Response to Referee #1

This manuscript investigated climate change effects on extreme temperatures in the Blue Nile Basin. After a description of dataset and case study, authors described applied methodologies, among which emerges the widely employed Mann-Kendall test. The investigation was carried out by applying these tools to extreme temperatures detected in Blue Nile Basin. The topic is of paramount importance for hydrological applications to be implemented in the areas covered by this study. However, to my opinion the paper needs substantially improvements, both in its structure and results analysis, that are of major importance.
response: thank you very much. Your substantial and very appreciated improvements were done in the revised version of the paper

2 General comments: The paper deals with a relevant topic for modern hydrology, highlighting the need of such analyses for a wide field of real applications. However, to my opinion the paper needs to be improved substantially in the introduction and in the result analysis, and the abstract reformulated in a more readable way. In particular, the introductive section should be rebuilt in order to provide a more logical discussion about the general framework and local situation, clearly specifying motivations and goals of the paper. More detailed comments will be shown in specific comments section.
response: the abstract was reformulated (lines 10-22) and the motivations and goals of the paper were specified clearly in the revised version of the paper (lines 103-107)
***all line numbers correspond to the tracked changes version of the paper to facilitate revision**

The second – and, to me, more important – issue is related to the analysis on Mann-Kendall test results and arise from the citation of the paper of Yue et al. (2002) at line 168. This is one of the most famous papers (1048 citations on Scopus ad November 17, 2020) on the use of Mann-Kendall test for detecting trends in hydrological series, highlighting the role of power evaluation when applying this test. In this way, a complete analysis of applications to real data can be performed, investigating both type I and II errors. A lot of papers discussed on the practical implications that the assessment of power can generate. Among the most recent, I suggest to refer to the following for the specific reference to Mann-Kendall (published in 2020): - Totaro, V.; Gioia, A.; Iacobellis, V. Numerical investigation on the power of parametric and nonparametric tests for trend detection in annual maximum series. Hydrol. Earth Syst. Sci. 2020, 24, 473–488.
- Wang, F.; Shao, W.; Yu, H.; Kan, G.; He, X.; Zhang, D.; Ren, M.; Wang, G. Reevaluation of the Power of the Mann-Kendall Test for Detecting Monotonic Trends in Hydrometeorological Time Series. Front. Earth Sci. 2020, 8.
This about an application of power evaluation with parametric Likelihood Ratio test: - Németh, L., Hübnerová, Z., Zempléni, A. Comparison of trend detection methods in GEV models. Communications in Statistics-Simulation and Computation, 2020, 1-16.
And these latter to implications and concerns on the need of evaluating the power:
- Vogel, R. M., Rosner, A., and Kirshen, P. H.: Brief Communication: Likelihood of

societal preparedness for global change: trend detection, Nat. Hazards Earth Syst. Sci., 2013 13, 1773–1778. - Serinaldi, F., Kilsby, C. G., and Lombardo, F.: Untenable nonstationarity: An assessment of the fitness for purpose of trend tests in hydrology,. Clarified this issue, I know that lots of hydrological applications are carried out in the same way as you did. However, to my opinion you should base your findings reporting some notes supported by literature references about Mann-Kendall test power, to reinforce your statements, in order to provide a more complete and appropriate interpretation of results.
response: the suggested references were studied and the current paper was enhanced using these papers in the revised version of the paper (lines 199-212)

Finally, in addition to these two remarks, I would like to see a more detailed discussion in Par. 3, that I found too short and an inversion between order of Par. 2.1 and 2.2..
response: more detailed discussion in Par. 3 were done (lines 199-303) and an inversion between the order of Par. 2.1 and 2.2in was presented in the revised version of the paper (lines 134-178)

Specific comments: - Line 13: specify which data; to me, monthly is too generic and is repeated at lines 13-14; - Lines 15-17: please, provide a clearer summary of your methodologies;
response: the repetition of monthly in the abstract was revised and a clearer summary of the methodologies was provided in the revised version of the paper (lines 10-15)

- Line 28: there has been: : :I think that it still is;
response: the sentence was updated in the revised version of the paper (line 30)

- Line 29: its direction. Please, use a more specific term;
response: the word direction was replaced with (trend) (line 31)

- Line 30: and the potential river basins in the Nile Basin: what do you mean?
response: the authors mean that this sub-basin has the potential for development and hydropower generation (lines 33-34)

- Line 35: please, remove comma;
response: was removed (line 39)

- Lines 39-40: this statement should be moved to the Conclusion section;
response: the statement will be moved to the Conclusion section (lines 365-367)

- Lines 42-44: please, support your statement with references;
response: the reference (Collins et al., 2019) was used (line 49)

- Line 46: what consequences are you referring to? –
response: the consequences as higher evaporation rates and deterioration of quality

Lines 48-51: please, support your statements with references;

response: the reference (Sohoulande Djebou and Singh, 2016) was used (line 57)

- Line 59: it is not clear what basins are you referring to;
response: the basins studied in the papers of (Anache et al., 2018, Bergström et al., 2001, Chen et al., 2012, Yan et al., 2020)

- Lines 63-64: is this statement referred to the work of Gleick (2000)?
response: yes, the statement referred to Gleick (2000) work

- Lines 71-72: to me, you can better specify the type of variable you are analyzing;
response: the variables are min, mean, and max monthly temperature (line 79)

- Lines 79-86: this detailed discussion should be moved to case study description, leaving only some notes about climate of Ethiopia that are strictly essential for developing the introduction;
response: this discussion was moved to the case study description section (lines 143-150)

- Line 103: please, remove &;
response: was replaced by “and” (line 160)

- Lines 104-107: to me, you have to provide a better declaration of hydrological variables you are investigating and to which you are applying tests;
response: hydrological variables were declared (lines 162)

- Lines 108-110: please, report more details on the occurrence and treatment of missing data;
response: more details on the occurrence and treatment of missing data was introduced in the revised version of the paper (lines 166-168)

- Line 118: Figure 1, pleas improve readability of words and numbers (e.g., increase dimensions);
response: the figure was updated in the revised version of the paper (line 177)

- Lines 142-144: please, provide a reference for your statement;
response: the references (Onyutha, 2017, Partal and Kahya, 2006) were used (line 189)

- Lines 153-154: I think you can rephrase your statement in a clearer way. I can’t understand what do you mean;
response: the statement will be rephrased to (Moreover, MK and Sen's slope estimator test were employed to reveal the temperature trend) (lines 211-212)

- Line 163: specify what do you mean with homogeneity and why you apply Pettitt test;
response: more explanation was introduced (lines 222-223)

- Lines 163-167: why describe this test only with words and dedicate little less to a full page to Mann- Kendall test with all formulas?
response: Pettitt's test formulas are very long so the reference only is presented

- Line 181: Zc?
response: corrected (line 245)

- Line 196: I think you are referring to Zc (attention when using the term p-value), and must declare it as the title of MK column in tables 2, 4, 6, 7. Furthermore, when you use *, **, *** in those tables I think that you have to clearly give meanings to these symbols in each caption. However, I understood what they mean, but they need an explicit explanation;
response: the explicit explanation of all symbols was introduced (lines 311-338)

- Line 199-201:
why reporting global statistics before showing your results? They can have place in the Discussion section, and only if compared with local findings;
response: moved to the appropriate place (lines 277-280)

- Lines 218-219: where?
response: in many parts worldwide

- Lines 223-224: I think you should address the use of the word significant in the whole document, also in the light of considerations about test power
response: the word significant was revised throughout the manuscript to assure that it used at the right place and used only when the significance level is found

Finally, we would like to thank you for your worthy comments that reinforced the paper totally

Response to Referee #2

Comments as shown in the comments on the manuscript PDF

1. be consistent with time (present or past) throughout the text

response: the past time is used in the updated manuscript (line 10-22)

all line numbers correspond to the tracked changes version of the paper to facilitate revision

2. are

response: modified in the updated manuscript (line 19)

3. significant

response: modified in the updated manuscript (line 22)

4. trends

response: modified in the updated manuscript (line 22)

5. makes no sense

response: Blue Nile river only constitutes about 55% of the water reaches Egypt, and there are about 14 proposed dams and 5 agriculture projects. So, it is considered the most important and has the greatest potential among other basins in the River Nile Basin for development projects

6. such as

response: modified in the updated manuscript (line 39)

7. the study of

response: modified in the updated manuscript (line 42)

8. due to

response: modified in the updated manuscript (line 46)

9. their

response: modified in the updated manuscript (line 48)

10. result in

response: modified in the updated manuscript (line 48)

11. can be noticed

response: modified in the updated manuscript (line 54)

12. considered as

response: modified in the updated manuscript (line 56)

13. and

response: modified in the updated manuscript (line 64)

14. New sentence: . In addition, higher peak flows have occurred in these basins

response: modified in the updated manuscript (line 65)

15. Gleick (2000)

response: modified in the updated manuscript (line 68)

16. almost

response: modified in the updated manuscript (line 72)

17. This has already been mentioned numerous times before. Generally, you have to better structure the introduction.

1) Why is climate change important (first generally and then for your basin)
2) Which variables need to be studied.
Why is temperature an important one.
3) What have other studies found regarding temperature trends in areas similar or close to yours.
4) What is the aim of the paper.

You have covered most of the points but you mix them up.
response: modified in the updated manuscript (line 30-109)

18. MT
response: modified in the updated manuscript (line 79)

19. follow
response: modified in the updated manuscript (line 80)

20. this sentence does not follow the previous
response: this is the first sentence in a new paragraph (line 80)

21. (
response: modified in the updated manuscript (line 85)

22. (
response: modified in the updated manuscript (line 100)

23. need rephrasing
response: modified in the updated manuscript (line 100-101)

24. has been
response: modified in the updated manuscript (line 102)

25. the
response: modified in the updated manuscript (line 158)

26. ?
response: modified in the updated manuscript (line 160)

27. And
response: modified in the updated manuscript (line 161-162)

28. Could you also show the altitudes, and the lake and rivers position on the map?
response: the map is modified totally in the updated manuscript (line 177)

29. which station?
response: at Dangla station is inserted in the updated manuscript (line 151)

30. needs better phrasing.
    Which are the technique categories that you used?
    I understand, from the next sentences, that The techniques are generally categorized as trend analysis and variability analysis techniques

response: both techniques are used in the study, and the sentence was modified in the updated manuscript (line 185)

31. assuming

response: modified in the updated manuscript (line 196)

32. You mentioned the MK before. You should move all the information on the MK in one place.

response: moved in the updated manuscript (line 227-230)

33. in

response: modified in the updated manuscript (line 293)

34. That

response: modified in the updated manuscript (line 361)

35. thorough

response: inserted in the updated manuscript (line 368)

Evaluation of Climate Change Impact on Extreme Temperature Variability in the Blue Nile Basin, Ethiopia

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Abstract

Climate change raised important issues concerning the hydrological engineer. The impact of climate change on important river basins should be investigated rigorously. Extreme temperature variability has a direct impact on the hydrological cycle, especially the evaporation component. In this paper, spatial and temporal patterns of changes in extreme temperatures ~~are~~ were investigated using 10 meteorological stations data for the period 1950-2018 in the Blue Nile basin. ~~Monthly temperature data for the basin were used in the study.~~ Long-term trends in the Blue Nile Basin annual and monthly temperatures were investigated. The statistical significance of the trend ~~is~~ was calculated by applying the Mann-Kendall (MK) test. The analysis of data was performed using the coefficient of variance~~,~~ and anomaly index. The results showed that the annual maximum and minimum temperatures ~~is~~ were increasing significantly with a magnitude of 0.037° and 0.025° C per decade respectively in the period from 1950 to 2018. The result of the Mann-Kendall analysis test revealed a marked increase in the mean maximum and minimum temperature~~s~~ trends over time ~~significantly~~ during the study period (the minimum temperature rate is more evident than the maximum). The long-term anomalies of mean annual minimum temperature revealed the inter-annual variability while the trend after 1977 was higher than the long-term average that is proof of the warming trend's existence since the last two decades of the 20th century.

Keywords: Trend Analysis, Mann-Kendall Test, Climate Variability, Minimum Temperature, Maximum Temperature, Blue Nile.

1. Introduction

Climate change is perceived to affect the whole world and there has been, and still, a growing concern about its ~~direction~~ trend and consequences. The Blue Nile River Basin (BNRB) is affected by climate change in temperature increase and rainfall decrease. The BNRB is the most important ~~and the potential~~ river basins in the Nile Basin and having a great development potential. Many development projects are under construction currently in the BNRB without detailed climate change thorough analysis. These projects are essential for irrigation schemes, hydropower generation, and national economic growth. As a trans-boundary river basin, it attracts the attention of some neighboring countries. For sound management and planning of water resources, it is important to predict the climate change and variability of crucial metrological factors such as temperature~~,~~ and precipitation (Tamiru, 2011). Temperature and precipitation are affecting directly the hydrology of the basin (El-Mahdy et al., 2019). Since temperature affects both evaporation and evapotranspiration, and precipitation is the source of runoff, so the study of ~~studying~~ these factors is very important in water resources management ~~of the basin~~. ~~The detailed analysis of the impact of these factors on basin hydrology will be addressed by forthcoming researches.~~ Here it is decided to explore the impact of climate change on temperature and in a forthcoming paper the impact on rainfall will be studied.

The assessment of extreme temperature variability due to ~~resulted from~~ climate change will help to better manage the development projects in the BNRB. Global and regional rises in air temperature, together with their ~~its~~ collateral rises in water temperature, result in ~~drive to~~ negative alterations in water quality, even with the same precipitation (Collins et al., 2019). Lake Tana, located upstream of BNRB, is one of the greatest natural lakes of Africa (El-Mahdy, 2014). Generally, the Lakes are sensitive to a wide range of climate change consequences. Even a slight change in climate can result in huge changes in lake salinity and levels (El-Mahdy et al., 2018, Mengistu et al., 2014, Tamiru, 2011).

The symptoms of global warming ~~could~~ can be noticed almost everywhere around the world. Heatwaves and droughts are striking a lot of places around the world, so that precipitations, humidity, and temperatures are rarely normal. These phenomena among others are considered as evidence of the presence of climate variability (Sohoulande Djebou and Singh, 2016). The analysis of data from ground stations and satellites showed that the mean surface temperature of the world has increased by about 0.6 degrees Celsius over the 20th century (Lindzen and Giannitsis, 2002, Tapley et al., 2019). The warmest years ever have all occurred since 1980 in this century (Janssens et al., 2020). The warmest recorded year was 1998 (Mann et al., 1999). These alterations appear to be out of the natural variability range (Houghton, 1996, Mann et al., 1999, Sippel et al., 2020, Watson et al., 1996). A lot of researches studied the impact of temperature rise on runoff~~,~~ and it was found, with high confidence, that the runoff has increased in winter and decreased in summer and spring~~, .~~. ~~in~~ In addition to higher peak flows have occurred in these basins (Anache et al., 2018, Bergström et al., 2001, Chen et al., 2012, Yan et al., 2020).

The results of the simulation studies conducted by Gleick (2000) in the USA concluded that small alterations in rainfall and temperature may lead to huge impacts on runoff. It was found that if temperature increases without a change in rainfall, the runoff will decrease. A 10% decrease in rainfall together with a temperature rise of 2°C will reduce the runoff by 13-40%. On the other hand, if rainfall increases by 10% and the temperature rise by 4°C, ~~almost~~ the rainfall increase will balance evaporation losses and no alteration on runoff is predicted. Although these findings are not comprehensive, but they reveal the possible size and uncertainty encircling the hydrologic and climatic implications of greenhouse warming (El-Mahdy, 2011).

~~Temperature is the most serious climate variable that affects hydrology and climate which, consequently, has an enormous direct and indirect impact on human life and the environment.~~ The temperature is a continuous variable in both space and time. The Monthly Mean Temperature (MMT), as well as the maximum and minimum Monthly Temperature ~~M~~(MT), always follow ~~matches~~ a normal distribution ~~(Jones and Hulme, 1996).~~ (Jones and Hulme, 1996).

The predicted climate change may affect most of the Ethiopian districts. Drought remains Ethiopia's major hazard, while floods following in another place (Conway and Schipper, 2011). Recently, it is clear that both drought and flood have increased in both frequency and size (Margaret, 2003).

A recent study by Gebrehiwot and van der Veen (2013) indicated that climate change in Ethiopia could lead to extreme temperatures and rainfall events, leading to more heavy and extended droughts and floods. ~~The climate of Ethiopia is composed of three distinct seasons named: Belg, Kiremt, and Bega seasons (Haile, 2005). Belg is a short rain season which covers the period from February to May. The rainfall in the Belg season results by the humid south-eastern and eastern winds that originate from the Indian Ocean. Kiremt is a long rainy season that starts in June and~~

~~normally ends in September. The Kiremt season's rainfall results substantially from the convergence of low-pressure winds and the Intertropical Convergence Zone (ITCZ). Finally, the dry season, called Bega, extends from October to January (Tabari et al., 2015).~~ Changes in sea surface temperature and El Niño Southern Oscillation (ENSO) periods in the Indian and Atlantic Oceans have effects on the timing and amount of rainfall in Ethiopia (Fekadu, 2015, Shanko and Camberlin, 1998). Asfaw et al. (2018) found that the drought events of Ethiopia are the result of both ENSO, Sea Surface Temperature (SST) variations in the Indian and Atlantic, and anthropogenic activities. Kiros et al. (2016) found that the result of different studies of temperature trend analyses in Northern Ethiopia is a mixture of non-significant negative and positive trends. Mengistu et al. (2014) noted that the trend of temperature was significantly increasing ~~and statistically significant~~ in Ethiopia. Although the concept of global warming and its impact on BNRB ~~was~~ has been studied before, but the analysis of long enough time series over multiple weather stations with the appropriate statistical tools was not found. Investigation of extreme temperature variability in the BNRB is not well presented in the literature. Making use of the statistical tools to explore climate change impact on Ethiopia is not performed in thorough studies. The availability of the long time series data (1950-2018) invokes the research on the climate change impact on the basin. The main objective of this research is to detect any climate change through the evaluation of extreme temperature variability using trend analysis of along temperature time series in the BNRB, Ethiopia.

2. Data and Methodology

~~2.1.1.1. Types of data~~

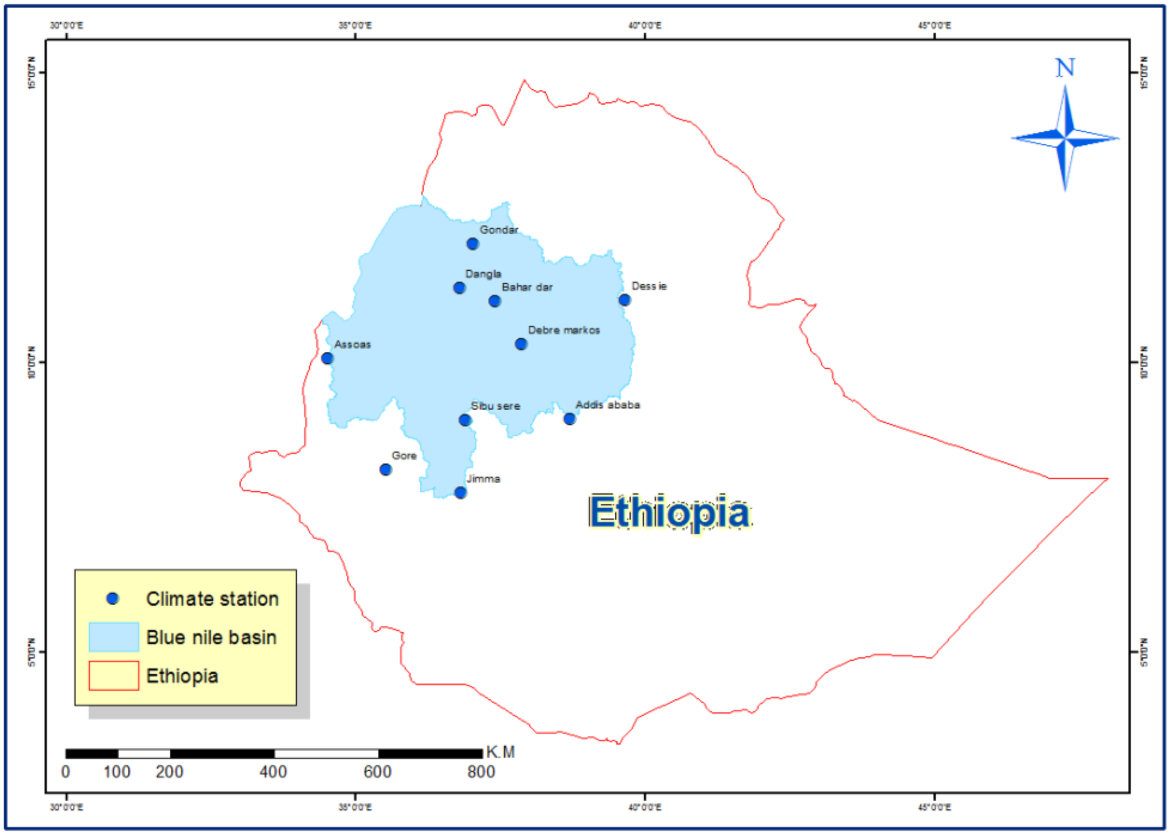
~~Temperature data, which is used in the variability and time series trend analysis, has been obtained from Ethiopia Meteorological Authority. Ten stations covering different parts of BNRB~~

~~have been chosen to study the variability of their data sets (see Table 1 and Figure 1). The climate data consist of maximum & minimum MMT data probably with long years of records for 10 stations that have been collected in the BNRB. The length of record of the data made available for this analysis varies from 62 to 68 years, most analyses have focused on changes in mean values due to the lack of the availability of high-quality daily data required for monitoring, detecting, and attributing climate extremes changes (Jones, 1999). The study period (1950-2018) was chosen according to the availability of the recorded data for all stations. The missing data were calculated using the average of previous and subsequent months (for missed monthly data), but the analysis excluded annual missing data.~~

~~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

~~(Source: Ethiopia Meteorological Authority)~~



~~Figure (1): Location map of the Blue Nile Basin and the selected meteorology~~

~~2.2.~~2.1. 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~~ at 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, which is located in this basin. The main rivers that feed Lake Tana are Gilgil Abai, Gomera, Rip, and Magek (El-Mahdy, 2017). These ~~short-~~short-length rivers constitute about 93% of the outflow of the lake (Kebede et al., 2006). The climate of Ethiopia is composed of three distinct seasons named: Belg, Kiremt, and Bega seasons (Haile, 2005). Belg is a short rain season which covers the period from February to May. The rainfall in the Belg season results ~~by~~from the humid south-eastern and eastern winds that originate from the Indian Ocean. Kiremt is a long rainy season that starts in June and normally ends in September. The Kiremt season's rainfall results substantially from the convergence of low-pressure winds and the Intertropical Convergence Zone (ITCZ). Finally, the dry season, called the Bega, extends from October to January (Tabari et al., 2015). The highest temperature recorded in the BNRB is located in the northwestern part at Dangla station. In some parts of Dabus, Dinder, Rihad, and Beles, the maximum recorded temperature reaches 38°C and the 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).

2.2.Types of data

Temperature data, which is used in the variability and time series trend analysis, has been obtained from the Ethiopia Meteorological Authority. Ten stations covering different parts of BNRB have been chosen to study the variability of their data sets (see Table 1 and Figure 1). The climate data consist of maximum ~~&~~and minimum ~~M~~MMT data ~~probably~~ with long years of records for 10 stations that have been collected in the BNRB. The length of the record of the data made available for this analysis varies from 62 to 68 years of MMT, maximum, and minimum MT~~,~~. Most analyses have focused on changes in mean values due to the lack of the availability of high-quality daily data required for monitoring, detecting, and attributing climate extremes changes (Jones, 1999). The study period (1950-2018) was chosen according to the availability of the recorded data for all stations. Although the missing data for the studied period is almost none. But for the missing data of a specific month ~~were~~was calculated using the average of previous year data of the same month and subsequent year month~~s~~ data (for missed monthly data), but the analysis excluded annual missing data.

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

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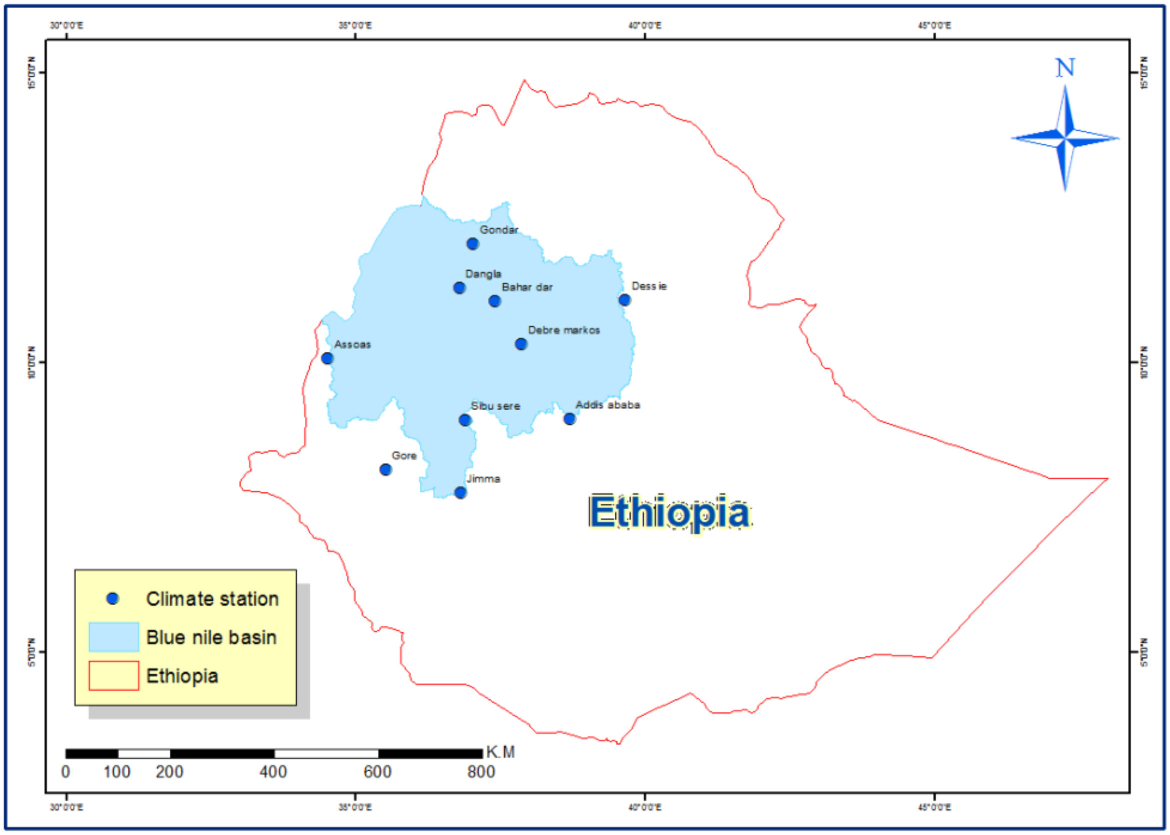
(Source: Ethiopia Meteorological Authority)


N
Gondar
Dangla
Bahar dar
Dess ie
Debre markos
Assoas
Sibu sere
Addis ababa
Gore
Jimma
Ethiopia
Climate station
Blue nile basin
Ethiopia
K.M
0 100 200 400 600 800

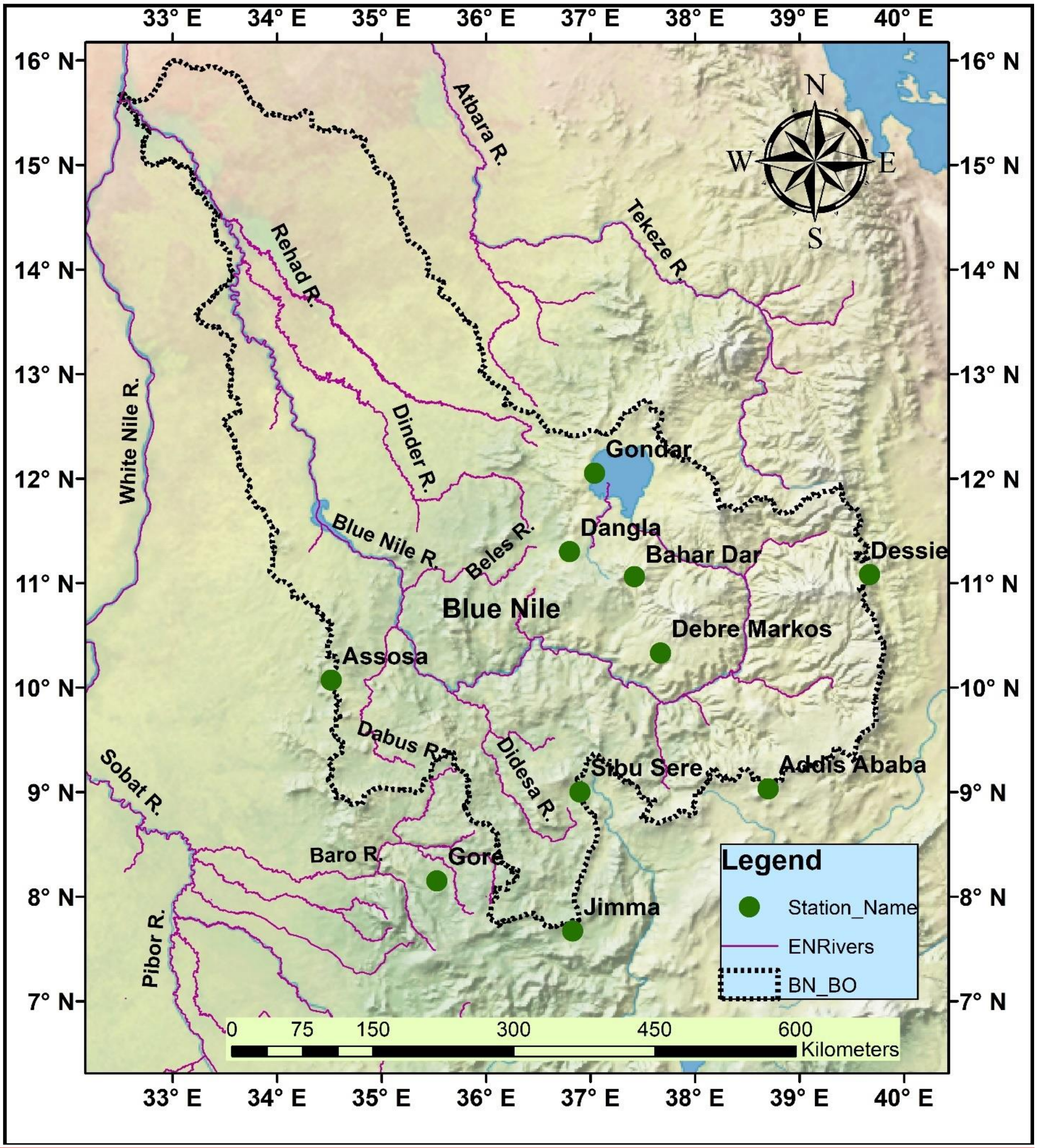


Figure (1): Location map of the Blue Nile Basin and the selected meteorology

2.3. Methods

The analysis of temperature was performed using many techniques. These techniques are generally categorized as variability and 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 (Onyutha, 2017, Partal and Kahya, 2006). 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 distributed, missing data, and outliers. This problem is repeatedly found in the hydrological and meteorological time series. For these reasons, Mann- Kendall (MK) test is commonly utilized to discover the trends of meteorological and hydrological variables (Degefu and Bewket, 2014, Kiros et al., 2016, Seleshi and Camberlin, 2006, Tabari and Tavakoli, 2016). MK is a nonparametric test, that assesses the trend of any time series without assuming ~~assigning~~ if the trend is non-linear or linear. MK test is commonly used to discover the monotonic (increasing or decreasing) trends in the time series of hydrological, meteorological, and environmental data (Yue et al., 2002). Totaro et al. (2020) conducted trend detection using a numerical investigation. The study focused on exploring the power of nonparametric and parametric tests in annual maximum time series data. The results showed paramount practical implications. It was proved that the dependence of test power on the parameters of parent distribution might affect the results significantly of both nonparametric and parametric tests. This result is comprising the widely applied MK test. The results of Monte Carlo simulations showed that the power of the MK test has a direct relationship with the data variance in addition to the trend magnitude (Wang et al., 2020). Németh et al. (2020) analyzed the characteristics of the test of the likelihood ratio for extremes by simulations and introduced a simulation-based method to overcome the issue of scarce data. A novel return level calculation procedure is -proposed. The probability or power of discovering trends relies on the development of efficient multivariate statistical and deterministic procedures for forecasting future trends in processes of the earth system (Vogel et al., 2013).In the current paper, the variability of temperature was calculated employing the SD and CV tests. Moreover, MK and Sen's slope estimator test were employed to reveal the temperature trend~~Moreover, MK was employed to reveal the temperature trend using Sen's slope estimator~~. SPSS v22 software was used to perform the data analysis. CV is computed to evaluate the rainfall variability. the higher the CV value, the larger variability of rainfall. CV is calculated using the following equation:

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

Where CV is the coefficient of variation; σ is the standard deviation and μ is the mean (Isioma et al., 2018). ~~MK test was employed to explore the presence of monotonic trends in the time series, and the statistical significance of the trend. Since outliers cannot be averted in any time-series, the MK test is advantageous because it is based on the (+ or -) signs instead of the random variable values. Therefore, the MK test is less influenced by the outliers (Asfaw et al., 2018).~~ The test of homogeneity was conducted employing Pettitt's test (Pettitt, 1979) to ensure that the data are homogenous and no misleading data are present. In this test, every value in the time series is compared with all posterior values in the data series. If the value of the subsequent period is greater than the value of the preceding period, the statistic (S) is raised by one and vice versa. The summation of all increments and decrements reveals the total value of the statistic (S). MK test was employed to explore the presence of monotonic trends in the time series, and the statistical significance of the trend. Since outliers cannot be averted in any time-series, the MK test is advantageous because it is based on the (+ or -) signs instead of the random variable values. Therefore, the MK test is less influenced by the outliers (Asfaw et al., 2018). The MK test statistic ‘S’ is calculated based on (Mann, 1945, McLeod, 2005, Yue et al., 2002), using the formula:

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

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 ranked as j = i 1, 2…. n. Each of the data point x_i is taken as a reference point to be compared with the other data point's x_j so that:

$$Sgn\left(x_j - x_i\right) = \begin{cases} +1 \; if \; (x_j - x_i) > 0 \\ 0 \; if \; \left(x_j - x_i\right) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases} \qquad (3)$$

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

It was reported that, if the number of observations is greater than 10 (n ≥10), the statistic (S) is usually normally distributed around the mean (McLeod, 2005). So~~ that~~, the variance could be formulated as:

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

where n is the number of observation and t_i are the ties of the sample time series. The test statistics Z_c is as follows:

$$Z_c \cancel{Z} = \begin{cases} \frac{S-1}{\sigma} if \quad S > 0 \\ 0 \;\; if \quad S = 0 \\ \frac{S+1}{\sigma} if \quad S < 0 \end{cases} \qquad (5)$$

If Z_c follows a normal distribution, its positive or negative value refers to an upward or downward trend for the studied period respectively. The trend magnitude could be calculated by slope estimator methods (Sen, 1968). Here, the slope (T_i) of all data pairs is calculated according to (Sen, 1968). In general, T_i for any time series x could be predicted from:

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

where x_j and x_k are considered as data values at time j and k (j > i) correspondingly. The median of these N values of T_i is represented as Sen's estimator of the slope which is calculated as $Q_{med=}\mathrm{T}_{(N+1)/2}$ *if* N is an odd number, and it is computed as $Q_{med=}\left[\mathrm{T}_{N/2} + \mathrm{T}(_{(N+2)/2})/2\right]$ if N is an even number. A positive value of T_i indicates an upward or increasing trend and a negative value of T_i gives a downward or decreasing trend in the time series.

3. Results and Discussion

The MK test and Sen's slope estimator were applied to the time-series 1950–2018 for the ten meteorological stations in BNRB. The annual and seasonal mean of the climatic parameters, particularly minimum and maximum MMT were analyzed. Table 2 shows the MK test statistics and p values at 5%, 1%, and 0.1% levels of significance~~s~~. In the MK test, parameters such as Kendall's tau, S, and Z statistics were computed to determine the positive or negative trend of climate parameters in the long time series studied.

~~Surface air temperature rises globally, although global warming is not uniform over the world, neither temporally nor spatially (Turner et al., 2020). The surface temperature increase is the direct demonstration of global climate change (Brunet et al., 2005).~~ Tables 2 and 4 show~~ed~~ the annual and monthly maximum and minimum MT and MMT ~~maximum and minimum~~ and their trend during the study period. The mean minimum temperature in the BNRB area was 6.7°C and the mean maximum was 25.5°C, with a mean annual temperature of 16.1°C. The regression line slope is about 0.036° and 0.024°C per decade for minimum and maximum annual temperatures respectively for the studied period of 1950–2018 as shown in Tables 3 and 5 in addition to Figures 2 and 3. These results are close to the previously found global warming rate which is 0.06° C per decade for the last century (Pachauri and Meyer, 2014). Figures 4 and 5 showed the long-range anomalies of mean annual minimum and maximum temperatures. It is clear that the trend after 1985 was greater than the long-term average. This is considered as strong evidence for the global warming trend since the 20th century last two decades. This result enhances the previously found results that the climate became~~s~~ warmer since the end of the last century (Bathiany et al., 2018, Guo et al., 2020, Nijsse et al., 2019). Surface air temperature rises globally, although global warming is ~~not~~ uniform over the world, neither temporally nor spatially (Turner et al., 2020). The surface temperature increase is the direct demonstration of global climate change (Brunet et al., 2005). However, other researchers proved that the last four decades of the 20th century showed a significantly increasing trend in global warming (Bhutiyani et al., 2008). Interannual variability of rainfall and temperature has intensified from the late 1960s. Also, droughts occur more frequently and over a greater spatial distribution. A stronger statistical relation between climate change and El Niño–Southern Oscillation (ENSO) phenomenon is observed (Fauchereau et al., 2003).

As shown in Tables 2 and 4, the result of the MK test detected that the mean maximum and minimum temperatures increased significantly overtime at a 99% confidence level. The trend for monthly minimum and maximum temperature is increasing significantly for all months. The gross increase in the observed annual temperature is attributed to the increase in the minimum temperature. Many researchers have reported that the minimum temperature rises more than the maximum (Bayramzadeh et al., 2018, Crimp et al., 2018, Gross et al., 2018, Scott et al., 2017)

The minimum temperature incremental increase is more evident than that of the maximum. The results are ~~of~~ in good agreement with the results by (Asfaw et al., 2018). The results of the MK analysis revealed an increase in both mean and minimum temperatures throughout the studied period significantly. On the other hand, the maximum temperature has a non-significant increasing trend. The studies that agree with these results such as (Mengistu et al., 2014, Roy and Das, 2013) found that the increasing trends in the maximum temperature series were less than the minimum temperature series. The cause that the minimum temperature increases more than the maximum may be explained as the sensitivity of minimum temperature to the greenhouse is higher than the maximum (Salawitch, 1998). In this regard, the maximum temperature over India was higher than the mean for the period (1901–2007) with a low trend. However, the minimum temperature displayed an upward trend (Kothawale et al., 2010). This result supported the findings of the current paper over BNRB. Table 6 showed that the minimum temperature has an increasing trend in Bega, Belg, and Kiremt seasons in the stations of Bahir Dar, Debre Markos, Gondar, Gore, and Jimma with a level of significance 5%, 1%, and 0.1%. Also, the maximum temperature in the three seasons has a significant increasing trend in Addis Ababa, Bahir Dar, Gondar, and Gore stations and the trend is statistically significant at 0.1%, 1%, and 5% level of significance as shown in Table 7.

Table (2): Basic statistics and MK trend analysis of minimum temperature in the Blue Nile basin (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

* Significant at 5% significance level

** Significant at 1% significance level

*** Significant at 0.1% significance level

Table (3): Linear regression result (Annual minimum temperature, Bega, Belg and Kiremt 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

Table (4): Basic statistics and MK trend analysis of maximum temperature in the Blue Nile basin (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

* Significant at 5% significance level
** Significant at 1% significance level
*** Significant at 0.1% significance level

Table (5): Linear regression result (Annual maximum temperature, Bega, Belg and Kiremt 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

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

* Significant at 5% significance level

** Significant at 1% significance level

*** Significant at 0.1% significance level

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

* Significant at 5% significance level

** Significant at 1% significance level

*** Significant at 0.1% significance level

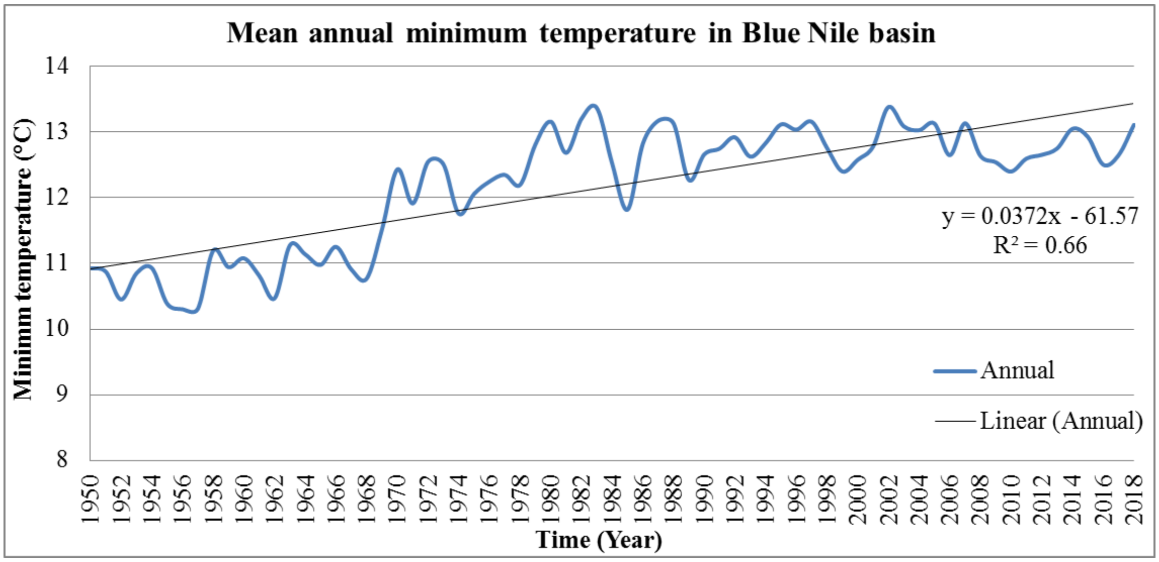


Figure (2): Linear regression result of annual minimum temperature (1950–2018)

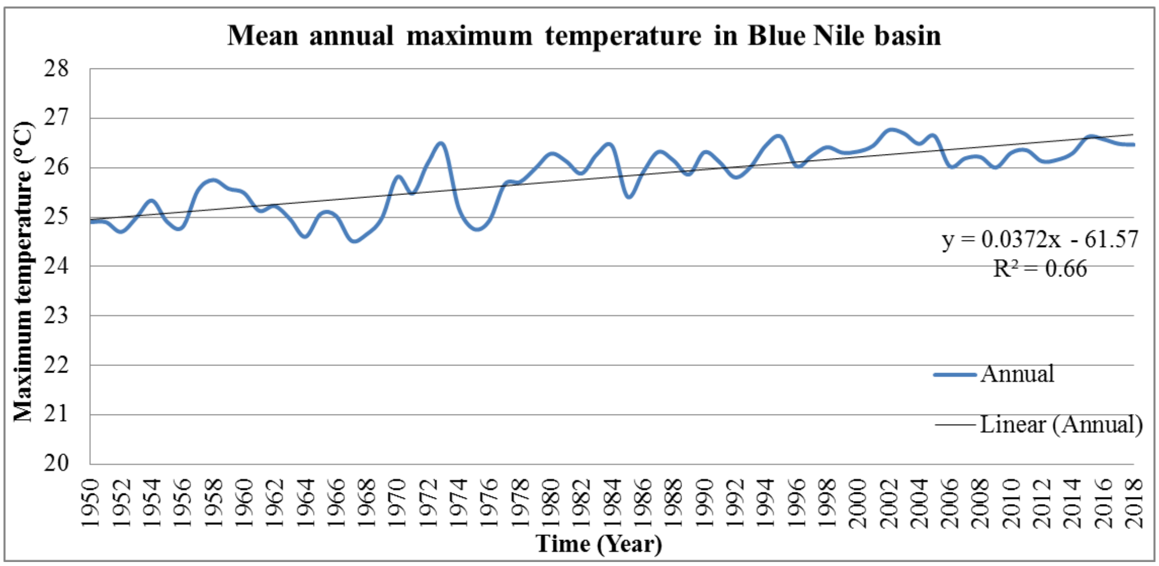


Figure (3): Linear regression result of annual maximum temperature (1950–2018)

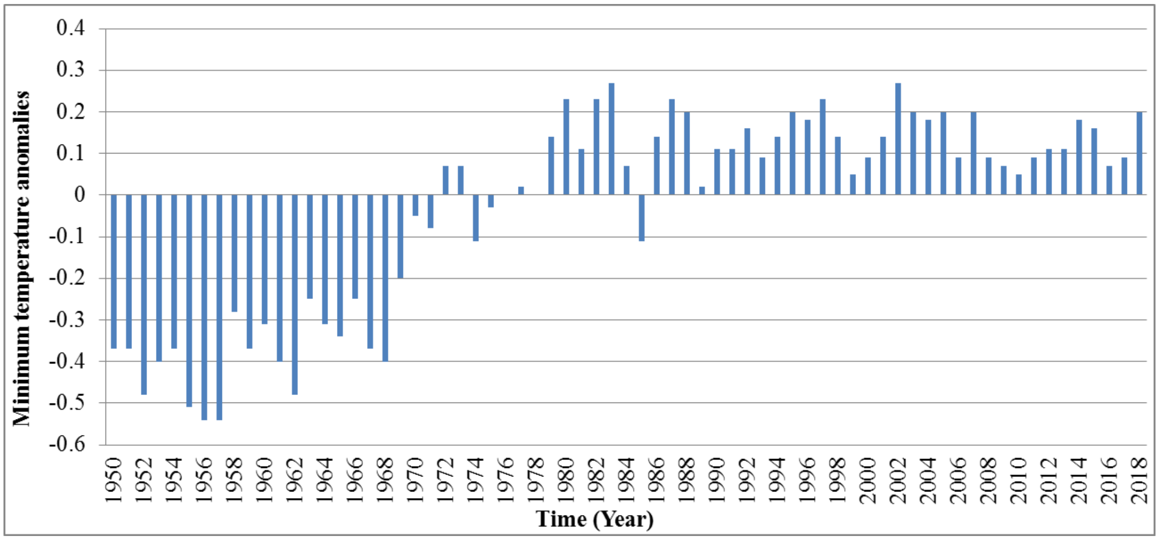


Figure (4): Minimum temperature anomalies index (RAI) of Blue Nile basin (1950–2018)

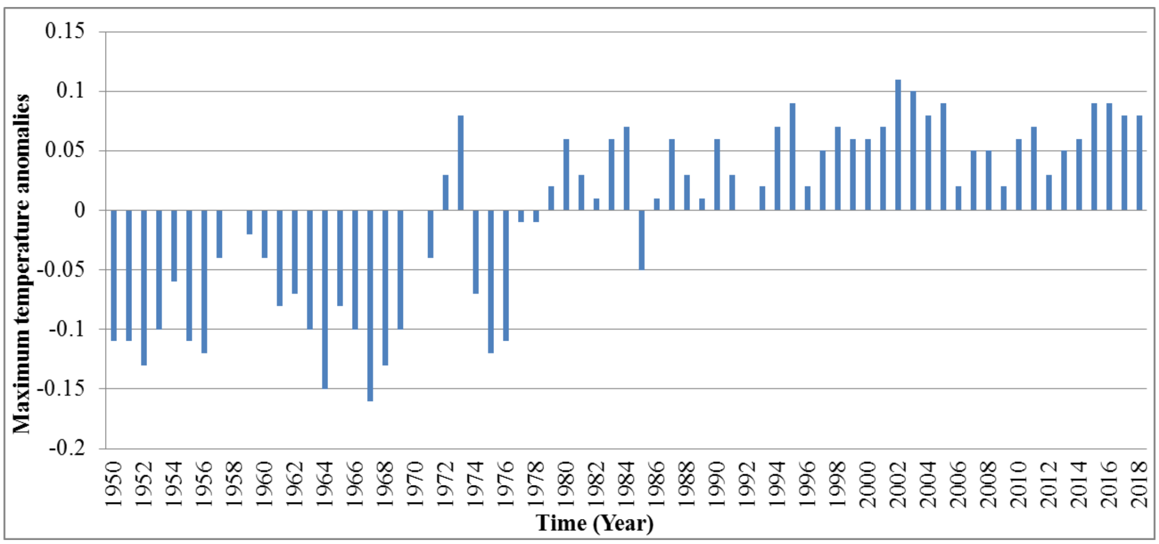


Figure (5): Maximum temperature anomalies index (RAI) of the Blue Nile basin (1950–2018)

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 increase was found to be 0.037° and 0.025°C per decade for minimum and maximum temperatures, respectively. The trend of the mean minimum annual temperature for the last quarter of the 20th century was greater than the long-term average. The trend analysis test showed a significant increase of the mean minimum and maximum temperatures for all months. The rate of increase for the minimum temperature is more pronounced than the maximum. Consequently, this indicates ~~the~~ that minimum temperature is more ~~likely~~ sensitive to climate change. Some stations showed a decrease in the inter-annual temperature range. rational climate change may aggravate the situations of climate extremes. Therefore, appropriate adaptation and mitigation strategies should be planned to lessen the impacts of such climatic risks in the Blue Nile River Basin. The detailed analysis of the impact of these factors on basin hydrology will be addressed by forthcoming researches. A further enhancement of the current work could be attained using a long record of daily data. ~~More~~ A more thorough investigation of the techniques used for trend analysis could lead to more accurate trend values. A Holistic climate change assessment over the whole Nile River Basin should get more attention and a thorough investigation. Researches on climate change detection should be done in various approaches in collaboration with worldwide concerned bodies.

5. Data Availability Statement

Some or all data, models, or code generated or used during the study are available from the corresponding author by request

6. Author contribution

All the process of the paper including but not limited to: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft preparation, and Writing – review & editing were done by the Mostafa A. Mohamed and Mohamed El-Sayed El-Mahdy in equal share

7. Competing interests

The authors declare that they have no conflict of interest.

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