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Climate change and trend analysis of temperature: the case of Addis Ababa, Ethiopia

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Abstract

Background: This paper presents the trend analysis of temperature and the effect of climate variation in the city of Addis Ababa, Ethiopia. The paper seeks to provide up-to-date information for the better management of climate change in the city. The analysis is based on the temperature difference in the city over two stations—Bole and Entoto. The overall purpose of this study is to investigate the possible trend of temperature variation as well as the effect of climate change in the study area.

Method: The Mann-Kendall (MK) trend test and Sen's slope estimate were employed to find the nature of the temperature trend and significance level in the city.

Results: It was found that the MK2/MK3 statistic (Z) value for minimum, maximum and average temperatures for Bole station are 6.21/5.99, 2.49/2.6, and 6.09/6.14 respectively. The positive Kendall's Z value shows an upward trend and implies an increasing trend over time. This indicates a significant increase in the trend at a 5% level of significance since the significance level (alpha) is greater than the computed p-value ($0.05 > p$ -values (0.0001)). Whereas for Entoto station, the MK1 statistic (Z) results are 1.64 for minimum, while the MK2/MK3 static (Z) are 0.71/0.65 for the maximum, and 0.17/1.04 for average temperature, and this positive value shows an indicator of an increasing trend. However, the increase is not significant at the 5% significant level since the computed p-value is larger than the significant level ($\alpha = 0.05$).

Conclusions: There is a tendency of temperature increments in Bole station. This could be due to the influence of climate change which can lead to weather extremes in the capital city. Therefore, the study recommends that the variability of temperature needs further monitoring technique, and there is a need to consider the increasing temperature trend to minimize its effects on human health.

Keywords: Temperature, Trend analysis, Climate change, Mann-kendall test, Sen's slope, Addis ababa

Background

Climate change has become one of the most essential concerns in the field of sustainable development, and its impacts (rising of sea levels, melting of polar ice caps, wild bush fires, intense droughts etc.) can be felt in different parts of the globe (Dioha and Kumar 2020; Ali et al. 2013). The warming of our planet due to the emission of

greenhouse gases is now unquestionable; and over the last century, the CO₂ atmospheric concentration has increased significantly and has, in turn, induced the average global temperature to increase by 0.74 °C as compared with the preindustrial era (UNFCCC 2007). The high temperature in urban areas affects mostly health, economy, leisure activities, and wellbeing of urban residents. Thermal stress caused by warming highly affects the health of vulnerable peoples (Tan et al. 2010; Patz et al. 2005). Developing countries are mostly affected by

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climate change, and Ethiopia is an example of the most vulnerable countries (Cherie and Fentaw 2015).

The intensity and frequency of extremes can be easily changed by climate change and the changes in climate extremes and their impacts on a variety of physical and biological systems examined by the Intergovernmental Panel on Climate Change (IPCC) and their effects can also contribute to global warming (IPCC 2007). Many factors such as the expansion of cities, and fast population growth rate along with migration from rural to urban areas pose a major challenge for city planners and also contributes to increasing climate change (WHO and UNICEF 2006; Alemu and Dioha 2020). Using various General Circulation Models, Feyissa et al. (2018) suggested future climatic changes and argued that a rise in temperature will exacerbate the urban heat highland effects in warm seasons and an increase in precipitation. Some environmental harms such as high temperature and extreme rainfall, which results in flooding in Addis Ababa, could be signals of climate change (Birhanu et al. 2016). Also, the city temperature is mostly affected by anthropogenic activities along with climate change.

The Mann–Kendall (MK) (non-parametric) test is usually used to detect an upward trend or downward (i.e. monotonic trends) in a series of hydrological data (climate data) and environmental data. The null hypothesis for this test indicates no trend, whereas the alternative hypothesis indicates a trend in the two-sided test or a one-sided test as an upward trend or downward trend (Pohlert 2020). The Sen's estimator is another non-parametric method used for the trend analysis of hydroclimate data set. It is also used to identify the trend magnitude. Hence, this test computes the linear rate of change (slope) and the intercept as shown in Sen's method (Sen 1968). The MK test is widely documented in various literature, as a powerful trend test for effective analysis of seasonal and annual trends in environmental data, hydrological data (climate data), and this test is preferred over other tests because of its applicability in time-series data, which does not follow the statistical distribution.

There are numerous examples of MK trend test applications such as Asfaw et al. (2018) who used the MK test for the detection of trends in time series analysis and the result revealed that inter-annual and intra-annual variability of rainfall as well as the severity index value for Palmer drought shows that the trend for the number of drought years was increasing. Another study also employed a non-parametric MK test and Sen's slope estimates to test the trend of each extreme temperature and rainfall indices as well as their statistical significance in

the Western Tigray, Ethiopia (Berhane et al. 2020). Similarly, the trend analysis of temperature in Gombe state, Nigeria was analyzed using the MK trend test and Sen's estimator to decide the nature of the temperature trend and significance level. The study found that average and maximum temperatures revealed positive Kendall's statistics (Z) (Alhaji et al. 2018). In a different study, Yadav et al. (2014) used the MK test and the Sen's Slope for the analysis of both trends and slope magnitude. The results indicated that in all thirteen areas of Uttarakhand (India), the trends of temperature and precipitation are increasing in some months, whereas in some other months the trends were decreasing. Getachew (2018) used the MK trend test for the analysis of rainfall and temperature trends in the south Gonder zone (Ethiopia). The study found that a statistically significant increase in Nefas Mocha and Addis Zemen for mean annual temperature. Kuriqi et al. (2020) applied the MK methodology to validate findings from Sen's slope trend analysis in a study on the seasonality shift and streamflow flow variability trends in India.

Furthermore, the MK test and the Sen's estimator test has been applied to examine the significant trend of rainfall, temperature, and runoff in the Rangoon watershed in Dadeldhura district of Nepal. The result revealed that there were warming trends in the study area (Pal et al. 2017). In contrast, Machida et al. (2013) studied whether the MK test is an effective methodology for detecting software aging from traces of computer system metrics. But, the MK test result shows it is not a powerful trend test. The authors' experimental study showed that the use of MK trend test in detecting software aging is highly exposed in creating false positives (Machida et al. 2013). Other studies have applied the MK test for the assessment of spatial and temporal trends such as in Northern Iran (Biazar and Ferdosi 2020) and in Kansas, USA (Anandhi 2013). Despite the various application of the MK trend test in different parts of the world, studies analyzing the non-parametric MK test is commonly employed to detect monotonic trends in a series of environmental data, climate data or hydrological data. But some limited studies such as Machida et al (2013) showed that the MK test is not a powerful trend test for software aging and the variation in this result and other studies is because of differences in study variables/materials.

However, the MK test is a non-parametric (distribution-free) test which is used to analyze time-series data for consistently monotonic trends. These non-parametric methods have several benefits such as the handling of missing data, the requirement of few assumptions, and the data distribution independence (Öztopal and

Sen 2016; Wu and Qian 2017; Kisi 2015). Nevertheless, the major disadvantage of the method is the influence of autocorrelation in data on its test significance. Several modifications in the MK test have been proposed by different authors to remove the influence of autocorrelation done with varied techniques and one of the most common tests is corrected for bias before pre-whitening (Malik et al. 2019; Sanikhani et al. 2018; Su et al. 2006). The MK test is mostly chosen for the analysis of climatic data since its measurement does not follow the normal distribution. Thus, the present study has employed the MK trend test and Sen's slope estimate to understand the nature of the temperature trend and significance level in the study area. Hence, the current study is conducted based on the temperature variation in the city of Addis Ababa over two stations—Bole and Entoto. The historic temperature used for Bole station is from 1983 to 2016 and the Entoto station from 1989 to 2016. In addition to this, the selection of this station is also classified based on geographical variation and the altitude differences.

The overall objective of this study is to investigate the trend of temperature in Addis Ababa City by using the Mann–Kendall trend test and Sen's slope estimate as well as to look at the effect of climate change in the study area. The result of this study (i.e. temperature trends and their descriptive statistics) will help city planners in forecasting weather variations. It will also support universal health coverage by predicting the situation/seasons in order to control seasonal disease outbreaks. In terms of contribution to the existing literature, this study introduces one of the earliest case studies in this subject matter for Ethiopia and the findings will be useful in mitigating the adverse impacts of climate change in the country. Also, the analytical framework presented here can be employed by other researchers to study temperature variations in other regions of the world. While this paper is crafted with a local case study, the results will also be useful for international literature.

The rest of this paper is structured thus: Sect. 2 explains the research methods used in the study which incorporates the study area, data quality control, different MK Tests, Sen's Slope estimator, ITA analysis, data collection, and processing, as well as data analysis tools. Section 3 describes the results and brief discussion, while the general study conclusions are presented in Sect. 4.

Materials and methods

We employed the Mann–Kendall (MK) trend test and Sen's slope estimate to examine the nature of the temperature trend and significance level in the study area. Figure 1 shows the general study methodological framework.

Description of the study area

Addis Ababa is the capital city of Ethiopia and it is found in the heart of the country surrounded by Oromia which is geographically located at longitude 38° 44' E and latitude of 9° 1' N. According to the 2007 census, the city have a total population of 2,739,551 inhabitants. Addis Ababa comprises 6 zones and 28 woredas. Addis Ababa covers an area of about 540 Km² and it lies between 2,200 to 2,500 m above sea level. The city lies at the foot of the 3,000 m high Entoto Mountains and the mountain Entoto is located in Gullele Sub City (within Addis Ababa city Administration). Furthermore, the lowest and the highest annual average temperature of the city is between 9.89 and 24.64 °C (FDRE 2018; CSA 2007). Figure 2 shows a map of the study area.

Data quality control

The quality of the data was visually and statistically assessed. Visually, the temperature data were checked and detected for outlier and missing data to avoid erroneous/typing error data that can cause changes in the final result. Whereas, the MK test method was checked and tested statistically with the trend free pre-whiting process and the variance correction approaches before applying the test. The trend free pre-whiting process was proposed to remove the serial correlation from the data before applying the trend test (Yue et al. 2002; Hamed 2009). Likewise, to overcome the limitation of the occurrence of serial autocorrelation in time series, the variance correction procedure was applied as proposed by (Hamed and Rao 1998).

Mann–Kendall test (MK1)

MK trend test is a non-parametric test used to identify a trend in a series. It is also used to determine whether a time series has a monotonic upward or downward trend. The non-parametric MK test is commonly employed to detect monotonic trends in a series of environmental data, hydrological data, or climate data. The null hypothesis (H₀) shows no trend in the series and the data which come from an independent population are identically distributed. The alternative hypothesis, H_a, indicates that the data follow a monotonic trend (i.e. negative, non-null, or positive trend). There are two benefits of using this test. First, it does not require the data to be normally distributed since the test is non-parametric (distribution-free test) and second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. The data values are evaluated as an order time series and all subsequent data values are likened from each data value. The time series $x_1, x_2, x_3, \dots, x_n$ represents n data points.

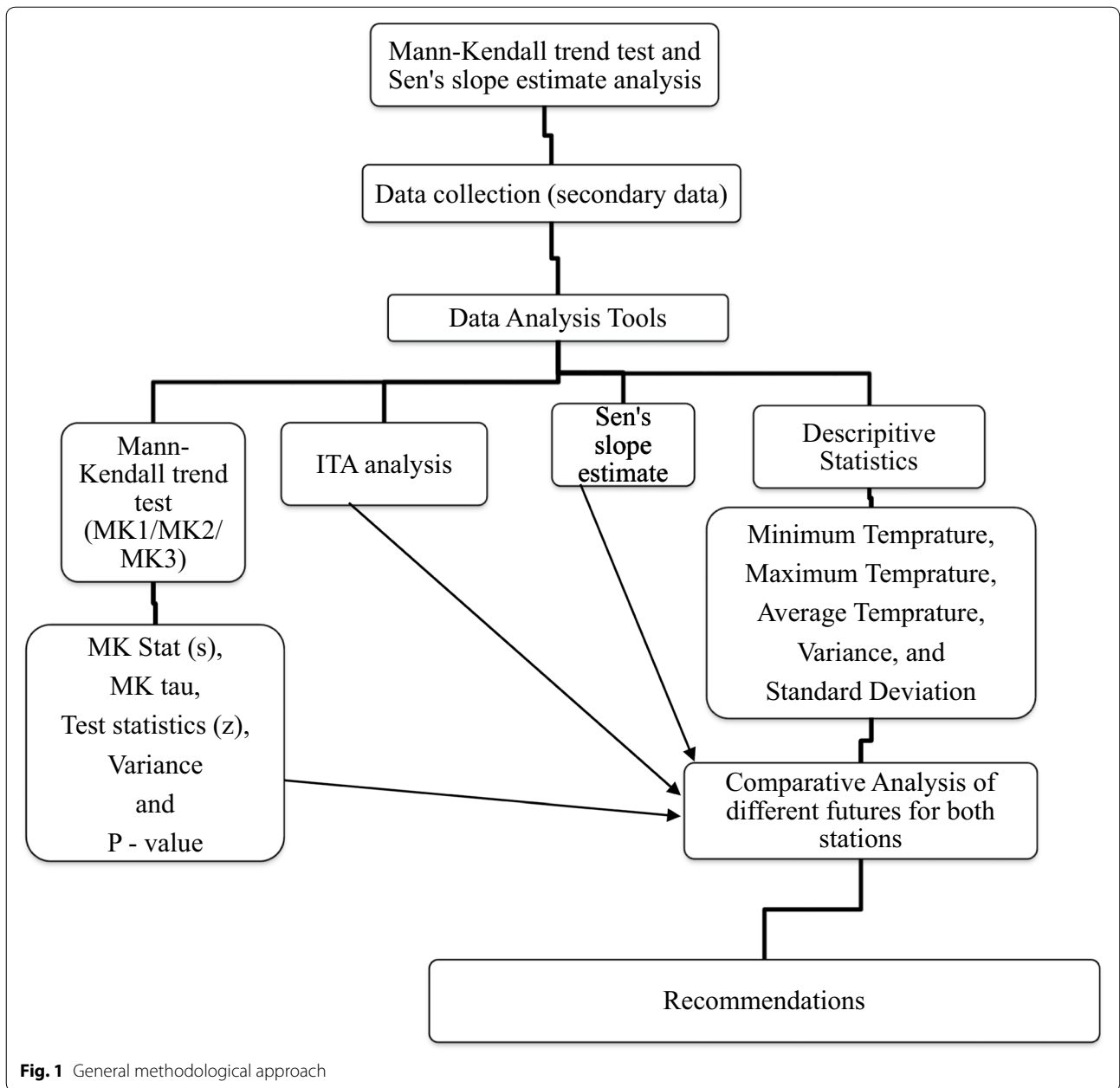


Fig. 1 General methodological approach

The MK test statistic (S) is calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(X_j - X_i) \tag{1}$$

where

$$\text{sgn}(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} \tag{2}$$

Note that if $S > 0$, then later observations in the time series tend to be larger than those that appear earlier

in the time series and it is an indicator of an increasing trend, while the reverse is true if $S < 0$ and this indicates a decreasing trend.

The mean of S is $E[S] = 0$ and the variance (σ^2) of S is given by

$$\sigma^2 = \frac{1}{18} \left\{ n(n-1)(2n+5) - \sum_{j=1}^p t_j(t_j-1)(2t_j+5) \right\} \tag{3}$$

where p is the number of the tied groups in the data set and t_j is the number of data points in the jth tied group.

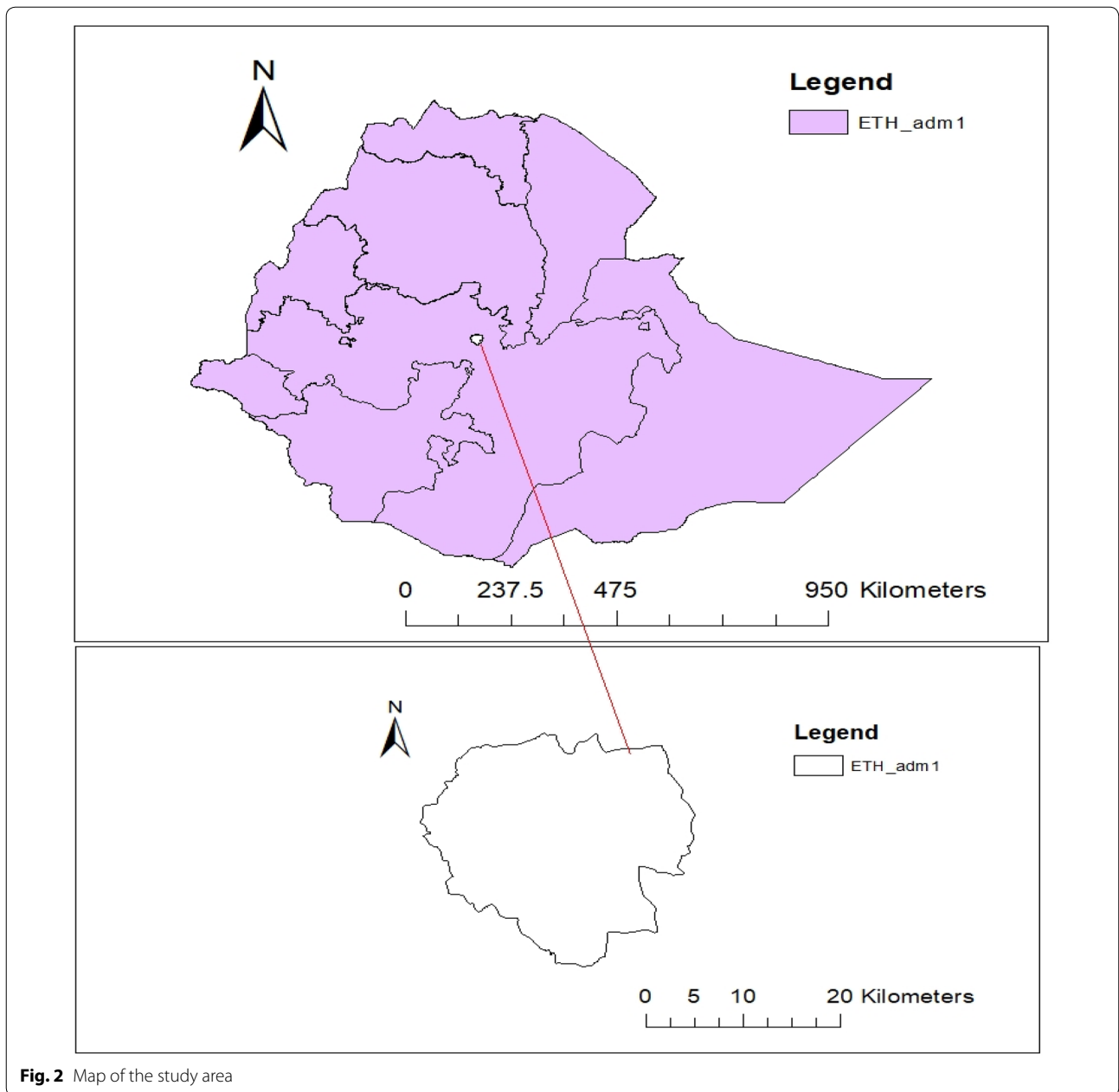


Fig. 2 Map of the study area

The statistic S is approximately normally distributed provided that the following Z-transformation is employed:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma^2}} & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \frac{S+1}{\sqrt{\sigma^2}} & \text{if } s < 0 \end{cases} \quad (4)$$

A normal approximation test that could be used for datasets with more than 10 values was described, provided there are not many tied values within the data set. If there is no monotonic trend (the null hypothesis), then

for time series with more than ten elements, $z \sim N(0, 1)$, i.e. z has a standard normal distribution. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} \quad (5)$$

The statistic S is closely related to Kendall's as given by:

$$\tau = \frac{S}{D} \tag{6}$$

where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^p t_j(t_j-1) \right]^{1/2} \left[\frac{1}{2}n(n-1) \right]^{1/2} \tag{7}$$

where p is the number of the tied groups in the data set and t_j is the number of data points in the j th tied group.

All the above procedures used to compute the Mann–Kendall Trend test were collected and referenced from (Zaiontz 2020; Kendall 1975; Pohlert 2020).

Mann–Kendall test with trend-free pre-whitening (MK2)

Hamed (2009) recommended that there will be a decrease or an increase in S value when autocorrelation is positive or negative which is underestimated or overestimated by the original variance $V(S)$. Therefore, when trend analysis is conducted for this data using MK1, it will show positive or negative trends when there is no trend. Hence, the trend free pre-whiting process (TFPW) was proposed by Hamed (2009) and the proposed pre-whitening technique in which the slope and lag-1 serial correlation coefficient are simultaneously estimated. The lag-1 serial correlation coefficient is then corrected for bias before pre-whitening. Finally, the lag-1 serial correlation components are removed from the series before applying the trend test. The following steps are used to determine trend analysis using the MK2 test. Calculate the lag-1 ($k = 1$) autocorrelation coefficient (r_1) using:

$$r_1 = \frac{\frac{1}{n-k} \sum_{i=1}^{n-k} (X_i - \bar{X})(X_{i+k} - \bar{X})}{\frac{1}{n} \sum_{i=1}^n (X_i - \bar{X})^2} \tag{8}$$

If the condition $\frac{-1-1.96\sqrt{n-2}}{n-1} \leq r_1 \leq \frac{-1+1.96\sqrt{n-2}}{n-1}$ is satisfied, then the series is assumed to be independent at a 5% significance level and there is no need for pre-whitening. Otherwise, pre-whitening is required for the series before applying the MK1 test.

Equation (9) is used to remove the trend in time series

$$X'_i = X_i - (\beta * i) \tag{9}$$

data to get detrended time series.

where

$$\beta = \text{median} \left[\frac{X_j - X_i}{j - i} \right] \text{ for all } i < j. \tag{10}$$

Equation (8) is used to calculate lag-1 autocorrelations for detrended time series given by X'_i . Using Eq. (11),

remove the lag-1 autoregressive component (AR (1)) from the detrended series to get a residual series.

$$Y'_i = X'_i - r_1 * X'_{i-1} \tag{11}$$

Yet again, $(\beta * i)$ value is added to the residual series as follows;

$$Y_i = Y'_i + (\beta * i) \tag{12}$$

Thus, the MK test is applied to the blended series Y_i to determine the significance of the trend.

Mann-Kendall test with variance correction (MK3)

Sometimes, removing lag-1 autocorrelation is not enough for many hydrological time-series datasets. To overcome the limitation of the presence of serial autocorrelation in time-series, a correction procedure was proposed by (Hamed and Rao 1998). First, the corrected variance S is calculated by Eq. (13), where $V(S)$ is the variance of the MK1 and CF is the correction factor due to the existence of serial correlation in the data.

$$\text{Corrected variance } S(V * (S)) = CF \times V(S) \tag{13}$$

where

$$CF = 1 + \frac{2}{n(n-1)(n-2)} \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2)r_k^R \tag{14}$$

where r_k is lag-ranked serial correlation, while n is the total number of observations.

The advantage of the MK3 test over the MK2 test is that it includes all possible serial correlations (lag- k) in the time series, while MK2 only considers the lag-1 serial correlation (Yue et al. 2002).

Sen's Slope estimator

Sen's estimator is another non-parametric test used to identify a trend in a series as well as it shows the magnitude of the trend. The Sen's slope estimate requires at least 10 values in a time series. This test computes both the slope (i.e. linear rate of change) and intercepts according to Sen's method (Sen 1968). Likewise, as Drápelová and Drápelová (2011) described that the linear model can be calculated as follows:

$$f(x) = Qx + B \tag{15}$$

where Q is the slope, B is constant. According to Pohlert (2020), initially, a set of linear slopes is calculated as follows (Eq. 16):

$$Q_i = \frac{X_j - X_k}{j - k} \text{ for } j = 1, 2, 3 \dots N \tag{16}$$

where Q is the slope, X denotes the variable, n is the number of data, and j, k are indices where $j > k$. The slope is estimated for each observation and the corresponding intercept is also the median of all intercepts. Median is computed from N observations of the slope to estimate the Sen's Slope estimator (Eq. 17):

$$Q = \begin{cases} Q_{\frac{N+1}{2}} & \text{if N is odd} \\ \frac{1}{2} \left(Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}} \right) & \text{if N is even} \end{cases} \quad (17)$$

where

$$N = \frac{n(n-1)}{2} \quad (18)$$

where N is the Slope observations and n is the values of X_k in the time series.

According to Mondal et al. (2012), when the N Slope observations are shown as Odd, the Sen's Estimator is computed as $Q_{med} = (N+1)/2$ and for Even times of observations the Slope estimate as $Q_{med} = [(N/2) + ((N+1)/2)]/2$. The two-sided test is carried out at $100(1 - \alpha) \%$ of the confidence interval to obtain the true slope for the non-parametric tests in the series.

The positive slope Q_i obtained shows an increasing/upward trend whereas the negative slope Q_i obtained shows a decreasing/downward trend. But, if the slope is zero there is no trend other than things remain the same. To obtain an estimate of B (constant) in Eq. (8), the n values of differences $x_i - Q_i t_i$ is calculated. The median of these values gives an estimate of constant B. The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure (Pohlert 2020; MAKESENS 2002).

Innovative trend analysis (ITA) method

The Innovative trend analysis method was proposed by Şen (2011) for the detection of trends in time series. In this method, data are equally divided into two segments between the first dates to the last date. Both segments are arranged in ascending order and presented in the X- and Y-axis. The first segment is presented in the horizontal axis (x-axis) while the second segment is presented in the vertical axis (y-axis) in the Cartesian coordinate system. A bisector line at 1:1 (45°) line divides the diagram into two equal triangles. If the data points lay on the 1:1 line, there is no trend in the data. If the data points exist in the top triangle, it is indicative of a positive trend (increasing trend). If the data lies in the bottom triangle, it indicates a negative trend (decreasing trend) in the data (Zhang et al. 2008; Şen 2011). The Innovative Trend Analysis (ITA) of different temperatures graphs/plots for both stations were investigated through RStudio (i.e. package

used 'trendchange::innovtrend (X)') as developed by Şen (2011).

Descriptive statistics

The descriptive statistics table provides summary information on the binning input variables. The descriptive procedure displays univariate summary statistics for several variables in a single table. Statistics include the sample size (observations), mean, minimum, maximum, variance, standard deviation, and the number of cases with valid values. Values for Minimum and Maximum correspond to the lowest and highest categories of the factor variable. Whereas, the mean (is computed as the sum of all data values X_i , divided by the sample size n:

$$\text{Mean}(\bar{X}) = \sum_{i=1}^n \frac{X_i}{n} \quad (19)$$

The sample variance is the classical measures of spread. Like the mean, they are strongly influenced by outlying values. Both the variance and standard deviation are measures of variability in a population. Variance is the average squared deviations from the arithmetic mean and the standard deviation is the square root of the variance. Thus, the variance is nothing but the square of the standard deviation, i.e.,

$$\text{Variance}(\sigma^2) = \frac{\sum (X - \bar{X})^2}{(n-1)} \quad (20)$$

$$\text{Standard Deviation}(\sigma) = \sqrt{\sigma^2} \quad (21)$$

All the above procedures used to compute the descriptive statistics were collected and referenced from (Gupta 2007; Helsel and Hirsch 2002).

Data collection and processing

The daily climatic data for minimum and maximum temperatures were obtained from the National Meteorological Agency (NMA). The historic temperature was collected from two stations which are Bole station from 1983 to 2016 (NY=34) and Entoto station from 1989 to 2016 (NY=28). The overall research data for this study were collected based on secondary data sources to address the goals of the study. The data was used to analyses the temperature trend of Addis Ababa city.

Data analysis tools

MK Trend Test and Sen's Slope estimator were used to study the trend analysis of temperature. The Mann-Kendall trend test results such as MK stat(s), Kendall's tau, test statistics (Z), and P-value as well as the Sen's slope Q were computed using XRealStats, XLSTAT 2020, and

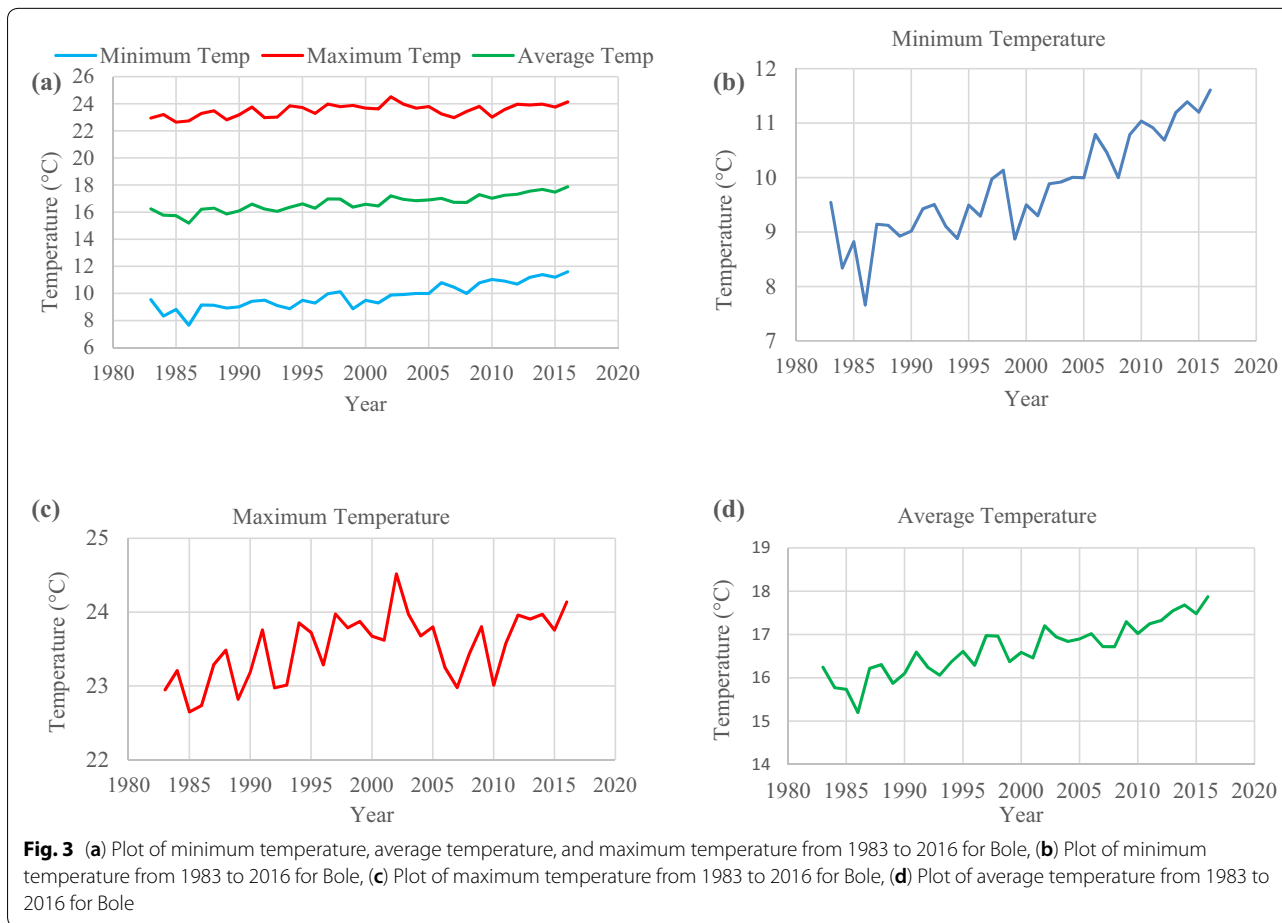
RStudio (i.e. documentation for package ‘modifiedmk’ version 1.5.0). MAKESENS version 1.0 was used for the graph of Sen’s estimate whereas the descriptive statistical techniques such as minimum, maximum, mean, standard deviation, variance, and also average annual temperatures graph were computed using Microsoft excel. The analyzed data was used to detect the trend of climate change.

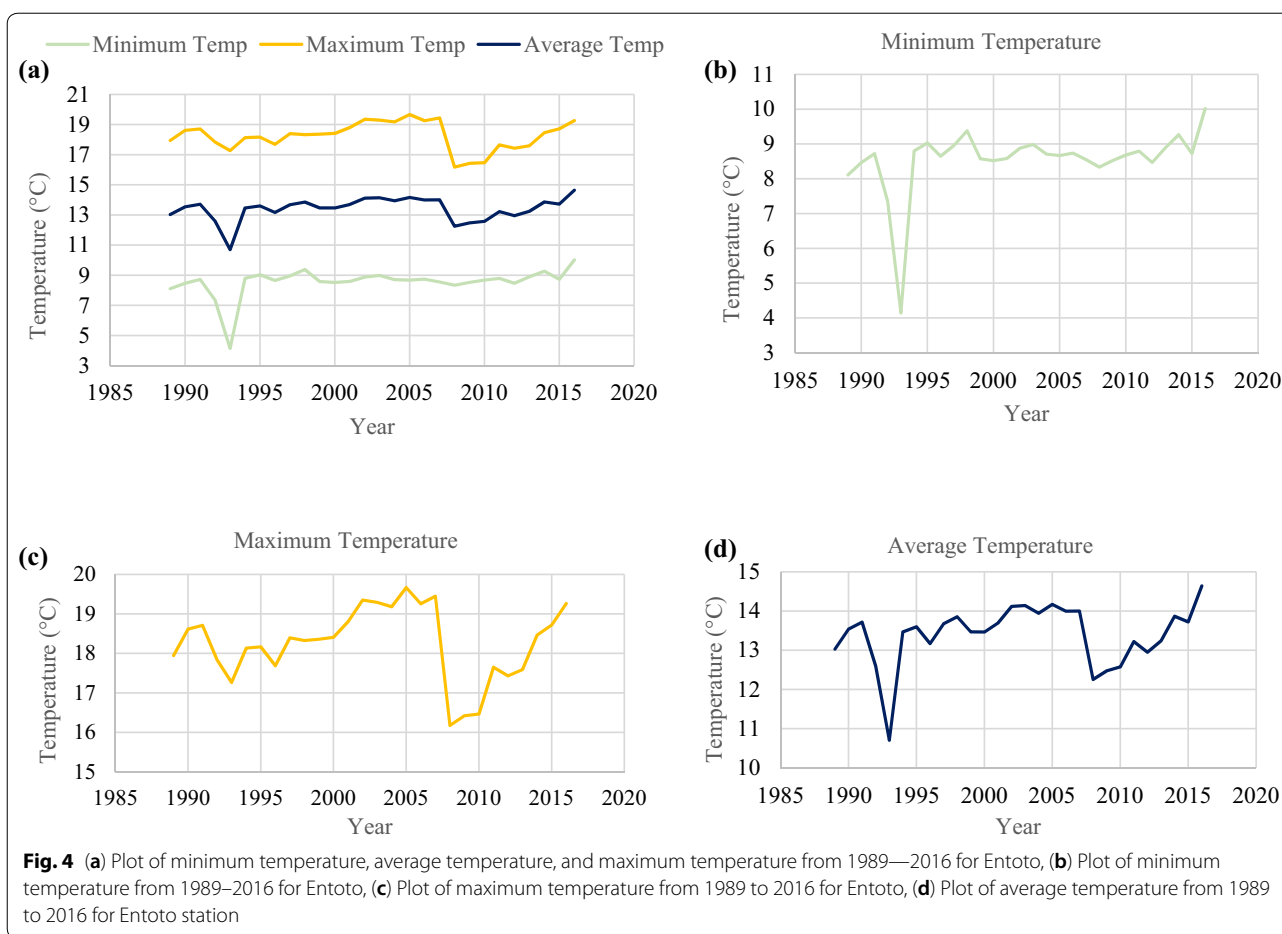
Results and discussion

Mann-Kendall test result

Trend analysis of Temperature for Addis Ababa City was done with 34 years of temperature data from Bole station (1983–2016) along with 28 years of temperature data from Entoto station (1989–2016). MK test and Sen’s Slope estimator has been used to determine the temperature trend. Figure 3a–d shows the graph of minimum, maximum, and average temperature, in addition to the comparison of the temperatures for Bole station, whereas Fig. 4a–d shows the graph of minimum, maximum, and average temperature, as well as the comparison of the temperatures for Entoto station.

From the MK test result, it was found that the Z value of MK2/MK3 for minimum, maximum, and average temperatures for Bole station are 6.21/5.99, 2.49/2.6, and 6.09/6.14 respectively, as stated in (Table 1). The positive Kendall’s Z value shows an upward trend and also implies an increasing trend over time. This indicates that there is a significant increase in the trend at a 5% level of significance since the p-value is less than the significant level alpha (0.05) (Table 1). Whereas, for the Entoto station, the test statistic (Z) value of MK1 for minimum temperatures is 1.64, and the test statistic (Z) value of MK2/MK3 for maximum and average temperatures are 0.71/0.65, and 0.17/1.04 respectively, as displayed in (Table 1) and the positive value indicates an increasing trend but not significant at 5% significant level since the p-value is greater than the significant level alpha = 0.05 (Table 1). However, the minimum temperature for the Entoto station used the original MK test without using the modified MK test since the criteria stated in Eq. (8) is satisfied and thus no need of pre-whitening test before applying the MK test. Therefore, we simply use the result of MK1 without applying the serial correlation test.





The result obtained in this study agrees with the findings of an earlier study by Getachew (2018), whose results revealed that for maximum temperature, an increasing trend analysis is found to be statistically significant as the computed p-value (i.e. 0.03) is lower than the significance level ($\alpha = 0.05$) and the researcher rejects the null hypothesis and accepts the alternative hypothesis for Addis Zemen station at south Gonder zone. Similarly, in Ethiopia, a study conducted by Johannes and Mebratu (2009) shows that over the past five decades the temperature has been increasing annually at a rate of 0.2 °C. Conversely, the increasing trend of minimum temperature for Addis Zemen station is statistically insignificant as the computed p-value (i.e. 0.284) is greater than the significance level ($\alpha = 0.05$) and thus the researcher cannot reject the null hypothesis (Getachew 2018). Table 1 shows the MK trend test result. The annual temperature (i.e. minimum, maximum, and average temperature) for Bole station shows a positive trend and statistically significant because the computed p-value is lower than the significance level $\alpha = 0.05$, and one can accept the alternative hypothesis and reject the null hypothesis. On

the other hand, the trend analysis of annual temperature (i.e. minimum, maximum, and average temperature) for the Entoto station shows an increasing trend but not statistically significant, thus, we can accept the null hypothesis as the computed p-value is greater than the significant level ($\alpha = 0.05$).

Sen’s estimate and computed data

The simple non-parametric procedure developed by (Zaiontz 2020) was used to estimate the slopes (change per unit time) present in the trend and the Sen’s estimate graph/figure was computed by (MAKESENS 2002). The positive sign indicates the increasing slope, and the negative sign implies the decreasing slope, whereas, the zero slope shows no trend in the data for the study period and things remain the same. The Sen’s slope estimates as shown in Table 1 and Fig. 5a–c for minimum, maximum, and average temperature from 1983 to 2016 for Bole station respectively shows an increasing trend and this agrees with the MK statistic (Z) result of positive values. It was found that the Z value of MK2/MK3 for minimum, maximum, and average temperatures for Bole station is

Table 1 Trend analysis of temperature using MK1/MK2/MK3 test for Bole and Entoto stations

Test	Bole Station			Entoto Station			
	Min Temp	Max Temp	Average Temp	Min Temp	Max Temp	Average Temp	
MK1	Test statistic (Z)	5.99	3.32	6.14	1.64	0.85	1.4
	P-value (two-tailed)	< 0.0001	0.001	< 0.0001	0.101	0.396	0.161
	Mann–Kendall stat (S)	405	225	415	84	44	72
	Kendall’s tau	0.722	0.401	0.74	0.222	0.116	0.19
	Alpha	0.05	0.05	0.05	0.05	0.05	0.05
	Sen’s slope Q	0.0857	0.0256	0.0547	0.0153	0.0228	0.0194
	Var (s)	4550	4550	4550	2562	2562	2562
	Trend	Increasing	Increasing	Increasing	No significant	No significant	No significant
MK2	Test statistic (Z)	6.21	2.49	6.09	–	0.71	0.17
	P-value (two-tailed)	< 0.0001	0.0126	< 0.0001	–	0.48	0.87
	Mann–Kendall stat (S)	402	162	394	–	35	9
	Kendall’s tau	0.761	0.306	0.746	–	0.099	0.026
	Alpha	0.05	0.05	0.05	–	0.05	0.05
	Sen’s slope Q	0.0865	0.0157	0.0551	–	0.0099	0.0015
	Var (s)	4165	4165	4165	–	2301	2301
	Trend	Increasing	Increasing	Increasing	–	No significant	No significant
MK3	Test statistic (Z)	5.99	2.6	6.14	–	0.65	1.04
	P-value (two-tailed)	< 0.0001	0.01	< 0.0001	–	0.518	0.297
	N/N*	1	1.63	1	–	1.73	1.81
	Kendall’s tau	0.722	0.401	0.722	–	0.116	0.19
	Alpha	0.05	0.05	0.05	–	0.05	0.05
	Sen’s slope Q	0.0857	0.0256	0.0547	–	0.023	0.019
	Var (s)	4550	7395	4550	–	4430	4636
	Trend	Increasing	Increasing	Increasing	–	No significant	No significant

where N- sample size (total number of observations) and N*—effective sample size

6.21/5.99, 2.49/2.6, and 6.09/6.14 respectively (Table 1). The positive Kendall’s Z value shows an upward trend and also implies an increasing trend over time. This indicates that there is a significant increase in the trend at a 5% level of significance since the computed p-value is less than the significant level alpha (0.05) (Table 1).

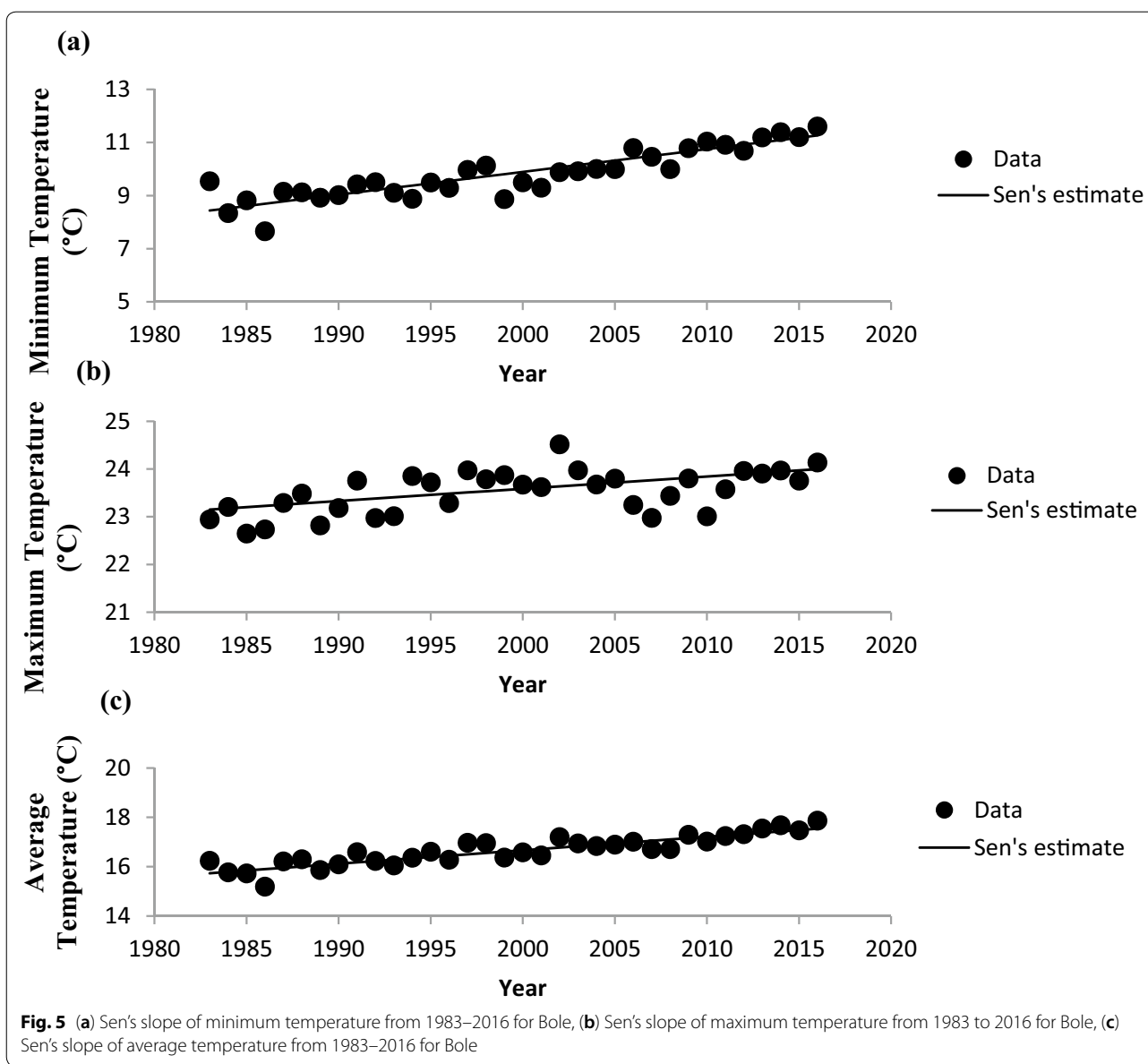
The Sen’s slope estimates as shown in Table 1 and Fig. 6a–c for minimum, maximum, and average temperature from 1989 to 2016 for Entoto station respectively, depicts an increasing trend and the Sen’s slope agrees with the MK1 statistic (Z) result of positive values of 1.64 for minimum temperature, whereas the MK2/MK3 statistic (Z) result of positive values of 0.71/0.65 for maximum and 0.17/1.04 for average temperature and this shows an indicator of an increasing trend. However, the increasing trend is not significant at 5% significant level since the computed p-value is greater than the significant level (Table 1).

Furthermore, the result found in this present study for minimum, maximum, and average temperature for Entoto station and Bole station are different even though the stations exist in the capital city and this dissimilarity

occurs because of geographical variation. Bole station exists inside the capital city and many constructions and other transport facilities take place due to this there is a temperature increment, whereas, the Entoto station exists near the National park and mountains and because of this, the temperature is almost stable. The Sen’s Slope estimator displays that there is a tendency of temperature increments in Bole station. Thus, the increasing trend of temperature due to climate change and other factors can lead to weather extremes in the capital city (FDRE 2018; Fig. 5a–c, Fig. 6a–c).

Innovative trend analysis (ITA) method and computed figures

The simple non-parametric procedure was used to estimate the graph/figure through Rstudio using the package ‘trendchange::innovtrend (X)’ (Şen 2011). A bisector line at 1:1 straight line divides the diagram into two equal triangles. If the data points lay on the 1:1 line, there is no trend in the data. If the data points exist in the top triangle, it is indicative of an increasing trend. If the data lies

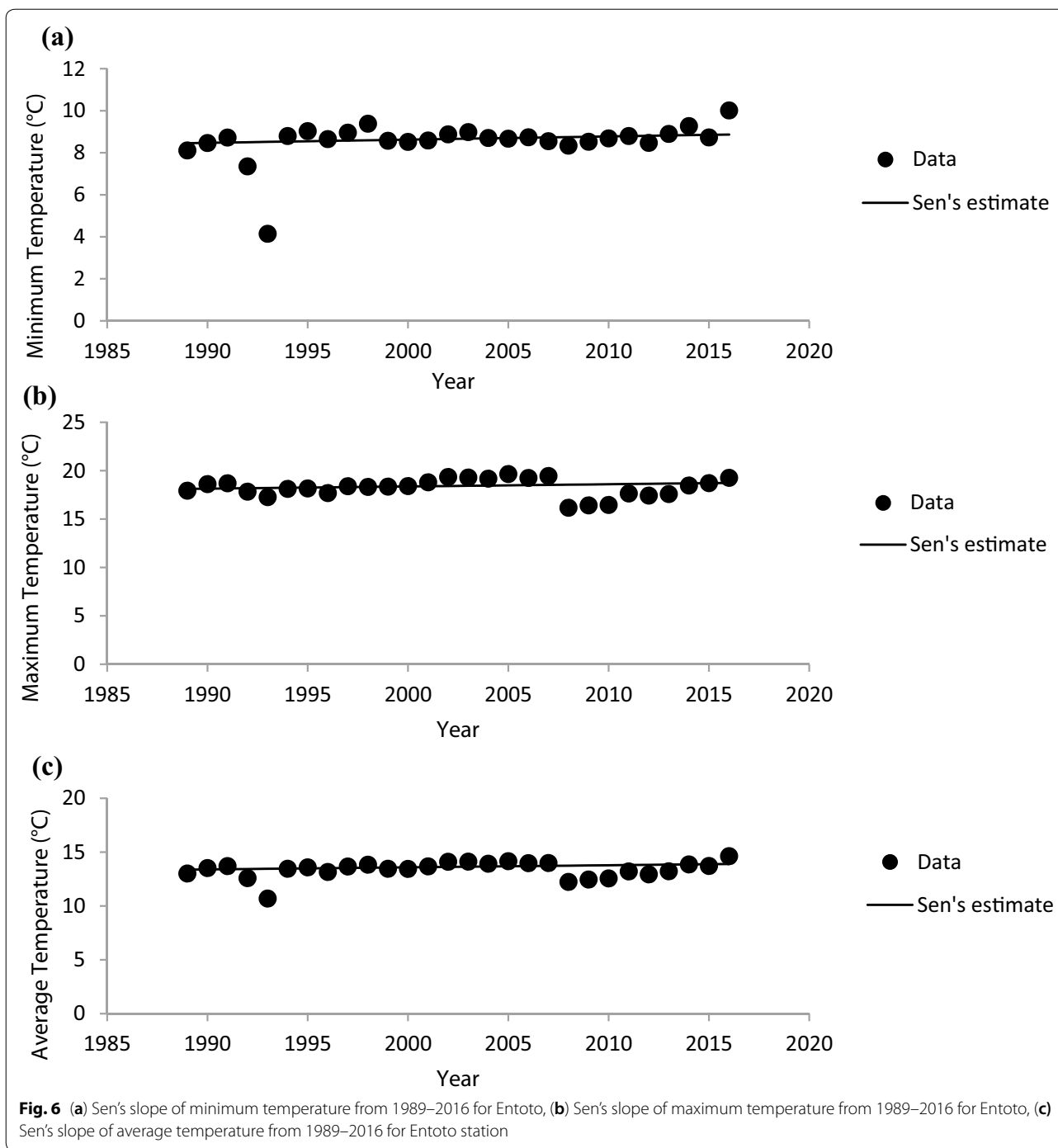


in the bottom triangle, it indicates a decreasing trend in the data.

The Innovative Trend Analysis in Fig. 7a–c for minimum, maximum, and average temperatures from 1983 to 2016 for Bole station was computed. So, the data points exist in the top triangle and this shows an increasing trend and this strongly agrees with the MK2/MK3 result of positive values. It was found that the Z value of MK2/MK3 for minimum, maximum, and average temperatures for Bole station is 6.21/5.99, 2.49/2.6, and 6.09/6.14 respectively. The positive Kendall's Z value shows an upward trend and also implies an increasing trend over time. This indicates that there is a significant increase in the trend at a 5% level of significance since the computed

p-value is less than the significant level ($\alpha=0.05$) (Table 1).

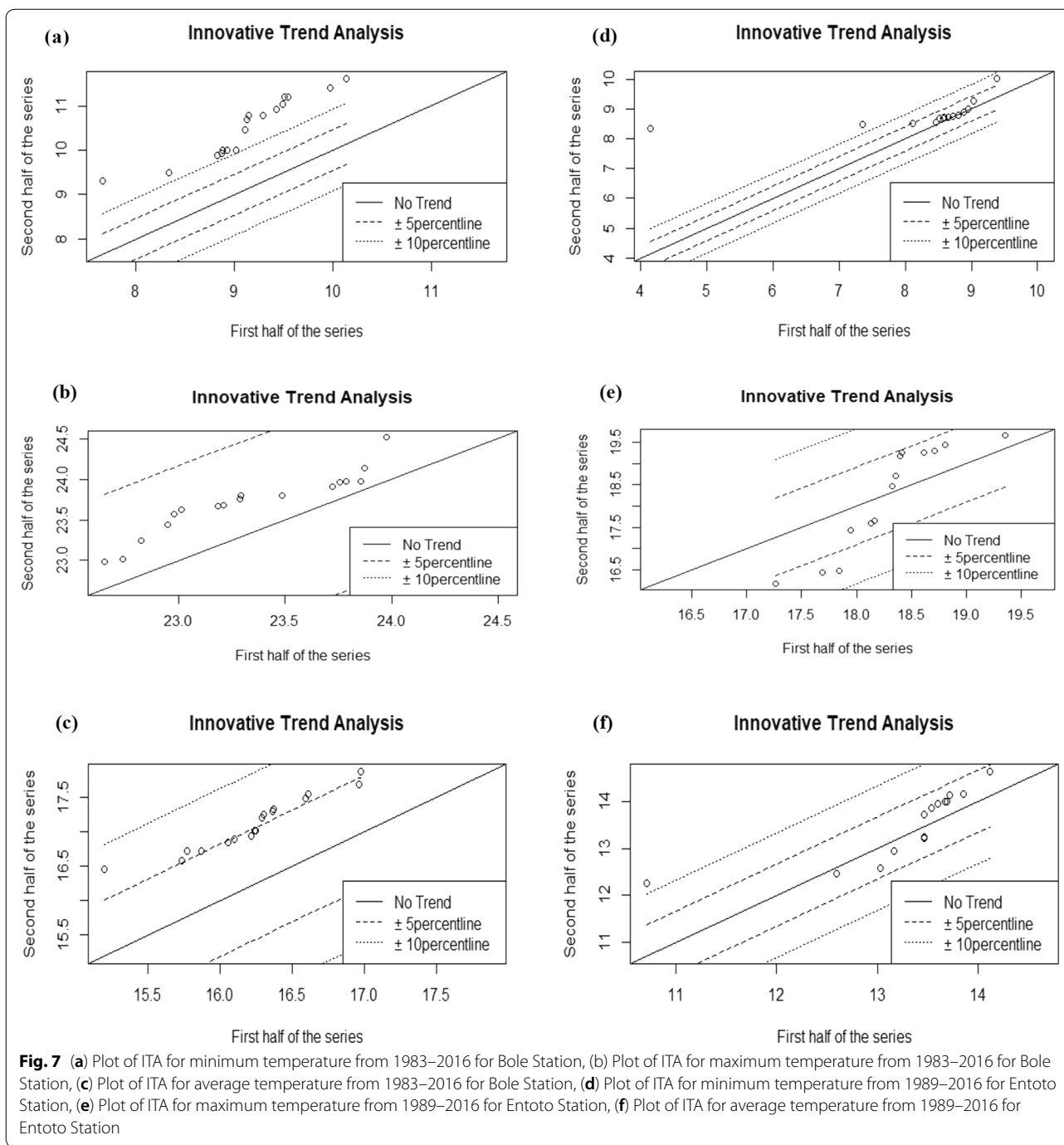
The Innovative Trend Analysis in Fig. 7d–f for minimum, maximum, and average temperatures from 1989 to 2016 for the Entoto station was computed. So, the data points lay on 1:1 line and this shows no trend in the data and this result agrees with the MK1 result of positive values for minimum temperature and MK2/MK3 result of positive values for maximum, and average temperature. It was found that the Z value of MK1 for minimum temperature for the Entoto station is 1.64 whereas the Z value of MK2/MK3 for maximum and average temperatures for the Entoto station is 0.71/0.65, and 0.17/1.04 respectively. The positive Kendall's Z value shows an indicator of an



increasing trend. But, the increasing trend is not significant at 5% significant level since the computed p-value is greater than the significant level $\alpha=0.05$. The Innovative Trend Analysis (ITA) Method was used for a further checkup to compare with the result of the MK1/MK2/MK3 and Sens slope estimate for the trend and significant test (Table 1; Fig. 7a-c, Fig. 7d-f).

Descriptive statistics of annual average temperature

Table 2 shows the minimum, maximum, and average temperature among the two stations. The average annual minimum temperature ranges from 7.66 °C to 11.61 °C, and from 4.14 °C to 10.02 °C for Bole and Entoto stations respectively. The average annual maximum temperature ranges from 22.65 °C to 24.52 °C for Bole station whereas,



for Entoto station, it ranges from 16.18 °C to 19.67 °C. The average annual average temperature ranges between 15.20 °C to 17.87 °C, and between 10.7 °C to 14.64 °C for Bole and Entoto stations respectively.

The result obtained in this study agrees with the findings of an earlier study, and whose results revealed that the mean annual maximum temperature ranges from 18.3 °C to 26.3 °C in Nefas Mewcha and Mekane Eyesus,

while the mean annual minimum temperature ranges from 7.82 °C to 11.57 °C for Nefas Mewcha and Addis Zemen stations at south Gonder zone (Getachew 2018). Likewise, in this current study, the mean annual minimum temperature ranges from 8.56 °C to 9.82 °C for Entoto and Bole station whereas the mean annual maximum temperature ranges from 18.25 °C to 23.52 °C for Entoto and Bole stations, as well as the mean annual

Table 2 Descriptive statistics of annual average temperature

Stations	Temperatures (°C)	Observations	Minimum	Maximum	Mean	Variance	Std. deviation
Bole	Min Temp	34	7.66	11.61	9.8226	0.881	0.938
	Max Temp	34	22.65	24.52	23.5191	0.203	0.451
	Average Temp	34	15.2	17.87	16.6706	0.369	0.607
Entoto	Min Temp	28	4.14	10.02	8.5561	0.949	0.974
	Max Temp	28	16.18	19.67	18.2529	0.869	0.932
	Average Temp	28	10.7	14.64	13.4039	0.603	0.776

average temperature, ranges from 13.40 °C to 16.67 °C for Entoto and Bole station (Table 2). Conversely (Getachew 2018), the mean annual maximum temperature ranges between 26.9 °C and 32.2 °C for Addis Zemen stations at the south Gonder zone and the result disagrees with the present study of the mean annual the maximum temperature for Entoto and Bole station and this dissimilarity happens as a result of topographic variation and geographical location of the station.

Conclusion

From the study, it can be concluded that the trend analysis of annual temperature for Bole station shows a positive trend and statistical significance. As the computed p-value is lower than the alpha (significance level), one should reject the null hypothesis and accept the alternative hypothesis. On the other hand, the trend analysis of annual temperature for the Entoto station shows an increasing trend but not statistically significant. Hence, one cannot reject the null hypothesis, H₀ as the computed p-value is greater than the significant level of alpha (0.05). Furthermore, the study showed that both the Mann–Kendall trend test and Sen's Slope estimator reveals that there is a tendency of temperature increase in the study area. Thus, the increasing trend of temperature due to climate change and other factors can lead to weather extremes in the capital city.

Abbreviations

CSA: Central Statistical Agency; CF: Correction Factor; FDRE: Federal Democratic Republic of Ethiopia; H₀: Null hypothesis; H_a: Alternative hypothesis; ITA: Innovative Trend Analysis; Km: Kilometer; MK: Mann Kendall; NMA: National Meteorological Agencies; NY: Number of years; TFPW: Trend Free Pre-Whiting Process; UNFCCC: United Nations Framework Convention on Climate Change; UNICEF: United Nations International Children's Emergency Fund; WHO: World Health Organization; Z: Normalized test statistics.

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Authors' contributions

ZA performed the study design, statistical analysis of results, data interpretation, and writing the manuscript. MO Conceptualization, draft review and edit of the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors have no competing interest to declare.

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