TX90p	Warm days	Percentage of days when TX>90th percentile	%
WSDI	Warm Spell Duration Indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	Days
DTR	Diurnal Temp Range	The monthly mean difference between TX and TN	°C
CSDI	Cold spell duration Indicator	Annual count of days with at least 6 consecutive days when TN<10th percentile	Days
TXn	Min Tmax	The monthly minimum value of the daily maximum temp	°C

Source: Zhang and Yang, 2004

Table 2: Precipitation-related extreme event Indices

ID	Indicator Name	Definitions	Units
PRCPTOT	Total precipitation	Annual total PRCP in wet days (RR≥ 1mm)	Mm
CDD	Consecutive Dry Days	Maximum no of consecutive days with RR<1mm	Days
CWD	Consecutive Wet Days	Maximum no of consecutive days with RR≥1mm	Days
SDII	Simple Daily Intensity Index (PRCP≥1.0mm)	Annual total precipitation divided by the no of wet days (defined as PRCP≥1.0mm) in the year	mm/day
RX1day	Max 1-day PRCP	Monthly maximum 1day precipitation amount	Mm
RX5day	Max 5-day PRCP	Monthly max consecutive 5day PRCP amount	Mm
R10mm	Heavy PRCP days	Annual count of days when PRCP≥10mm	Days
R20mm	Very heavy PRCP day	Annual count of days when PRCP≥ 20mm	Days
R95p	Very wet days	Annual total PRCP when RR>95th percentile	Mm
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	Mm

Source: Zhang and Yang, 2004

Data Analysis Method

The annual trend statistics of climate change-induced weather extreme events were assessed based on the non-parametric Mann-Kendall (MK) test and Sen's Slope estimate analysis in the time series. It is a non-parametric test with no requirement for the data to be normal (Yue *et al.,* 2002: Wang *et al.,* 2015). Mann-Kendal statistic (S if data values are less than 10 and Z if data values are more than 10) measures the time series trend of different temperature and rainfall extreme indices. The test statistic (S) is calculated by computing the difference between the later measured value and all earlier measured values following (Yue *et al.*, 2002: Wang *et al.*, 2015).

$$S= \sum_{i=1}^{n-1} q \sum_{j=i+1}^{n} q \quad \text{sign}(Yj\text{-}Yi)$$

…………………………………………………..……. (1)

Where the sign (Y_j–Y_i) is equal to + 1, 0, or − 1. The trend test is applied to a time series X_i, ranked from i = 1, 2 …n-1 and X_j, ranked from j= i + 1, 2, 3, …. n. Each data point X_i is taken as a reference point, which is compared with the rest of the data point's X_j so that:

$$\text{sign}(Xj\text{-}Xi)\{+1 \text{ if } Xj\text{-}Xi >0 \text{ , } 0 \text{ if } Xj\text{-}Xi=0 \text{ and } -1 \text{ if } Xj\text{-}Xi <0\}$$

…………….………………… (2)

Where X_i and X_j are the annual values in years i and j (j >i), respectively. The magnitude of the slope of the trends from temperature and rainfall extremes was calculated using Sen's slope estimator (ß) (Sen 1968), which is the median of a set of slopes using (Eq.3) that j > 1.

$$\beta=\frac{y_j\text{-}y_i}{t_j\text{-}t_i}$$

………………………………………………………………………………..…… (3)

The Z statistic is another important parameter to measure the significance of the trend for each parameter. The test statistics Z_c is as follows:

$$Z= \left\{\frac{S\text{-}1}{\sigma} \text{ if } S >0, 0 \text{ if } S=0, \frac{S+1}{\sigma} \text{ if } S <0\right\}$$

…………………………...…………………………..…. (4)

When Z_C follows a normal distribution, a positive Zc signifies an upward trend and a negative Zc value signifies a downward trend of extreme events.

For the assessment and analysis of Mann Kendall and Sen's slope of the time series, Microsoft Excel-based template MAKESENS (Mann Kendall and Sen's Slope) and XLSTAT were used for four different significance levels α: 0.1, 0.05, 0.01, and 0.001. The significance level of 0.001 means that there is a 0.1% probability that the values x_i are from a random distribution, and with that probability, we can make a mistake when rejecting H_0 (null hypothesis) of no trend. A significance level of 0.001 means that a monotonic trend is very probable. The significance level of 0.1 means that there is a 10% probability of making a mistake when rejecting H_0 (Hussain *et al.*, 2015).

RESULTS AND DISCUSSION

Temperature-related Events Trend Analysis

Air temperature has a crucial impact on the water cycle in the study area, and temperature extremes have become a prime concern under the present global climatic variations. Analysis of daily temperature data (Table 3) was undertaken to detect the trend of climate change-induced extreme events associated with temperature.

Table 3: Mann-Kendall and Sen's Slope statistics of temperature-related extreme indices

Mann-Kendall trend				Sen's slope	
Index	Test Z	p-value2 tailed	Sig.	Q	B
TXx	4.35	<0.0001	***	0.08	30.00
TXn	0.44	0.694		0.006	20.09
TNx	4.75	< 0.0001	***	0.065	14.85
TNn	0.64	0.522		0.0104	6.28
TN10p	-4.9	< 0.0001	***	-0.305	13.965
TX10p	-1.91	0.056	+	-0.10	11.69
TX90p	5.65	< 0.0001	***	0.54	0.07
TN90p	6.23	< 0.0001	***	0.50	- 0.73
DTR	- 1.77	0.076	+	- 0.01	13.81
WSDI	2.99	<0.0001	***	0.281	4.35
CSDI	- 3.26	<0.0001	***	- 0.22	8.22
SU	4.07	<0.0001	***	1.492	192.03

***, **, *, and + stands for statistically significant at 0.001, 0.01, 0.05, and 0.1 probability levels

Monthly Maximum value of Daily Maximum Temperature (TXx) and Monthly Minimum value of Daily Minimum Temperature (TXn)

In Legambo district, TXx showed a statistically significant increasing trend (Table 3). So, TXx showed a warming trend in the study area from 1979-2019. The result agrees with the findings of Bhuyan *et al.* (2018), Meehl *et al.* (2009), Hayelom *et al.* (2017), Teshome and Zhang (2019), and Worku *et al.* (2019). TXn also showed a positive trend but was not statistically significant. Respondents to the interviews agreed with the study area's rising temperature trend. In contrast to their prior experiences, informants claim that the exceptionally cold months are improving. The frequency of forests is declining over time despite an increase in the perceived increment in temperature.

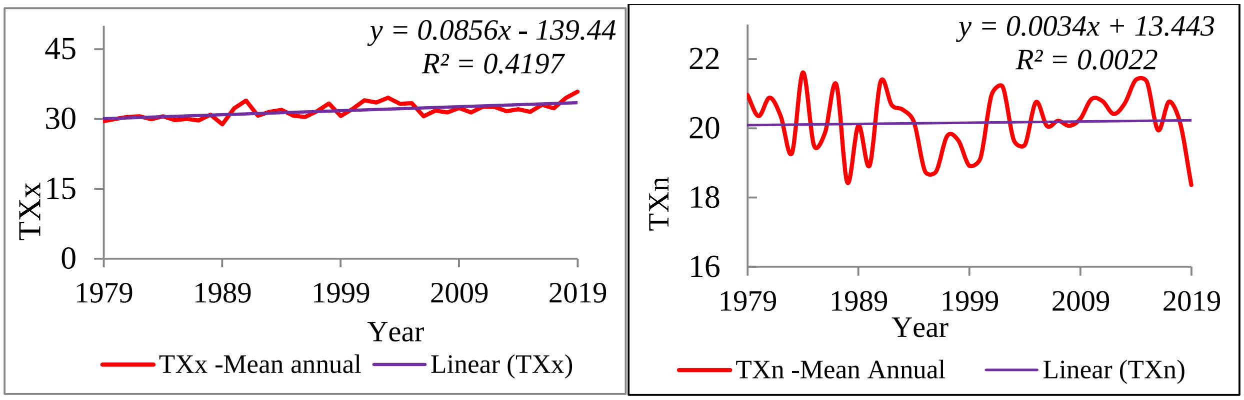

Figure 2: Trend of TXn and TXx in Legambo district (1979-2019)

Mann Kendall test statistics (MKZ) result indicates that TNx (4.75) has shown a statistically significant increasing trend at a 5% significance level. So, like TXx, TNx also showed a warming trend in Legambo district. The result is in line with the findings of Gedefaw (2023) (see Table 3 and Figure 2).

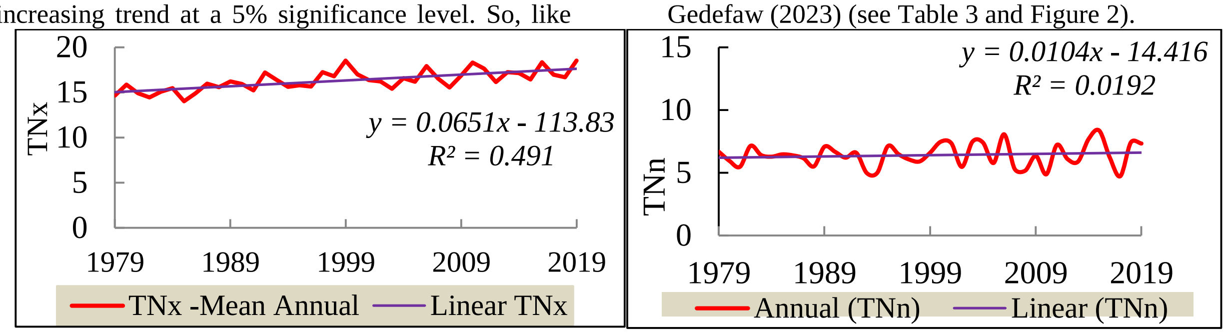

Figure 3: TNx and TNn trend of Legambo district (1979-2019)

The rate of change in TNx defined by slope (Q) is 0.065 ^{O}C (Table 2). This shows that the rate of increase/rise in TNx was 0.065 ^{O}C per year between 1979 and 2019. On the other hand, the coefficient of determination (R^2) of TNx was 0.491, implying that 49.1% of the trend in TNx was expressed by the linear regression of the change in time series (see Table 3 and Figure 3). In line with this finding, Gedefaw (2023) also reported an increasing trend of these variables.

Cool Nights (TN10p) and Cool Days (TX10p)

The computed p-value of the number of cool days (TX10p) is (0.056), which is greater than 0.05 and indicates no statistically significant trend in cool days. Mann Kendall trend test statistics (MKZ) result also revealed cool nights (MKZ= -4.9), indicating there is a significant downward trend of cool nights at a 5% level of significance, implying a decreasing trend of TN10p (see Table 3 and Figure 4). The result agrees with other findings like Worku *et al.* (2019), Teshome and Zhang (2019), Berhane *et al.* (2020), and Gedefaw (2023).

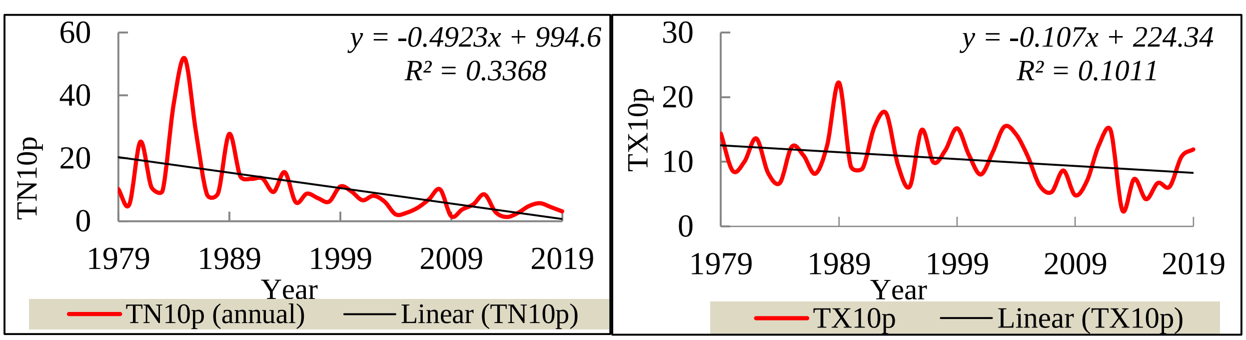

Figure 4: Trend of Cool Nights and Cool Days in Legambo District

Warm Nights (TN90p) and Warm Days (TX90p)

There is a statistically significant trend in warm nights and warm days. Mann Kendall test (5.65 = warm days and 6.23 = warm nights) revealed that both warm days and warm nights have a positive trend (see Table 3 and Figure 5). This result agrees with the findings of Teshome and Zhang (2019), Berhane *et al.* (2020), and Gedefaw (2023). Hence, the result evidenced an increase in abnormally hot days and warm nights, implying that heat waves will likely become more frequent in Legambo district. Sen's slope (Q value) result indicates that the rate of change in the number of warm days and warm nights increases by 0.5 days annually.

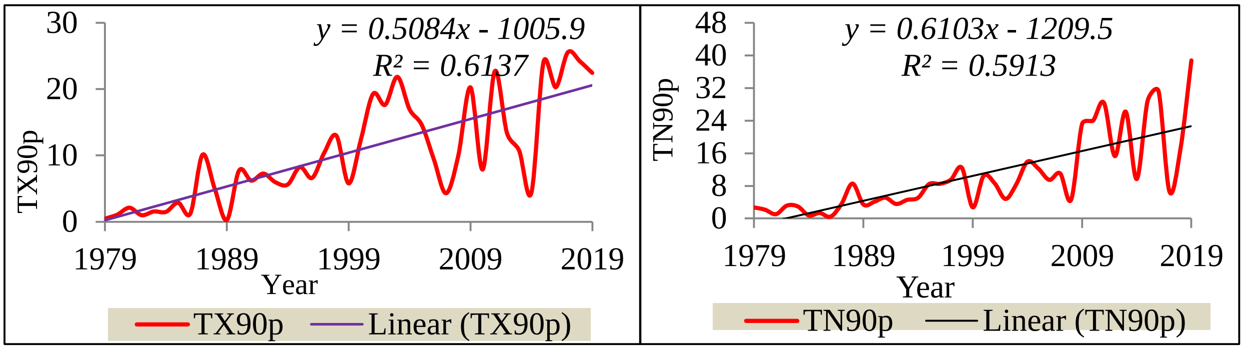

Figure 5: Trend of Warm Days and Warm Nights (1979-2019)

Diurnal Temperature Range and Warm Spell Duration Indicator

The computed p-value result implies no statistically significant trend in DTR and a statistically significant trend in WSDI at 0.001 alpha level. Mann Kendall test of trend statistics (MKZ) value of the WSDI indicates the trend of warm spell duration indicator was positive/upward (see Table 3 and Figure 6). The result conforms to Teshome and Zhang (2019) and Worku *et al.* (2019), who concluded from their study that WSDI has shown a significantly increasing trend.

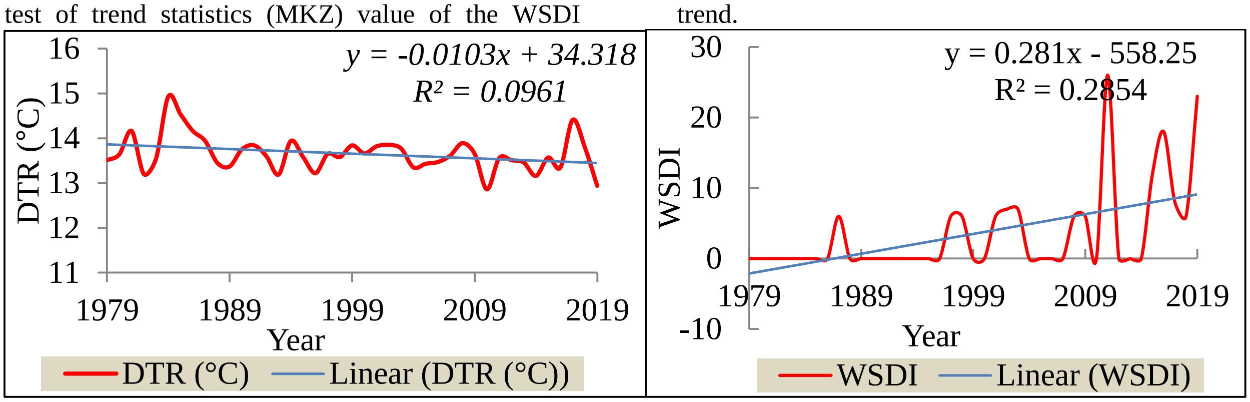

Figure 6: Pattern of DTR and WSDI (1979-2019)

Trend Analysis of Cold Spell Duration Indicator (CSDI) and Hot Days (SU)

Mann-Kendall (MKZ= -3.55) and Sen's (Q=-0.22) indicated a statistically significant decreasing trend of CSDI at a magnitude/slope of -0.22, showing a decrease in CSDI by 0.22 days annually, i.e., CSDI falls by 1 day after 4 years and 7 months. The negative Q value indicates a downward trend (see Table 3 and Figure 7). The result agrees with Gebrecherkos *et al.* (2018) and Worku et al. (2019). The coefficient of determination (R^2) of CDSI was 0.1829, implying that 18.29% of CSDI was expressed by linear regression of the change in time series. On the other hand, the computed p-value of SU (<0.05) indicates that we should accept the alternative hypothesis that there is a trend in the series. The result infers a statistically significant positive trend of SU within the time series. This result conforms to the finding of Teshome and Zhang (2019), who concluded that hot days in Addis Ababa and Kombolcha, Ethiopia, increase over time. The Sen's slope result implies that hot days in Legambo district increase by 1.4 days per year. The interviewee saw an improvement in the cold spell length while the temperature rose compared to the previous scenario, which is consistent with the trend result. The respondents stated that these circumstances have produced a favorable environment for an upward agronomic shift in agricultural activities. However, the unpredictability of the rainfall has prevented them from taking advantage of this opportunity.

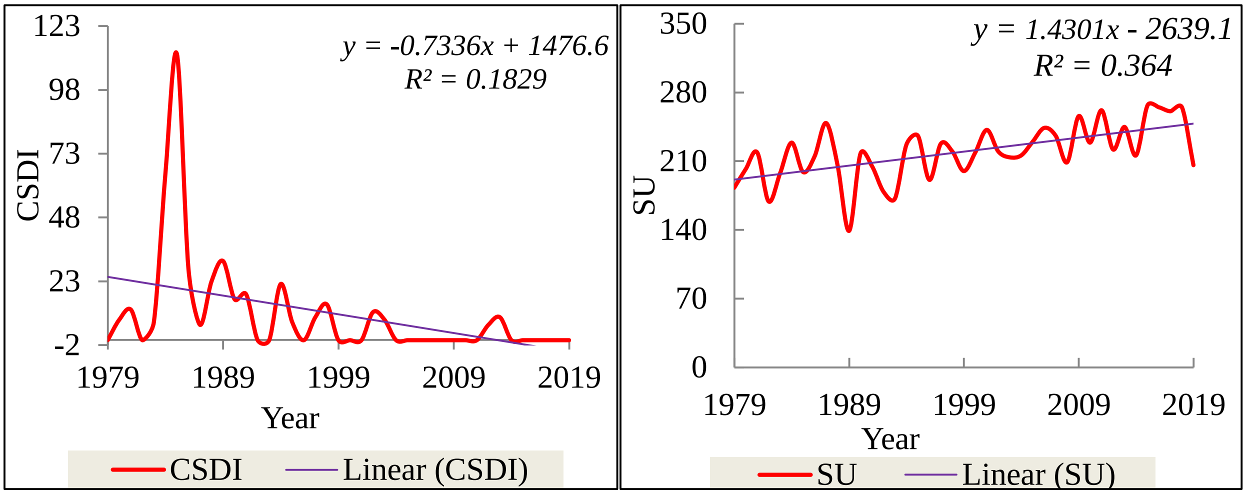

Figure 7: Trend of CSDI and Hot Days (1979-2019)

Precipitation-related Extreme Events

The variation in local climate and the frequency of extreme events are among the significant manifestations of global climate change, and precipitation-related weather extremes (Table 2) affect various socioeconomic activities. Therefore, understanding the intensity and frequency of these extreme events is very important.

Table 4: Mann-Kendall and Sen's Slope statistics of precipitation-related extreme indices

Mann-Kendall trend				Sen's slope	
Index	Test Z	p-value 2 tailed	Sig.	Q	B
PRCPTOT	-2.48	0.013	*	-10.305	1148.885
SDII	-2	0.045	*	-0.027	8.131
CDD	1.6	0.11		0.50	46
CWD	-1.136	0.256		-0.148	17.926
RX1day	-2.6	0.009	**	-0.5	49.27
RX5day	-1.63	0.103		-0.56	93.68
R10	-1.89	0.059	+	-0.3	37.9
R20	-3.505	0.000	***	-0.189	10.56
R95p	-3.796	0.000	***	-5.537	286.856
R99p	-2.595	0.009	**	-1.534	71.84

***, **, *, and + stands for statistically significant at 0.001, 0.01, 0.05, and 0.1 probability levels

Annual Total Precipitation and SDII analysis

As depicted in Table 4 and Figure 8, the MKZ result implies a statistically significant negative trend of total annual precipitation and simple daily intensity index in Legambo district. The result agrees with the findings of Asfaw *et al.* (2018), Berhane *et al.* (2020), and Teshome and Zhang (2019), where a statistically decreasing trend in precipitation-related indices was reported. However, it differs from Worku *et al.* (2019), where a statistically increasing trend was reported. Presence of such extreme rainfall indices mainly in annual precipitation may suggest signs of climate change in Legambo district. Such variability of precipitation extremes during the main rainy season would have adverse effects on various socioeconomic activities, predominantly in agricultural and water resource sectors.

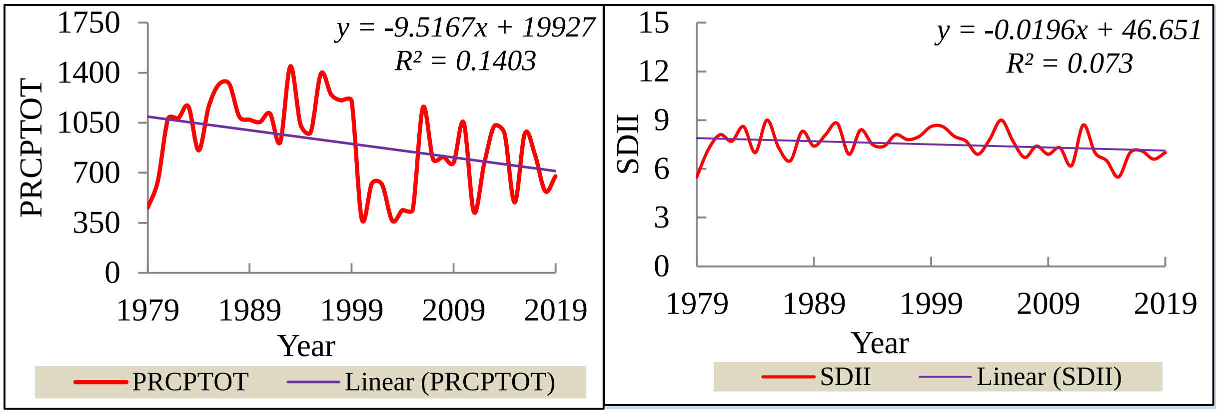

Figure 8: Trend of PRCPTOT and Simple daily intensity index (SDII)

The trend of Consecutive Dry Days and Consecutive Wet Days

As depicted in Table 4, no statistically significant trend in consecutive dry days and consecutive wet days in the study area leads to the acceptance of the null hypothesis (Figure 9).

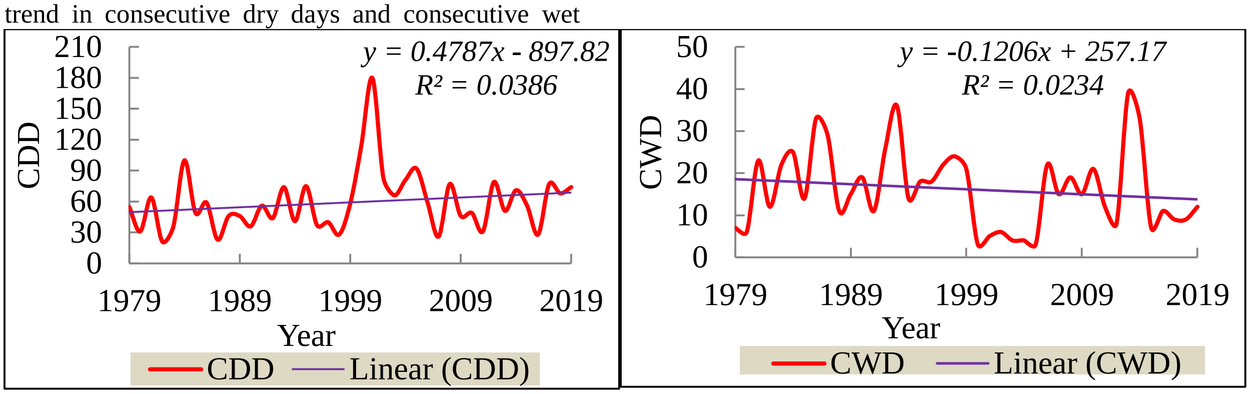

Figure 9: Pattern of Consecutive Dry Days and Consecutive Wet Days

Maximum 1day (RX1day) and Maximum 5day (RX5day) rainfall

There is a statistically significant trend in the RX1 day, and there is no statistically significant trend in the RX5 day in the time series in the study area. Mann Kendall non-parametric test of trend statistics (MKZ) negative value of RX1 day has a negative trend (see Table 4 and Figure 10). The result agrees with the findings of Berhane *et al.* (2020) and Teshome and Zhang (2019). However, Teshome and Zhang found that RX1 day and RX5 day over Addis Ababa show a decreasing trend but an increasing trend over Kombolcha. From this, it can be inferred that the trend has spatio-temporal variation. Sen's slope estimator result indicates that RX1 day decreases at 0.5 mm per annum.

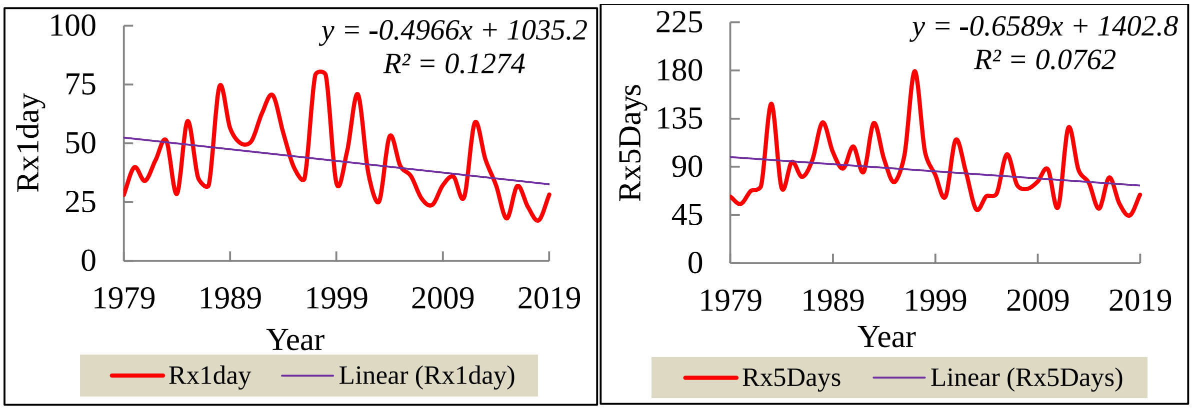

Figure 10: Trend of monthly maximum 1-day and 5-day precipitation amount

Number of Heavy (R10) and Very Heavy (R20) Precipitation

R10 is not statistically significant, while R20 shows a statistically significant decreasing trend (Table 4 and Figure 11). The result is similar to the findings of Berhane et al. (2020) and Teshome and Zhang (2019). The interviewed farmers agreed unequivocally for a shift in the region's rainfall patterns. Respondents stated that overall precipitation has decreased and that unpredictable variability in belg rainfall, critical in the study area, has affected their agricultural activities. Rainfall, mainly belg rainfall, since the recent past, has shown a late-onset and early cessation nature that makes the cropping calendar uncertain.

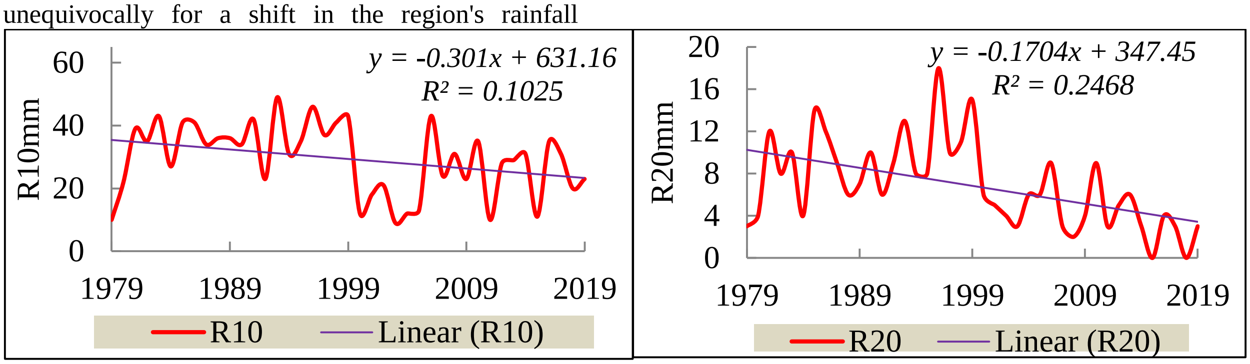

Figure 11: Pattern of Heavy (R10) and very heavy precipitation days (R20)

Extremely wet Days (R99p) and very wet days (R95p)

MKZ result (Table 4) reveals a statistically significant negative trend in R95p and R99p (see Table 4 and Figure 12). The findings differ from those of Worku *et al.* (2019), who reported an increasing trend of very wet days and extremely wet days in Jemma sub-basin of upper Nile basin.

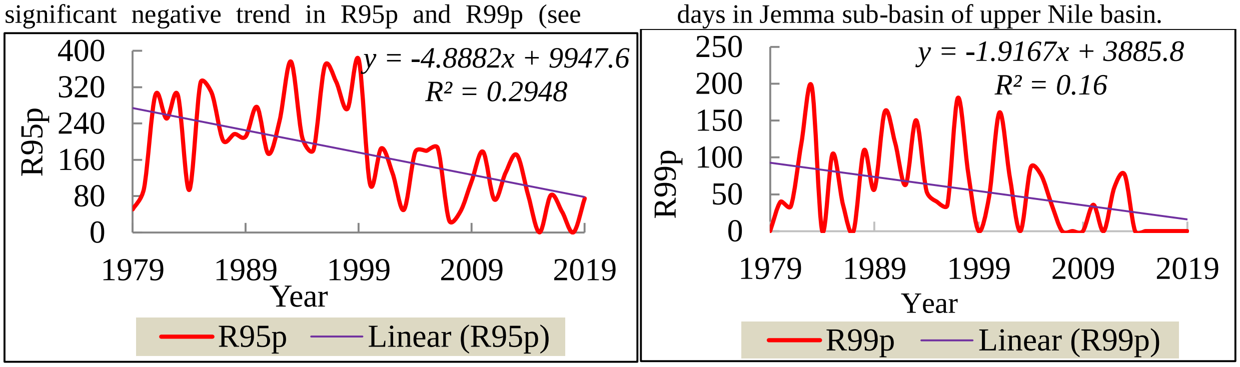

Figure 12: Pattern of Very Wet and Extremely Wet Days

CONCLUSION AND POLICY IMPLICATIONS

Climate change-induced extreme values cross a prescribed statistical threshold from the normal expectation. This statistic can quantify the rarity of an extreme weather event (for example, a one-in-five-year torrential rain) or extreme weather condition (consecutive dry days). Climate change-induced extreme events are the primary development challenge of the 21st century, especially in the agricultural sector. This study attempted to generate the most relevant information that may fill the knowledge gap on the localized incidence of extreme events and is expected to contribute to development activities and policy formulation. Analysis of historical climate data for 41 years (1979-2019) was conducted using R software (RClimDex), XLSTAT, and MAKESENS Mann-Kendal non-parametric trend tests simultaneously. The output result witnessed a trend in both temperature and precipitation-related extreme events. The finding revealed an increasing, positive and warming trend in temperature-related indices such as monthly maximum value of daily maximum temperature (TXx), minimum value of daily maximum temperature (TXn), monthly minimum value of daily minimum temperature (TNn), monthly maximum value of daily minimum temperature (TNx), Warm days (TX90p) and Warm nights (TN90p), Warm Spell Duration Indicator (WSDI) and Hot days (SU). The finding also revealed a negative trend in temperature-related extreme indices of the number of cool nights (TN10p), cool days (TX10p), Cold Spell Duration Indicator (CSDI) and Diurnal Temperature Range (DTR). There was a positive trend only in Consecutive Dry Days (CDD) on precipitation-related extreme events. Such variability in extreme events urged the design of locally specific adaptation strategies. For example, there is an indication of an agronomic shift in the research area. Reducing cool nights and cold spell days, among the significant issues for crop production, primarily for highland areas, would be an excellent opportunity to shift crop production upwards. Nevertheless, as highland ecosystems are particularly fragile, caution must be used when farming in these locations.

This study showed that the district's weather extremes caused by climate change are highly variable and ever-changing. This suggested the need for a planned intervention system, such as the development of dependable irrigation schemes to lengthen the harvesting seasons and decrease reliance on rain-fed agriculture, particularly in one-season cropping areas; the expansion of non-farm and off-farm livelihood diversification activities; the introduction of crop varieties with short maturation and high yields; and the timely and comprehensive dissemination of weather information. Thus, it is crucial to consider the variability of extreme events for any concerned body in designing adaptation strategies. As the change in temperature and precipitation-induced extremes become more variable, smallholder rain-fed agriculture will no longer enable farmers to achieve food security and should be supported by irrigation schemes. Hence, it is believed that investment in irrigation schemes can buffer farmers from dependence on food aid in times of crop failure when climate change-induced extreme events happen. Moreover, general initiatives to assist smallholder farmers in better coping with the variability of climate change-induced extreme events should be more embedded in the local context of their decision-making. Adaptation to the changing climate should not be considered in isolation but in the context of comprehensive management by local agroecological, physical, socioeconomic, institutional, and political factors.

Since almost all precipitation-related indices showed a decreasing trend, and most temperature-related indices witnessed a warming trend, rain-fed-dependent agriculture with poor coping capacity and fewer adaptation measures (Asfaw *et al*., 2018; Mohammed *et al*., 2018; Mekonen and Berlie, 2020) in the study area will lead farmers to fall into the vicious circle of poverty. In conclusion, this study proved that the intensity and frequency of climate extremes have increased in the last four decades. Extreme weather events such as heat waves, dry spells, droughts, and shifts in the onset and cessation significantly affect farming, especially in nations where rainfed subsistence farming is the norm. These extreme weather events may result in decreased output and increased crop damage from pests and diseases, significantly impacting food security and subsistence farmers' lives.

Teshome and Zhang (2019) have emphasized that extremes are expected to become more frequent and intense across many regions, including East Africa. That means further climate change may aggravate the situation of climate extremes in the study area. Under this condition, rain-fed agriculture will no longer enable farmers to achieve food security. As a result, designing context-specific adaptation strategies is crucial, and one-size-fits-all does not work as far as adaptation to climate change is concerned. Hence, it is believed that investment in irrigation schemes can buffer farmers from dependence on food aid in times of crop failure. Hence, policy development has to focus on developing appropriate adaptation strategies to lessen the adverse impacts of the change, like the provision of high-yield crop variety and hybrid livestock species resistant to extreme events, as indices are expected to be more variant in the future than today. Moreover, non-farm sources of income in the study area are minimal (Asfaw *et al.*, 2018). Securing alternative sources of income and related interventions that would enhance the adaptive capacity of subsistence farmers and reduce their sensitivity plays a paramount role in building resilient livelihoods.

REFERENCES

Addisu, S., Selassie, Y. G., Fissha, G., and Gedif, B. (2015). Time series trend analysis of temperature and rainfall in Lake Tana Sub-basin, Ethiopia. *Environ Syst Res*. 4:25. DOI 10.1186/s40068-015-0051-0.

Ageet, S., Fink, A.H., Maranan, M., Ssali, A.L., Diem, J.E., and Ayabagabo, P. (2022). Validation of Satellite Rainfall Estimates over Equatorial East Africa. Journal of hydrometeorology; 23: 129- 151. DOI: 10.1175/JHM-D-21-0145.1

Alho, C. J., and Silva J. S. (2012). Effects of severe loads and droughts on wildlife of the Pantanal Wetland (Brazil) – a review. Animals: 591–610.

Asfaw, A., Simane, B., Hassen, A., and Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in Northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and Climate extremes*, 19: 29-41. DOI: org/10.1016/j.wace.2017.12.002.

Ayalew, D., Tesfaye, K., Mamo, G., Yitaferu, B., and Bayu, W. (2012). Variability of rainfall and its current trend in Amhara region, Ethiopia. *African Journal of Agricultural Research*; **7**(10): 1475-1486.

Ayehu, G.T., Tadesse, T., Gessesse, B., Dinku, T. (2018). Validation of new satellite rainfall products over the upper Blue Nile Basin, Ethiopia. *Atmos. Meas. Tech*. 11(4), 1921–1936.

Bantider, A., Hurni, H. and Zeleke G. (2011). Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wello, Ethiopia. *Norwegian Journal of Geography*, 65: 42-53. DOI 10.1080/00291951.2010.549954.

Berhane, A., Hadgu, G., Worku, W., and Abrha, B. (2020). Trends in extreme temperature and rainfall indices in the semi-arid areas of Western Tigray, Ethiopia. *Environ Syst Res*; 9:3. DOI.org/10.1186/s40068-020-00165-6.

Bhuyan, M.D., Islam, M., and Bhuiyan, K. (2018). A Trend Analysis of Temperature and Rainfall to Predict Climate Change for Northwestern Region of Bangladesh. *American Journal of Climate Change*; 7,115-134. https://doi.org/10.4236/ajcc.2018.72009

Cafer, A., and Rikoon, S. (2017). Coerced agricultural modernization: a political ecology perspective of agricultural input packages in South Wollo, Ethiopia. *Journal of rural social sciences*, **32**(1): 77-97.

Degefu, M.A., Bewket, W., and Amha, Y. (2022). Evaluating performance of 20 global and quasi-global precipitation products in representing drought events in Ethiopia I: Visual and. correlation analysis. *Weather and Climate Extremes*; 35:100416. DOI: 10.1016/j/wace.2022.100416.

Dinku, T., Asefa, K., Hilemariam, K., Grimes, D., and Connor, S. (2011). Improving availability, access, and use of climate information. *Bulletin of the World Meteorological Organization*, 60 (2).

Dubache G., Asmerom, B., Ullah, W., Ogwang, B.A., Amiraslani, F., and Gul, C. (2021). Testing the accuracy of high-resolution satellite-based and numerical model output precipitation products over Ethiopia. *Theoretical and Applied Climatology*; 146:1127–1142. DOI: 10.1007/s00704-021-03783-x.

Eckstein, D., Hutfils, M.L., and Winges, M. (2018). Global Climate Risk Index 2019. Who Suffers Most from Extreme Weather Events? Weather-related Loss Events in 2017.

Emerta, A. (2013). Climate change, growth and poverty in Ethiopia, working paper No. 3

Edris, S., Teka, D., and Zenebe, A. (2021). Assessment of Spatio-temporal Relationship Between Gauge and Satellite Rainfall Estimates over Awash River Basin, Ethiopia. *J Remote Sens GIS*; 10: 7(1000P151)

Esayas, B., Simane, B., Tefera, E., Ongoma, V., and Tefera, N. (2018). Trends in Extreme Climate Events over Three Agroecological Zones of Southern Ethiopia. *Advances in Meteorology*; DOI.org/10.1155/2018/7354157

Evangelista, P., Young, N. and Burnett, J. (2013). How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops. *Climatic Change* **119**:855–873. DOI 10.1007/s10584-013-0776-6.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. (2015). The climate hazards infrared precipitation with stations-A new environmental record for monitoring extremes. *Sci. Data*; 2,150066. DOI:10.1038/sdata.2015.66

Funk, C., Rowland, J., Eilerts, G., Kebebe, E., Biru, N., White, L. and Galu, G. (2012). A Climate Trend

Analysis of Ethiopia. U.S. Geological Survey Fact Sheet 2012–3053,

Gebretsadkan, K.N., Tamrie, M.B., and Haile Belay Desta, H.B. (2023). Performance evaluation of multi-satellite rainfall products in the Gidabo catchment, Rift Valley Basin, Ethiopia. *Journal of Water and Climate Change*; 14:11 (3950) DOI: 10.2166/wcc.2023.097

Gebrechorkos S. H., Hulsmann S., Bemofer C., (2018). Changes in temperature and precipitation extremes in Ethiopia, Kenya and Tanzania. *Int J Climatol;* 39:18–30

Gedefaw, M. (2023). Assessment of changes in climate extremes of temperature over Ethiopia. *Cogent Engineering*, 10: 2178117. DOI: 10.1080/23311916.2023.2178117.

Getaneh, B., and Getachew, T. (2021). Validation of Different Weather Generator Tools under Various Climatic Condition of North Shewa, Amhara Region, Ethiopia. *Research in agricultural and veterinary sciences*. 5 (3):128-141.

Gray, S.T., Betancourt J. L., Jackson S.T., Eddy, R.G. (2006). Role of multi-decadal climate variability in a range extension of pinyon pine. *Ecology*; 87:1124–1130

Hadgu, G., Tesfaye, K., Mamo, G., and Kassa, B. (2013). Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. *Academia Journal of Environmental Sciences*: **1**(8): 159-171. DOI: 10.15413/ajes.2013.0117.

Hayelom, B., Chen, Y., Marsie, Z., and Negash, M. (2017). Temperature and Precipitation Trend Analysis over the Last 30 Years in Southern Tigray RegionalState,Ethiopia.DOI:10.20944/preprints2017 02.0014.v1

Hordofa, A.T., Leta, O.T., Alamirew, T., Kawo, N.S., Chukalla, A.D. (2021). Performance Evaluation and Comparison of Satellite-Derived Rainfall Datasets over the Ziway Lake Basin, Ethiopia. *Climate***;** 9, 113. https://doi.org/10.3390/cli9070113

Hussain, F., Nabi, G., and Boota, W. (2015). Rainfall Trend analysis by using the Mann-Kendall test and Sen's slope estimates: A case study of district Chakwal rain gauge, Barani area, Northern Punjab Province, Pakistan

IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., DOI:10.1017/9781009325844.

IPCC (2007). Intergovernmental Panel on Climate Change the Physical Science Basis, Cambridge University Press. Cam-bridge, UK, 2007.

Kahsay, B. (2013). Diagnosis and intervention plans for south Wollo zone, Amhara region: livestock and irrigation value chains for Ethiopian smallholders (LIVES) (Unpublished).

LDPC (2021). Legambo District Plan Commission Annual Plan Report (unpublished)

Lemma, E., Upadhyaya, S., and Ramsankaran, R. (2019). Investigating the performance of satellite and reanalysis rainfall products at monthly timescale across different rainfall regimes of Ethiopia. *Int. J. Remote Sens*.; 40: 4019-4042.

Leulseged, Y., Nicol, A. and Srinivasan, S. (2013). Warming to Change? Climate Policy and Agricultural Development in Ethiopia. Future agriculture; working Paper 071.

Meehl, G., Arblaster, J. M., Fasullo, J. T., Hu, A., and Trenberth, K. W., (2009). Relative Increase of Record High Maximum Temperatures Compared to Record Low Minimum Temperature in the U.S. *Geophysical Research Letters*; 36, L23701, www.doi:10.1029/2009GL040736.

Mengistu, D., Bewket, W. and Lal, R. (2014). Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. *Int. J. Climatol.* 34: 2278–2292; DOI: 10.1002/joc.3837.

Mekonen and Birlie (2020). Spatiotemporal variability and trends of rainfall and temperature in the Northeastern Highlands of Ethiopia. *Modeling Earth Systems and Environment*; 6:285–300. DOI: 10.1007/s40808-019-00678-9

Mintenbeck, E. V., Engel, S., Brouwer, R., and Dekkers, J. (2011). Climate change and agricultural vulnerability in Sub-Saharan Africa. *Environmental Science and Policy*; 44: 89-94.

Misganaw, T., Adigo, E., and Tilahun, T. (2014). Investigating the Determinants of Adaptation Measures to Climate Change: A Case of Batii District, Amhara Region, Ethiopia. *Int. J. Agric. Res.* 9(4): 169–186.

Mohammed, Y., Yimer, F., Tadesse, M., and Tesfaye, K. (2018). Variability and trends of rainfall extreme events in northeast highlands of Ethiopia. *International Journal of Hydrology*; 2(5): 594-605. DOI: 10.15406/ijh.2018.02.00131.

Nawaz, M., Iqbal, M. E., and Mahmood, T. (2020). Validation of CHIRPS satellite-based precipitation dataset over Pakistan, *Atmospheric Research;* DOI: 10.1016/j.atmosres.2020.105289

Philip, S., O'keefe, S., Kew, S. F., Haustein, K., Hailemariam, K., Singh, R., Oldenborgh, G. J.V., King, A., Jjemba, E., Otto, F., Zegeye, A., Funk, C., Eshetu, Z. and Cullen, H. (2015). Attribution Analysis of the Ethiopian Drought of 2015. *American*

Meteorological Society. DOI: 10.1175/JCLI-D-17-0274.1
Planton, S., Déqué, M., Chauvin, F., and Terray, L. (2008). Expected impacts of climate change on extreme-climate-events. http://france.elsevier.com/direct/CRAS2A/
Rosell, S., and Holmer, B. (2015). Erratic rainfall and its consequences for the cultivation of teff in two adjacent areas in South Wollo, Ethiopia. *Norsk-Geografisk Tidsskrift–Norwegian Journal of Geography;* 69(1):38-46.
Rosell, S. (2011). Regional perspective on rainfall Change and variability in the central highlands of Ethiopia, 1978–2007. *Applied Geography*; 31(1): 329-338.
Smith T. T., Zaitchik B. F., Gohlke J. M., (2013). Heat waves in the United States: definitions, patterns and trends. *Clim. Change*; 118: 811–825.
Serdeczny, O., Adams, S., Baarsch, F., Bebb, D., Bell, M., Berry, S., and Zscheischler, J. (2016). Heat Stress and human health in the Greater Horn of Africa: A review of the scientific evidence. *International Journal of Environmental Research and Public Health;* 13(8), 868
Tefera, A. S., Ayoade, J. O. and Bello, N. J. (2019). Comparative analyses of SPI and SPEI as drought Assessment tools in Tigray Region, Northern Ethiopia.SN-Applied-Sciences; 1:1265.https://doi.org/10.1007/s42452-019-1326-2.
Tesfamariam, B. G., Gessesse, B., and Melgani, F. (2019). Characterizing the spatiotemporal distribution of meteorological drought as a response to climate variability: The case of rift valley lakes basin of Ethiopia. Weather and Climate Extremes; 26: 100237. DOI: 10.1016/j.wace.2019.100237.
Teshome, A. and Zhang, J. (2019). Increase of Extreme Drought over Ethiopia under Climate Warming. *Advances in Meteorology*; Article ID 5235429. Doi.org/10.1155/2019/5235429
Tesso, G., Emana, B. and Ketema, M. (2012). A time series analysis of climate variability and its impacts on food production in the North Shewa zone in Ethiopia. *African Crop Science Journal*; **20**(2): 261–274
Tote, C., Patricio, D., Boogaard, H., Van der Wijngaart, R., Tarnavsky, E., and Funk, C. (2015). Evaluation of satellite rainfall estimates for drought and flood monitoring in Mozambique. *Remote Sens*.; 7: 1758-1776.
Wagesho, N., Goel, N.K. and Jain M.K. (2013). Temporal and spatial variability of annual and seasonal rainfall over Ethiopia. *Hydrological Sciences Journal*; 58 (2):354-373. DOI: 10.1080/02626667.2012.754543.
UNDP (United Nations Development Programme) (2016). Human development report 2016: Human development for a changing climate. United Nations Development Programme.
Wang, W., Yuanfang Chen, Stefan Becker and Bo Liu, (2015). Linear Trend Detection in Serially Dependent Hydrometeorological Data Based on a Variance Correction Spearman Rho Method. *Water*: 7: 7045–065; DOI: 10.3390/w7126673
Weldegerima, T. M., Birhanu, B.S., and Terefe Zeleke, T.T. (2023). Trend Analysis for Temperature and Precipitation Extreme Events over the Headwater of Upper Blue Nile, Ethiopia. *J Earth Sci Clim Change*; 14:3
Worku, G., Teferi, E., Bantider, A., and Dile, Y.T. (2019). Observed changes in extremes of daily rainfall and temperature in Jemma sub-basin, Upper Blue Nile Basin, Ethiopia. *Theoretical and Applied Climatology*; 135:839–854. Doi.org/10.1007/s00704-018-2412-x.
World Bank (2010). Economics of Adaptation to Climate Change-Ethiopia. The World Bank Group; Washington, DC.
Yue, S., Pilon, P., and Cavadias, G. (2002). Power of the Mann-Kendall and Spearman Rho's test for detecting monotonic trends in hydrological series. *Journal of hydrology*; 259: 254-271. Meteorological Service of Canada, Ontario, Region
Zhang *et al.* (2005). Trends in Middle East climate Extreme indices from 1950 to 2003. *J. Geophys. Res.;* 11 0, D22104. DOI: 10.1029/2005JD006181.
Zhang X., and Yang F. (2004). RClimDex (1.0) User Manual. Climate Research Branch, Environment Canada, Ontario (Canada).