1 **Evaluation of Climate Change Impact on Extreme Temperature Variability in**

2 **the Blue Nile Basin, Ethiopia**

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11 **Abstract**

12 In this paper, spatial and temporal patterns of changes in extreme temperatures are investigated

13 using 10 meteorological stations data for the period 1950-2018 in the Blue Nile basin. Monthly

14 temperature data for the basin were used in the study. Long-term trends in the Blue Nile Basin

15 annual and monthly temperatures were investigated. The statistical significance of the trend is

16 calculated by applying the Mann-Kendall (MK) test. The analysis of data was performed using

17 the coefficient of variance, anomaly index. The results showed that the annual maximum and

18 minimum temperature is increasing significantly with a magnitude of $0.037°$ and $0.025°$ C per

19 decade respectively in the period from 1950 to 2018. The result of the Mann-Kendall analysis

20 test revealed a marked increase in mean maximum and minimum temperatures trend over time

21 significantly during the study period (the minimum temperature rate is more evident than the

22 maximum). The long-term anomalies of mean annual minimum temperature revealed the inter-

23   annual variability while the trend after 1977 was higher than the long-term average that is proof

24   of the warming trend existence since the last two decades of the 20th century.

25   *Keywords:* Trend Analysis, Mann-Kendall Test, Climate Variability, Minimum Temperature,

26   Maximum Temperature, Blue Nile.

27   1. Introduction

28   Climate change is perceived to affect the whole world and there has been a growing concern

29   about its direction and consequences. The Blue Nile River Basin (BNRB) is the most important

30   and the potential river basins in the Nile Basin. Many development projects are under

31   construction currently in the BNRB without detailed climate change thorough analysis. These

32   projects are essential for irrigation schemes, hydropower generation, and national economic

33   growth. As a trans-boundary river basin, it attracts the attention of some neighboring countries.

34   For sound management and planning of water resources, it is important to predict the climate

35   change and variability of crucial metrological factors as temperature, and precipitation (Tamiru,

36   2011). Temperature and precipitation are affecting directly the hydrology of the basin (El-Mahdy

37   et al., 2019). Since temperature affects both evaporation and evapotranspiration, and

38   precipitation is the source of runoff, so studying these factors is very important in water

39   resources management of the basin. The detailed analysis of the impact of these factors on basin

40   hydrology will be addressed by forthcoming researches.

41   The assessment of extreme temperature variability resulted from climate change will help to

42   better manage the development projects in the BNRB. Global and regional rises in air

43   temperature, together with its collateral rises in water temperature, drive to negative alterations

44   in water quality, even with the same precipitation. Lake Tana, located upstream of BNRB, is one

45   of the greatest natural lakes of Africa (El-Mahdy, 2014). Generally, the Lakes are sensitive to a

46   wide range of climate change consequences. Even a slight change in climate can result in huge

47   changes in lake salinity and levels (El-Mahdy et al., 2018, Mengistu et al., 2014, Tamiru, 2011).

48   The symptoms of global warming could be noticed almost everywhere around the world.

49   Heatwaves and droughts are striking a lot of places around the world, so that precipitations,

50   humidity, and temperatures are rarely normal. These phenomena among others are considered

51   evidence of the presence of climate variability. The analysis of data from ground stations and

52   satellites showed that the mean surface temperature of the world has increased by about 0.6

53   degrees Celsius over the 20th century (Lindzen and Giannitsis, 2002, Tapley et al., 2019). The

54   warmest years ever have all occurred since 1980 in this century (Janssens et al., 2020). The

55   warmest recorded year was 1998 (Mann et al., 1999). These alterations appear to be out of the

56   natural variability range (Houghton, 1996, Mann et al., 1999, Sippel et al., 2020, Watson et al.,

57   1996). A lot of researches studied the impact of temperature rise on runoff, it was found, with

58   high confidence, that the runoff has increased in winter and decreased in summer and spring, in

59   addition to higher peak flows have occurred in these basins (Anache et al., 2018, Bergström et

60   al., 2001, Chen et al., 2012, Yan et al., 2020).

61   The results of the simulation studies conducted by (Gleick, 2000) in the USA concluded that

62   small alterations in rainfall and temperature may lead to huge impacts on runoff. It was found

63   that if temperature increases without a change in rainfall, the runoff will decrease. A 10%

64   decrease in rainfall together with a temperature rise of 2°C will reduce the runoff by 13-40%. On

65   the other hand, if rainfall increases by 10% and the temperature rise by 4°C, almost the rainfall

66   increase will balance evaporation losses and no alteration on runoff is predicted. Although these

67   findings are not comprehensive, but they reveal the possible size and uncertainty encircling the

68   hydrologic and climatic implications of greenhouse warming (El-Mahdy, 2011).

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69　Temperature is the most serious climate variable that affects hydrology and climate which,

70　consequently, has an enormous direct and indirect impact on human life and the environment.

71　The temperature is a continuous variable in both space and time. The Monthly Mean

72　Temperature (MMT), as well as the maximum and minimum MMT, always matches a normal

73　distribution (Jones and Hulme, 1996). The predicted climate change may affect most of the

74　Ethiopian districts. Drought remains Ethiopia's major hazard, while floods following in another

75　place (Conway and Schipper, 2011). Recently, it is clear that both drought and flood have

76　increased in both frequency and size (Margaret, 2003).

77　A recent study by (Gebrehiwot and van der Veen, 2013) indicated that climate change in

78　Ethiopia could lead to extreme temperatures and rainfall events, leading to more heavy and

79　extended droughts and floods. The climate of Ethiopia is composed of three distinct seasons

80　named: Belg, Kiremt, and Bega seasons (Haile, 2005). Belg is a short rain season which covers

81　the period from February to May. The rainfall in the Belg season results by the humid south-

82　eastern and eastern winds that originate from the Indian Ocean. Kiremt is a long rainy season

83　that starts in June and normally ends in September. The Kiremt season's rainfall results

84　substantially from the convergence of low-pressure winds and the Intertropical Convergence

85　Zone (ITCZ). Finally, the dry season, called Bega, extends from October to January (Tabari et

86　al., 2015). Changes in sea surface temperature and El Niño Southern Oscillation (ENSO) periods

87　in the Indian and Atlantic Oceans have effects on the timing and amount of rainfall in Ethiopia

88　(Fekadu, 2015, Shanko and Camberlin, 1998). Asfaw et al. (2018) found that the drought events

89　of Ethiopia are the result of both ENSO, Sea Surface Temperature (SST) variations in the Indian

90　and Atlantic, and anthropogenic activities. Kiros et al. (2016) found that the result of different

91　studies of temperature trend analyses in Northern Ethiopia is a mixture of non-significant

92 negative and positive trends. (Mengistu et al., 2014) noted that the trend of temperature was

93 increasing and statistically significant in Ethiopia. Although the concept of global warming and

94 its impact on BNRB was studied before, but the analysis of long enough time series over

95 multiple weather stations with the appropriate statistical tools was not found. The main objective

96 of this research is to detect any climate change through the evaluation of extreme temperature

97 variability using trend analysis of along temperature time series in the BNRB, Ethiopia.

98 **2. Data and Methodology**

99 **2.1.Types of data**

100 Temperature data, which is used in the variability and time series trend analysis, has been

101 obtained from Ethiopia Meteorological Authority. Ten stations covering different parts of BNRB

102 have been chosen to study the variability of their data sets (see Table 1 and Figure 1). The

103 climate data consist of maximum & minimum MMT data probably with long years of records for

104 10 stations that have been collected in the BNRB. The length of record of the data made

105 available for this analysis varies from 62 to 68 years, most analyses have focused on changes in

106 mean values due to the lack of the availability of high-quality daily data required for monitoring,

107 detecting, and attributing climate extremes changes (Jones, 1999). The study period (1950-2018)

108 was chosen according to the availability of the recorded data for all stations. The missing data

109 were calculated using the average of previous and subsequent months (for missed monthly data),

110 but the analysis excluded annual missing data.

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115   Table (1): Selected weather stations of the Blue Nile basin and their general information.

No	Station Name	Longitude (E)	Latitude (N)	Altitude (m)	Area (%)	Mean annual rainfall (mm)
1	Addis Ababa	38.7	9.03	2408	16.45	1165
2	Assosa	34.52	10.07	1560	7.89	1126
3	Bahir Dar	37.42	11.06	1770	-	-
4	Debre Markos	37.67	10.33	2515	11.84	1303
5	Gondar	37.04	12.05	2000	13.82	1102
6	Gore	35.53	8.15	2002	8.55	2181
7	Dangla	36.8	11.3	2030	4.61	1491
8	Jimma	36.83	7.67	1676	12.5	1480
9	Sibu Sere	36.9	9.00	1750	8.55	1420
10	Dessie	39.67	11.08	2460	15.79	1045

116   (Source: Ethiopia Meteorological Authority)
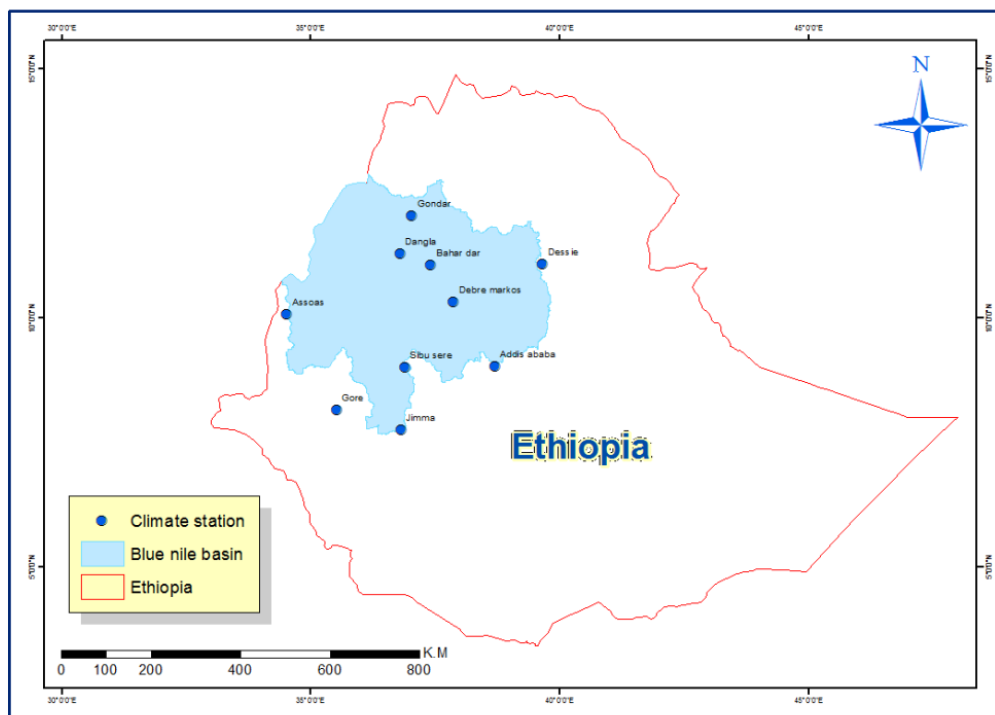
118   Figure (1): Location map of the Blue Nile Basin and the selected meteorology

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2.2. Description of the study area

The BNRB starts at the outlet of Lake Tana in Ethiopia and flows downstream to Khartoum in Sudan where it meets the White Nile. The basin surface area is 324,530 km^2. The terrain of the BNRB is generally hilly which contains valleys, highlands, and a lot of rock peaks. The Lake Tana Basin is located in north-western Ethiopia of Latitude 10.95$^°$ and 12.7$^°$ N, and longitude 36.89$^°$ and 38.2$^°$ E with a drainage area of about 15,000 km^2 (Sintayehu, 2015). Lake Tana, upstream of BNRB, is the greatest natural lake in Ethiopia and the third greatest natural lake in the Nile Basin, is located in this basin. The main rivers that feed Lake Tana are Gilgil Abai, Gomera, Rip, and Magek (El-Mahdy, 2017). These short length rivers constitute about 93% of the outflow of the lake (Kebede et al., 2006). The highest temperature recorded in the BNRB is located in the northwestern part. In some parts of Dabus, Dinder, Rihad, and Beles, the maximum recorded temperature reaches 38$^°$C and minimum approaches 15$^°$C. on the other hand, the lower temperature is recorded in the eastern and central parts of the basin in the Ethiopian highlands. In these areas, the maximum temperature is 20$^°$C and the minimum is -1$^°$C (Tamiru, 2011).

2.3. Methods

The analysis of temperature was performed using many techniques. These techniques are generally categorized as trend analysis and variability as standard deviation (SD). The variability analysis encompasses the Coefficient of Variation (CV), moving average, and the percentage departure from the mean (Gebrechorkos et al., 2020). On the other hand, trend analysis is applied to consistent data only utilizing parametric and non-parametric tests. The homogeneity and normality of the variance over the data series are usually affected by missing data and outliers in parametric tests. The non-parametric test is used to overcome the problem of non-normally

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145   distributed, missing data, and outliers. This problem is repeatedly found in the hydrological and

146   meteorological time series. For these reasons, Mann- Kendall (MK) test is commonly utilized to

147   discover the trends of meteorological and hydrological variables (Degefu and Bewket, 2014,

148   Kiros et al., 2016, Seleshi and Camberlin, 2006, Tabari and Tavakoli, 2016). MK is a

149   nonparametric test, that assesses the trend of any time series without assigning if the trend is

150   non-linear or linear. MK test is commonly used to discover the monotonic (increasing or

151   decreasing) trends in the time series of hydrological, meteorological, and environmental data

152   (Yue et al., 2002). In the current paper, the variability of temperature was calculated employing

153   the SD and CV tests. Moreover, MK was employed to reveal the temperature trend using Sen's

154   slope estimator. SPSS v22 software was used to perform the data analysis. CV is computed to

155   evaluate the rainfall variability. the higher the CV value, the larger variability of rainfall. CV is

156   calculated using the following equation:

157   $$CV = \frac{\sigma}{\mu} \times 100 \qquad\qquad (1)$$

158   Where CV is the coefficient of variation; σ is the standard deviation and μ is the mean (Isioma et

159   al., 2018). MK test was employed to explore the presence of monotonic trends in the time series,

160   and the statistical significance of the trend. Since outliers cannot be averted in any time-series,

161   the MK test is advantageous because it is based on the (+ or -) signs instead of the random

162   variable values. Therefore, the MK test is less influenced by the outliers (Asfaw et al., 2018).

163   The test of homogeneity was conducted employing Pettitt's test (Pettitt, 1979). In this test, every

164   value in the time series is compared with all posterior values in the data series. If the value of the

165   subsequent period is greater than the value of the preceding period, the statistic (S) is raised by

166   one and vice versa. The summation of all increments and decrements reveals the total value of

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167   the statistic (S). The MK test statistic 'S' is calculated based on (Mann, 1945, McLeod, 2005,

168   Yue et al., 2002),   using the formula:

169    $S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$ (2)

170   The trend test is applied on a time series x_i which is ranked as i = 1, 2… n-1 and x_j, that is

171   ranked as j = i 1, 2…. n. Each of the data point x_i is taken as a reference point to be compared

172   with the other data point's x_j so that:

173    $Sgn\,(x_j - x_i) = \begin{cases} +1\ if\ (x_j - x_i) > 0 \\ 0\ if\ (x_j - x_i) = 0 \\ -1\ if\ (x_j - x_i) < 0 \end{cases}$ (3)

174   where x_i and x_j are the data values in the years i and j respectively (j > i).

175   It was reported that, if the number of observations is greater than 10 (n ≥10), the statistic (S) is

176   usually normally distributed around the mean (McLeod, 2005). So that, the variance could be

177   formulated as:

178    $Var(S) \ = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_1(t_1-1)(2t_1+5)}{18}$ (4)

179   where n is the number of observation and t_i are the ties of the sample time series. The test

180   statistics Z_c is as follows:

181    $Z = \begin{cases} \frac{S-1}{\sigma}\,if\quad S > 0 \\ 0\ \ if\quad S = 0 \\ \frac{S+1}{\sigma}\,if\quad S < 0 \end{cases}$ (5)

182   If Z_c follows a normal distribution, its positive or negative value refers to an upward or

183   downward trend for the studied period respectively. The trend magnitude could be calculated by

184   slope estimator methods (Sen, 1968). Here, the slope (T_i) of all data pairs is calculated according

185   to (Sen, 1968). In general, T_i for any time series x could be predicted from:

186     $T_i = \frac{x_j - x_k}{j - k}$ (6)

187   where x_j and x_k are considered as data values at time j and k (j > i) correspondingly. The median

188   of these N values of T_i is represented as Sen's estimator of the slope which is calculated as

189     $Q_{med=}T_{(N+1)/2}$ if N is an odd number, and it is computed as $Q_{med=}\left[T_{N/2} + T_{((N+2)/2)}/2\right]$ if N

190   is an even number. A positive value of T_i indicates an upward or increasing trend and a negative

191   value of T_i gives a downward or decreasing trend in the time series.

192   **3. Results and Discussion**

193   The MK test and Sen's slope estimator were applied to the time-series 1950–2018 for the ten

194   meteorological stations in BNRB. The annual and seasonal mean of the climatic parameters,

195   particularly minimum and maximum MMT were analyzed. Table 2 shows the MK test statistics

196   and p values at 5%, 1%, and 0.1% level of significances. In the MK test, parameters such as

197   Kendall's tau, S, and Z statistics were computed to determine the positive or negative trend of

198   climate parameters in the long time series studied.

199   Surface air temperature rises globally, although global warming is not uniform over the world,

200   neither temporally nor spatially (Turner et al., 2020). The surface temperature increase is the

201   direct demonstration of global climate change (Brunet et al., 2005). Tables 2 and 4 showed the

202   annual and monthly MMT maximum and minimum and their trend during the study period. The

203   mean minimum temperature in the BNRB area was 6.7°C and the mean maximum was 25.5°C,

204   with a mean annual temperature of 16.1°C. The regression line slope is about 0.036° and

205   0.024°C per decade for minimum and maximum annual temperatures respectively for the studied

206   period of 1950–2018 as shown in Tables 3 and 5 in addition to Figures 2 and 3. These results are

207   close to the previously found global warming rate which is 0.06° C per decade for the last

208   century (Pachauri and Meyer, 2014). Figures 4 and 5 showed the long-range anomalies of mean

209   annual minimum and maximum temperatures. It is clear that the trend after 1985 was greater

210   than the long-term average. This is considered as strong evidence for the global warming trend

211   since the 20th century last two decades. This result enhances the previously found results that the

212   climate becames warmer since the end of the last century (Bathiany et al., 2018, Guo et al., 2020,

213   Nijsse et al., 2019).

214   As shown in Tables 2 and 4, the result of the MK test detected that the mean maximum and

215   minimum temperatures increased significantly overtime at a 99% confidence level. The trend for

216   monthly minimum and maximum temperature is increasing significantly for all months. The

217   gross increase in the observed annual temperature is attributed to the increase in the minimum

218   temperature. Many researchers have reported that the minimum temperature rises more than the

219   maximum (Bayramzadeh et al., 2018, Crimp et al., 2018, Gross et al., 2018, Scott et al., 2017)

220   The minimum temperature incremental increase is more evident than that of the maximum. The

221   results are of good agreement with the results by (Asfaw et al., 2018). The results of the MK

222   analysis revealed an increase in both mean and minimum temperatures throughout the studied

223   period significantly. On the other hand, the maximum temperature has a non-significant

224   increasing trend. The studies that agree with these results such as (Mengistu et al., 2014, Roy and

225   Das, 2013) found that the increasing trends in the maximum temperature series were less than the

226   minimum temperature series. The cause that the minimum temperature increases more than the

227   maximum may be explained as the sensitivity of minimum temperature to the greenhouse is

228   higher than the maximum (Salawitch, 1998).Table 6 showed that the minimum temperature has

229   an increasing trend in Bega, Belg, and Kiremt seasons in the stations of Bahir Dar, Debre

230   Markos, Gondar, Gore, and Jimma with a level of significance 5%, 1%, and 0.1%. Also, the

231   maximum temperature in the three seasons has a significant increasing trend in Addis Ababa,

232   Bahir Dar, Gondar, and Gore stations and the trend is statistically significant at 0.1%, 1%, and

233   5% level of significance as shown in Table 7.

234   Table (2): Basic statistics and MK trend analysis of minimum temperature in the Blue Nile basin
235   (1950–2018).

Month	Min.	Max.	Mean	SD	CV(%)	Skewness/ Kurtosis	MK Test	Sens slope
January	6.7	11.8	10.0	1.2	11.8	-0.9/0.7	5.26***	0.031
February	8.6	13.5	11.3	1.1	10.0	-0.5/-0.1	5.62***	0.035
March	10.0	14.6	12.8	1.1	8.8	-0.8/-0.4	5.70***	0.037
April	11.2	15.5	13.6	1.0	7.4	-0.5/-0.7	5.54***	0.036
May	11.6	15.4	13.8	1.0	7.2	-0.5/-0.8	5.63***	0.035
June	10.7	15.0	13.6	1.1	7.8	-0.9/-0.3	5.75***	0.038
July	10.7	14.9	13.5	0.9	6.9	-0.8/-0.1	6.76***	0.037
August	10.5	14.7	13.3	0.9	6.8	-0.8/0.0	7.45***	0.039
September	10.0	14.3	12.9	0.9	7.0	-0.8/0.1	6.83***	0.035
October	8.8	13.1	11.5	1.0	9.1	-0.7/-0.5	6.73***	0.040
November	8.0	12.3	10.2	1.0	9.5	-0.5/-0.5	5.24***	0.031
December	7.1	11.9	9.5	1.1	11.7	-0.1/-0.8	5.47***	0.036
Annual	10.3	13.4	12.2	0.9	7.5	-0.7/-0.9	6.53***	0.036
Bega (ONDJ)	8.2	11.8	10.3	0.9	8.9	-0.6/-0.8	6.85***	0.035
Belg (FMAM)	10.6	14.5	12.9	1.0	7.9	-0.6/-0.7	5.70***	0.036
Kiremt (JJAS)	10.4	14.6	13.3	0.9	7.0	-0.9/0.0	6.96***	0.037

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237   Table (3): Linear regression result (Annual minimum temperature, Bega, Belg and Kiremt
238   season) (1950–2018)

Season	Change in minimum (°C/year)	P-value	R^2	CV (%)
Annual	0.037	0.001	0.65	7.5
Bega (ONDJ)	0.037	0.001	0.64	8.9
Belg (FMAM)	0.038	0.001	0.55	7.9
Kiremt (JJAS)	0.037	0.001	0.63	7.0

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244   Table (4): Basic statistics and MK trend analysis of maximum temperature in the Blue Nile basin
245   (1950–2018).

Month	Min.	Max.	Mean	SD	CV(%)	Skewness/ Kurtosis	MK Test	Sens slope
January	24.5	27.9	26.5	0.8	2.9	-0.6/-0.3	4.88***	0.023
February	24.2	30.0	27.6	1.1	3.8	-0.5/1.1	4.93***	0.027
March	25.5	30.9	28.4	1.0	3.6	-0.6/0.9	5.39***	0.027
April	25.5	30.3	28.0	1.1	4.0	-0.4/-0.6	5.51***	0.036
May	25.2	29.0	27.1	0.9	3.2	-0.3/-0.6	4.59***	0.024
June	23.3	26.6	25.1	0.7	2.9	-0.5/-0.3	5.13***	0.022
July	20.8	25.0	23.2	0.8	3.5	-0.5/0.4	5.94***	0.024
August	21.3	24.2	23.1	0.7	3.0	-0.6/-0.4	6.14***	0.024
September	22.6	25.4	24.2	0.6	2.5	-0.4/-0.1	6.06***	0.019
October	23.3	26.2	25.1	0.6	2.6	-0.5/0.0	4.78***	0.018
November	23.5	26.8	25.6	0.8	3.1	-0.7/-0.3	5.26***	0.022
December	23.2	26.9	25.9	0.8	3.1	-1.1/0.9	5.82***	0.025
Annual	24.5	26.8	25.8	0.6	2.5	-0.5/-1.0	7.09***	0.024
Bega (ONDJ)	24.1	26.8	25.8	0.7	2.6	-0.7/-0.5	6.05***	0.023
Belg (FMAM)	25.6	29.2	27.8	0.9	3.1	-0.5/-0.2	6.16***	0.028
Kiremt (JJAS)	22.4	25.0	23.9	0.6	2.6	-0.8/-0.1	6.59***	0.021

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247   Table (5): Linear regression result (Annual maximum temperature, Bega, Belg and Kiremt
248   season) (1950–2018)

Season	Change in maximum (°C/year)	P-value	R^2	CV (%)
Annual	0.025	0.001	0.644	2.5
Bega (ONDJ)	0.023	0.001	0.493	2.6
Belg (FMAM)	0.030	0.001	0.482	3.1
Kiremt (JJAS)	0.023	0.001	0.534	2.6

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250   Table (6): Mann-Kendal minimum temperature trend analysis (Based on gauge stations)

|	Season		Addis Ababa	Assosa	Bahir Dar	Debre Markos	Gondar	Gore	Dangla	Jimma	Sibu Sere	Dessie
Minimum temperature (°c)	Annual	Mean	9.5	15.1	11.9	9.6	13.0	13.5	18.3	11.6	11.0	11.9
		SD	0.9	0.7	1.4	0.9	0.7	0.5	0.8	1.0	0.5	1.3
		CV	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1
		MK	1.22	0.3	5.1***	7.0***	4.5***	4.4***	-2.6*	4.5***	2.7**	1.2
		Sen's slope	0.005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bega	Mean	7.6	14.2	9.8	8.2	11.6	13.5	15.5	8.3	8.4	9.4
		SD	1.2	0.9	1.6	1.0	0.9	0.5	1.3	1.6	1.0	1.1
		CV	0.2	0.1	0.2	0.1	0.1	0.0	0.1	0.2	0.1	0.1
		MK	0.33	-0.3	4.9***	6.7***	4.8***	4.1***	-1.8	4.6***	0.9	1.0
		Sen's slope	0.002	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Belg	Mean	10.5	16.1	12.4	10.5	14.3	14.2	18.8	11.7	11.5	12.5
		SD	0.9	1.2	1.7	1.1	0.9	0.7	1.0	1.5	0.8	1.5
		CV	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1
		MK	0.99	0.6	5.0***	5.9***	3.7***	2.7**	-2.7**	3.2**	3.1**	1.2
		Sen's slope	0.006	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kiremt	Mean	10.6	15.1	13.7	10.0	13.2	12.8	20.5	14.6	13.1	13.9
		SD	0.7	0.8	1.2	0.9	0.7	0.4	0.6	1.2	0.4	1.8
		CV	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1
		MK	2.17*	1.4	4.7***	6.9***	3.4***	5.6***	-2.0*	2.7**	2.2*	1.5
		Sen's slope	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

251

252   Table (7): Mann-Kendal maximum temperature trend analysis (Based on gauge stations)

|	Season		Addis Ababa	Assosa	Bahir Dar	Debre Markos	Gondar	Gore	Dangla	Jimma	Sibu Sere	Dessie
Maximum temperature (°c)	Annual	Mean	22.8	28.2	26.8	22.4	26.6	23.5	29.8	27.3	26.9	26.2
		SD	0.8	0.6	0.6	0.4	0.5	0.5	1.8	0.5	0.5	0.7
		CV	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		MK	5.25***	1.6	4.3***	3.4***	4.0***	4.8***	1.5	1.5	-0.2	2.5*
		Sen's slope	0.026	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bega	Mean	22.7	28.6	26.4	22.7	26.9	23.9	29.7	27.2	27.5	24.4
		SD	1.0	0.7	0.7	0.7	0.6	0.6	1.8	0.4	0.6	0.8
		CV	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		MK	5.08***	2.1*	4.4***	3.1**	3.5***	3.9***	1.1	-0.4	0.6	4.2***
		Sen's slope	0.027	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Belg	Mean	24.4	31.2	29.1	24.7	29.0	25.4	33.5	28.4	28.4	26.7
		SD	1.2	0.8	0.9	0.7	0.9	0.7	2.1	0.8	0.7	1.0
		CV	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		MK	3.44***	1.8	2.5*	2.3*	2.4*	2.7**	2.4*	1.5	-0.6	0.2
		Sen's slope	0.026	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kiremt	Mean	21.3	25.0	24.9	19.7	23.9	21.3	26.2	26.5	24.8	27.6
		SD	0.8	0.7	0.6	0.4	0.6	0.5	2.0	0.6	0.6	0.7
		CV	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		MK	4.41***	0.2	3.9***	1.1	2.8**	4.5***	1.3	1.8	-0.6	1.8
		Sen's slope	0.021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

253
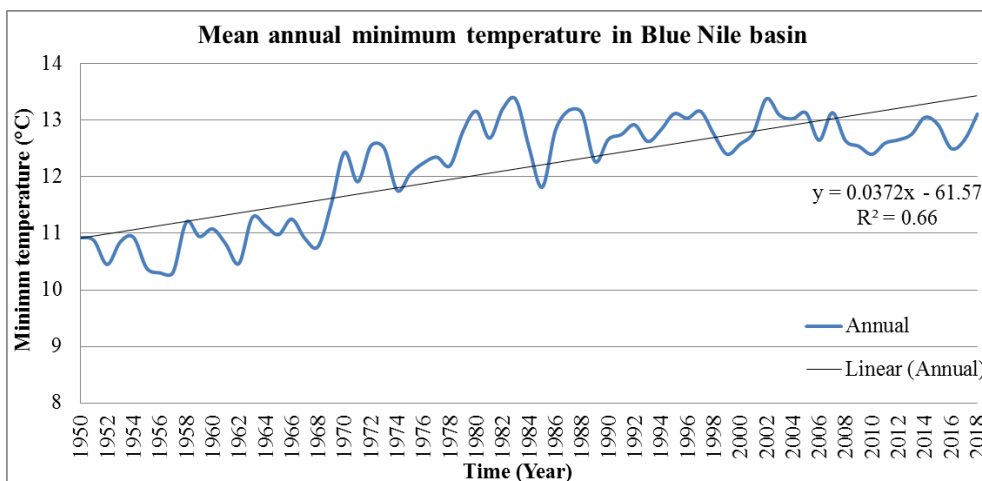
254
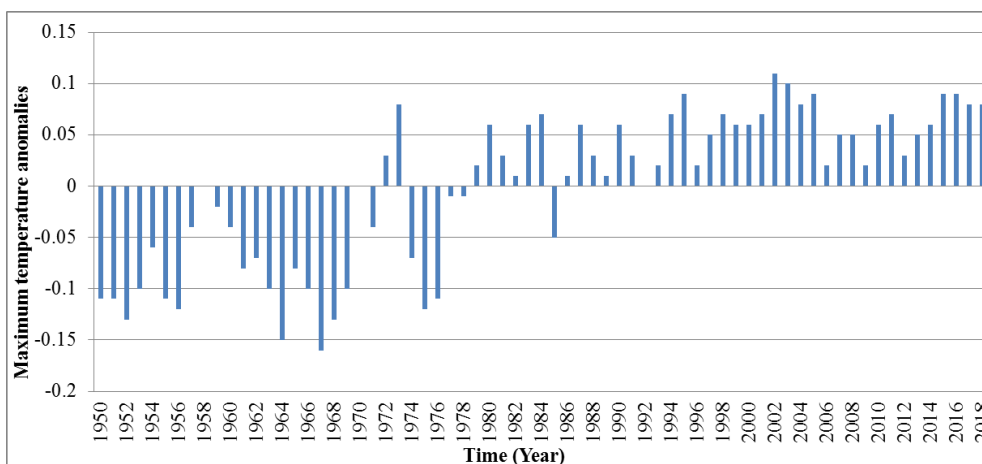255   Figure (2): Linear regression result of annual minimum temperature (1950–2018)
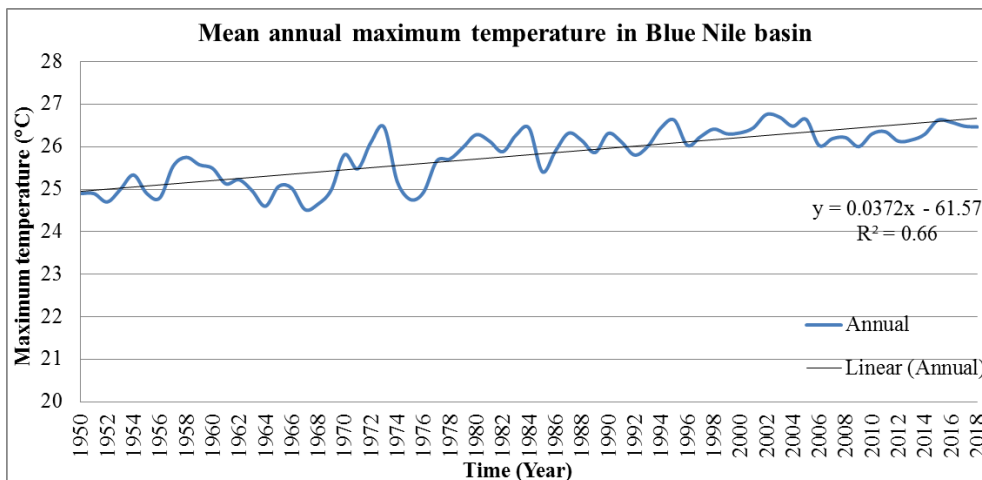
256
257   Figure (3): Linear regression result of annual maximum temperature (1950–2018)
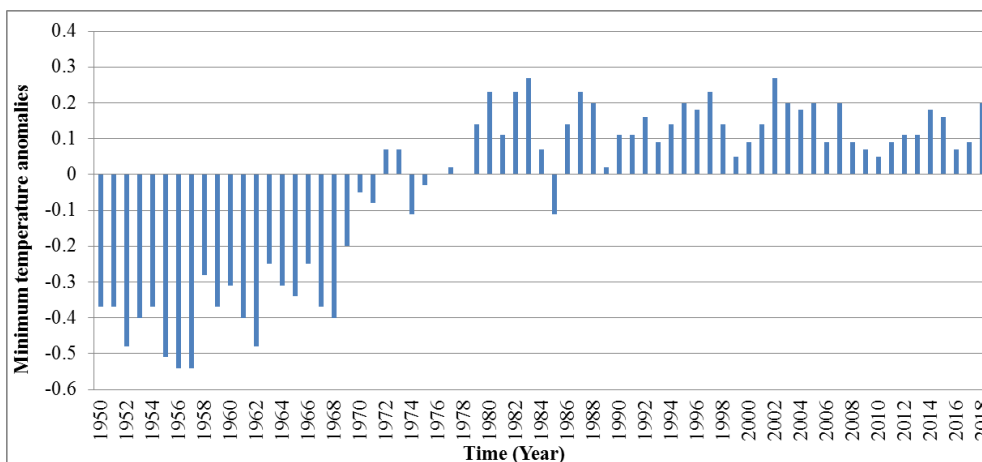
Figure (4): Minimum temperature anomalies index (RAI) of Blue Nile basin (1950–2018)

Figure (5): Maximum temperature anomalies index (RAI) of the Blue Nile basin (1950–2018)

4. Conclusion

Temporal and spatial patterns of changes in extreme temperatures are investigated in the

Blue Nile River basin. The study used data from 10 meteorological stations in the basin

for the period 1950-2018. The statistical data analysis used in this research work includes

standard deviation, coefficient of variation, Skewness/ Kurtosis, Mann-Kendall Test, and

Sens slope. The results showed that there is an increase in both maximum and minimum

temperatures in the basin over the study period of 68 years. The rate of temperature

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271   increase was found to be 0.037° and 0.025°C per decade for minimum and maximum

272   temperatures, respectively. The trend of the mean minimum annual temperature for the

273   last quarter of the 20th century was greater than the long-term average. The trend analysis

274   test showed a significant increase of the mean minimum and maximum temperatures for

275   all months. The rate of increase for the minimum temperature is more pronounced than

276   the maximum. Consequently, this indicates the minimum temperature is more likely

277   sensitive to climate change. Some stations showed a decrease in the inter-annual

278   temperature range. rational climate change may aggravate the situations of climate

279   extremes. Therefore, appropriate adaptation and mitigation strategies should be planned

280   to lessen the impacts of such climatic risks in the Blue Nile River Basin. A further

281   enhancement of the current work could be attained using a long record of daily data.

282   More investigation of the techniques used for trend analysis could lead to more accurate

283   trend values. A Holistic climate change assessment over the whole Nile River Basin

284   should get more attention and a thorough investigation. Researches on climate change

285   detection should be done in various approaches in collaboration with worldwide

286   concerned bodies.

287   **5. Data Availability Statement**

288   Some or all data, models, or code generated or used during the study are available from

289   the corresponding author by request

290   **6. Author contribution**

291   All the process of the paper including but not limited to: Conceptualization, Data

292   curation, Formal analysis, Investigation, Methodology, Project administration, Resources,

293   Software, Supervision, Validation, Visualization, Writing – original draft preparation,

294   and Writing – review & editing were done by the Mostafa A. Mohamed and Mohamed

295   El-Sayed El-Mahdy in equal share

296   **7.   Competing interests**

297   The authors declare that they have no conflict of interest.

298   **8.   References**

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