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Variability and trends of observed minimum, maximum and average temperature over Northwestern parts of Ethiopia Since 1987

[1]*Belay Ejigu Feke, [2]Tadesse Terefe [2]Kassahun Ture and [3]Debela Hunde

[1]*Jimma University College of Agriculture and Veterinary Medicine, Department of Natural Resources Management, Jimma, Oromia, Ethiopia,
[2]Addis Ababa University Institute of Geophysics, Space, Science and Atmosphere, Addis Ababa, Ethiopia
[2]Addis Ababa University Center for Environmental Sciences, Addis Ababa, Ethiopia.
[3]Jimma University College of Agriculture and Veterinary Medicine, Department of Natural Resources Management, Jimma, Oromia, Ethiopia

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ABSTRACT

This study examined the Spatio-temporal variability and time-series trends of 33 years' temperature ranging from 1987 to 2019. Dataset for statistical analysis obtained from the national meteorological agency and national aeronautics and space administration data portal. All statistical examinations were conducted using Python3. There was a non-significant difference between the months of the years 1987 to 2016 and 1987 to 2019. A less variable annual minimum temperature observed over the period with the lowest record of 16.341 ^{o}C and maximum-minimum temperature of 17.45 ^{o}C. Significantly different monthly maximum temperatures recorded over the period from 1987 to 2016 and from 1987 to 2019. There was a statistically a non-significant difference (P>0.05) between the winter, spring, summer, autumn, belg, kiremt and bega seasons over the periods of 30 and 33 years. Statistically significant (P<0.05) differences evaluated among the months of the year ranging from 1987 to 2016 and 1987 to 2019 in the observed average temperature. Increasing of average temperature valued during all months of the year 1987 to 2016. Growing trends in average temperature during all months of the period from 1987 to 2019 observed. There was a non-significant difference in observed average temperature during the winter, spring, summer and autumn seasons. There was statistically non-significant variation in average temperature among the Belg, Kiremt and Bega seasons during the period of the last 30 and 33 years. Increasing annual and decadal average temperature was observed over the series of years within the range of 30 and 33 years.

Key words : *Variability, Trend, Temperature, Linear regression*

Introduction

Heating of the world due to the emission of Greenhouse Gases (GHGs) is now undeniable. Over the past century, the atmospheric concentration of CO_2 has increased significantly, drive the average global temperature to increase by 0.74 ^{o}C as compared with the pre-industrial era (UNFCCC, 2007; IPCC, 2007). The decade of 2000s was the warmest decade with 2005 and 2010 being the warmest years in more than a century of global records (AMS, 2012). Trends in the maximum and minimum temperatures are useful indicators of climate variability and change (Braganza *et al*., 2004). Some of the previous studies on these key climate variability and trend indicators have also been conducted in Ethiopia by Conway (2000), NMA (2007), Osman and Sauerborn (2002), Conway *et al*. (2004), Bewket and Conway (2007), Cheung *et al*. (2008), McSweeney *et al*. (2008), Abtew *et al.* (2009), ACCRA (2012), Ayalew *et al*. (2012), Jury and Funk (2012), Taye and Zewdu (2012), Tesso *et al.* (2012). NMA (2007) reported an increment of 0.1%C per decade for maximum temperature and 0.25–0.37 %C per decade for the minimum temperature. Climate variation is a global concern (IPCC, 2014), and it detected in Ethiopia (NMA, 2006, McSweeney *et al*., 2008). Between 1951 and 2006, the annual minimum temperature in Ethiopia was increased by about 0.37°C per decade (NMA, 2006, Adem and Bewket, 2011).

The warming varied with seasons; the most rapid rate of change of 0.32 %C per decade found for summer (McSweeney *et al*., 2008). Smallholder subsistence farmers are among the worst hit by climate variability and change due to their low adaptive capacity and their dependence on rain-fed agriculture, which is very sensitive to the climate variability and change (Ifejika Speranza, 2010; Easterling, 2011). Ethiopia in general and the study area in particular, due to low adaptive capacity and high sensitivity of socio-economic systems, is one of the most vulnerable regions highly affected and to be affected by the impacts of climate variability and change. Climate variability and change is already imposing a significant challenge to Ethiopia by deterring the struggle to reduce poverty and sustainable development efforts (NMA, 2007). World Bank (2010) has ranked Ethiopia among the most vulnerable countries in the world to the adverse effects of climate variability and change; mainly due to its high dependence on rain-fed agriculture, low adaptive capacity and a higher reliance on natural resources base for livelihood, among others (NMA, 2007; World Bank, 2010; EPCC, 2015). In terms of livelihood, smallholder rain-fed subsistence farmers and pastoralists are considered to be the most vulnerable to climate variability and change and need interventions to adapt their livelihood systems to changing climatic conditions (NMA, 2007; EPCC, 2015).

Several studies have linked the climate variability over Ethiopia with the El Niño-Southern Oscillation (ENSO) phenomena (Seleshi and Zanke, 2004). Ethiopia is among the largest countries of Africa, and it is characterized by a wide variety of landscapes, with marked contrasts in relief and altitudes ranging from about 155 m below sea level of Assale Lake, in the Danakil depression, to about 4,533 m a.s.l. at Ras Dejen (EMA, 1988). Climate, in turn, has many obvious implications on landforms and morphodynamic evolution of natural landscapes as much as on the living conditions of local people, in a country whose economy is heavily dependent on rain-fed agriculture. The variability and trend analysis of temperature has received a great deal of attention recently because its accurate prediction determines the economic development and, adaptation and mitigation plan of the country to combat climate extremes. Several studies have carried out to investigate temperature trends across the country to know the spatial and temporal variability (Asfaw *et al.,* 2018; Degefu and Bewket, 2014; Dereje *et al.*, 2012; Girma *et al.,* 2016; Urgessa, 2013; Amogne *et al.,* 2018). Other studies also have investigated the variability and trends of temperature (including precipitation) in different areas of the country.

The value of doing this scientific study expected to be high, especially for countries like Ethiopia and specific areas like the study area, where economic development almost totally depends on rain-fed agriculture. The results of this analysis can significantly contribute to management decision-making and policy planning processes for different economic development sectors of the country and the study area with integrated climate. In particular, frankly speaking, the results of this study greatly contribute to deciding about sustaining agricultural production and productivity in the study area with adjusted strategies. This study mainly aimed to investigate the Spatio-temporal variability and trends of minimum, maximum and average temperature that prevailed over the northwestern parts of Ethiopia in the case of the study area.

Materials and Methods

The Study Area

This climatic study conducted at Horro Guduru Wollega Zone of Oromia National Regional State. The study area located in the northwestern part of Ethiopia. It has about 12 administrative woredas. It lies between Latitude 9°102 North and 9°502 North and Longitude 36°002 East and 36°502 East direction. However, the range of climatic envelope or coverage analyzed with this study was to the extent of Longitude 36.33° West and 37.9553° East direction and Latitude 9.021° South and 10.661° North direction. The study area has total land coverage of 8,097 km2 (Tamene and Megento, 2017). Shambu is the capital town of the study area (zone) and found at 314 km West of the capital city of Ethiopia, Addis Ababa. According to the report of CSA (2011), this zone has a total population of 641,575, of which 50.09% are male, and 49.91% are female. According to the same source, about 89% of the population lives in rural areas of the zone driving their livelihoods based on rain-fed Agriculture.

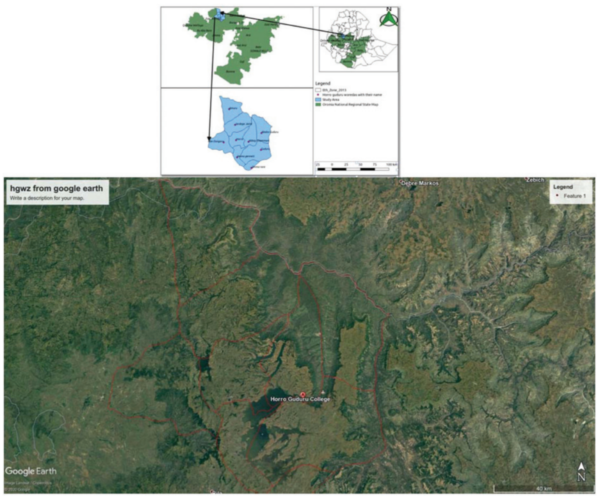


Fig1. Map of the study area

The average annual temperature in the study area is 22.1°C, with an average minimum of 13°C and an average maximum of 30°C (Beyene *et al.*, 2015). The average altitude of Horro Guduru Wollega Zone ranges from 860 to 2657 meters above sea level (Beyene *et al.*, 2015). Mixed crop-livestock agriculture is the leading agricultural system in the study area with notable food crops including wheat (Triticum aestivum), barley (Hordeum vulgare), teff (*Eragrostis tef*), maize (Zea mays), pulses (Vicia faba, Pisum sativum) and cash crops like sesame (Sesamum Orientale), niger (Guizotia abyssinica), and linseed (Linum usitatissimum) (CSA, 2014). Climatic seasons of the study area categorized into two class. These are three-monthly and four-monthly seasons. Three-monthly seasons include Winter or locally the Bega (December-January), Spring (March-May), Summer (June-August) and Autumn (September-November). Four-monthly seasons include locally known as Kiremt or Meher (primary rainy season) extending from June-to-September, and Belg (short rainy season extending from February-to-May and Bega (dry season) extending from October-to-January month (NMSA, 1996; Korecha and Barnston, 2007). The high amount and heavy rainfall during Summer season. Spring (locally known as Tseday) known season with occasional showers. Autumn (locally named Belg) season sometimes known as the harvest season or months. Winter (Bega) season is the driest season with sometimes frost in the morning, especially during January month. Summer and Kiremt seasons are the two climatic seasons with high and heavy rainfall.

Data Type and Sources

Observed temperature data for Spatio-temporal variability and time series trend analysis obtained from different sources. 4km by 4km resolution gridded daily minimum, maximum and average temperature data obtained from National Meteorological Agency (NMA) of Ethiopia. Daily average temperature data generated from the combined mean of daily minimum, maximum and average temperature dataset. Totally 24 meteorological stations under the NMA including those located in the extent and nearby to the border of the study area used as a source of time series rainfall dataset (daily) for the statistical analysis applied as presented in Table 1. The combined average of temperature dataset from 24 Ethiopian national meteorological stations used to represent the full extent of the studied climatic envelope or area. In contrast, minimum, maximum and average temperature dataset from individual station used for the statistical spatial analysis. Additionally, satellite observed minimum and maximum temperature data from GIS-based NASA powered data access viewer data accessed via an available public link.

Data Processing and Validation

Assumptions of normality, linearity and homogeneity of variance tested before the employment of the intended further data analysis. Observed minimum and maximum temperature dataset obtained from FDRE National Meteorological Agency (NMA) was validated with a comparison to the dataset from publically available online NASA powered data portal link for the period from 1987 to 2019. Observed minimum and maximum temperature at 2m

Table 1. List of 24 national meteorological stations with their altitudinal range

Station Name	Latitude	Longitude	Altitude
Agallo Mitti	9.68	36.33	2523
Alibo	9.88633	37.074	2513
Ayehu	10.661	36.793	1771
Birr Sheleko	10.5916	37.17163	1707
Combolcha	9.502333	37.472667	2341
Ehud Gebeya	9.21667	36.4333	2100
Fincha	9.57	37.37033	2248
Gebete	9.38383	37.4092	2287
Gedo	9.021	37.4575	2520
Gidayana	9.86667	36.61667	1850
Goben	9.1725	37.318666	2500
Hareto	9.35	37.12	2260
Haro	9.9	36.45	2200
Harodoyo	9.5568	37.9553	2532
Homi	9.621333	37.241167	2371
Ifabia	9.2682	37.1065	2387
Kachis e(Rs)	9.583333	37.86	2520
Kiramu	9.916667	36.8	2040
Kokeffe	9.983333	36.766667	1990
Kuy	10.3	37.594	1888
Neshi	9.72333	37.26833	2060
Sebader	10.65588	36.987	2057
Shambu	9.5712	37.121167	2460
Wadeyesus	10.52925	37.3501	2013

dataset from online source pre-processed by using Python3 general-purpose programming language to prepare it for further statistical analysis. Different statistical tests were applied to check for the stationarity (using rolling statistics plottings and employing of augmented dicky_fuller test), the significance of the difference among datasets tested using paired independent t_test with P-value. Linearity and degree of linkage between datasets were tested by conducting correlation analysis (computing r-value) and scatter plottings of all variables. Homogeneity of variance testing applied using the standard deviation ratio test and hypothesis testing method (Paired independent sample T-test).

Statistical Data Analysis

All statistical analysis was employed using Python3 integrated into Jupyter notebook platform implementing the functionality of Python3 multiple codes, built-in and external and user-defined functions, modules, packages and libraries. Observed minimum, maximum and the average temperature at 2m dataset was analyzed and interpreted on the temporal scale of monthly, seasonal, annual, decadal, and 30 years period basis. Even though Ethiopia in general and the study area, in particular, has three main seasons but in this study, the seasonal analysis applied to four three-monthly seasons and three four-monthly seasons separately. The four three-monthly seasons tough winter or locally Bega (December-February), spring (March-May), summer (June-August) and autumn (September-November). The three four-monthly seasons involved Kiremt or Meher (main rainy season) extending from June-to-September, and Belg, short rainy season extending from February-to-May; and Bega (dry season) extending from October-to-January month (NMSA, 1996; Korecha and Barnston, 2007). Several techniques have developed for the analysis of temperature, which generally falls into variability and time series trend analysis. Total, average (mean), minimum, maximum, Coefficient of Variation (CV %), slope (m) and P computed statistical values used for the interpretation of the Spatio-temporal variability and trend analysis results. These values also computed for the time series observed minimum, maximum and average temperature dataset at each NMA station to describe and investigate the spatial variation based on temporal time scales. One-way ANOVA with type II error was employed to test the significance of difference among considered time scales and stations. Variability analysis involves the use of the Coefficient of Variation (CV). CV calculated to evaluate the variability of the temperature. A higher value of CV is the indicator of larger variability, and vice versa, which computed as:

$$CV = \sigma/\mu * 100$$

Where CV is the coefficient of variation; ó is the standard deviation, and μ is the mean minimum, maximum and average temperature. According to Hare (2003), CV used to classify the degree of variability of minimum, maximum and average temperature events as less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$). Trend detection and analysis performed through applying parametric test method. Linear regression analysis performed to detect the Spatio-temporal trend of observed minimum, maximum and average temperature prevailed over the study area. The linear regression model developed using the functionality of the scikit-learn library of Python3 programming language. Scikit-learn is a widely used Python3 library for machine learning, built on the top of Numpy and some other packages. Like other packages of advanced Python3 programming, Scikit-learn is an open-source package. However, to use its functionality first Python with the version of choice (1.x.., 2.x.., 3.x.., 4.x.) should be installed on any computer platform (Windows, Linux/Ubuntu, Macintosh, Debian, other OSs). Other strong Python libraries such as Statsmodels, etc. can be utilized to perform any regression modelling to develop an equation that determines dependent variables from independent variable/s considered. Time series trend detection performed using the following Python3 codes and procedural steps:

Step 1. Validation of data sets for regression analysis

Step 2. Calling of the linear regression model and; modules and functions for their functionalities

```
import pandas as pd
import NumPy as np
import matplotlib.pyplot as plt
import sklearn
from sklearn import linear_model
import seaborn as sns
from sklearn.linear_model import LinearRegression
```

Step 3. calling of function to split the data to train the model and testing

```
from sklearn.model_selection import train_test_split
```

Step 4. splitting of the data of independent (time) and dependent variable (min., max. And average temperature)

```
x_train, x_test, y_train, y_test= train_test_split(x,y, random_state =1)
```

Step 5. Assigning of the model for prediction

```
linreg = LinearRegression()
```

Step 6. Fitting of the model to the data sets (time and temperature)

```
linreg.fit(x_train, y_train)
```

After fitting the model to variables with Scikit-learn, again, we fitted the OLS model to the data using statsmodels. The main benefit of statsmodels is the other statistics it provides rather than coefficients. The coefficient of regression and intercept of the trend line computed of Scikit-learn. Statsmodels also helps us to determine which of our variables are statistically significant through the p-values. The following codes used:

```
import statsmodels.api as sm
model = sm.OLS(y, x)
results = model.fit()
print(results.summary())
```

Step 7. Predicting the dependent variable (minimum, maximum and average temperature) from the independent variable (time)

```
y_pred = linreg.predict (x_test (time))
```

Step 8. Computation of regression coefficient (slope of regression line) and intercept points

```
print (linreg.coef_)
print (linreg.intercept_)
```

Step 9. Formulation of regression model function

y = MX + b; where y is minimum, maximum and average temperature variable (dependent) m is regression coefficient (slope), x is time variable (independent) and b is the intercept point indicating the point where the regression trend line touch or cross the y-axis.

Step 10. Validating robustness or prediction performance of the model using R-squared value and P-value for trend significance testing from sklearn.metrics import r2_score

```
r2_score(y_test, y_pred)
```

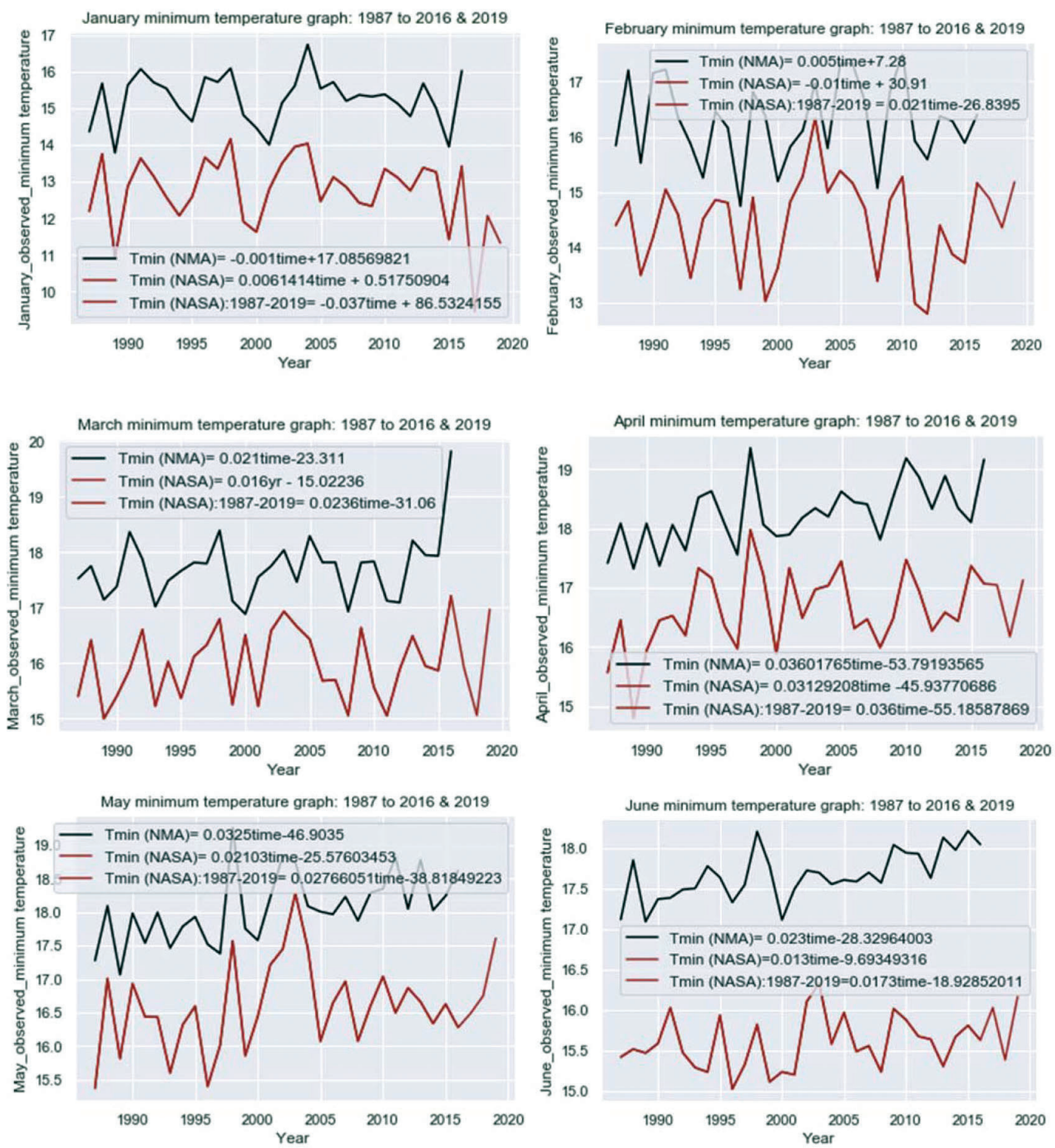
Step 11. Generating of graphical trend line plots of the regression association between all temperature variables and series of time using the Python3 codes:

```
Importing of Python3 libraries for use
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
Loading of data sets for plotting
file = pd.read_csv ()
Sheet = file.parse()
Assigning of x and y axis
X-axis= np.array()
Y-axis= np.array()
Labeling of plot axis and printing of plot output
plt.xlabel()
plt.ylabel()
plt.title()
plt.legend()
plt.show()
```

Results

Observed minimum temperature

The minimum temperature dataset was analyzed under this study at different time scales using NMA and NASA minimum temperature at 2m datasets. There was non-significant difference among the months of the year 1987 to 2016 and 1987 to 2019 with P-value of 0.421 and 0.08 for months of former and latter period, respectively (Appendix 2). The monthly time scale analysis showed that the mean minimum temperature observed over the period 1987 to 2016 (30 years) and 1987 to 2019 (33 years) was relatively maximum during April and May months of the two periods (Appendix 2). The lowest monthly minimum temperature observed during the January month of the two periods. In contrast, the highest minimum temperature over 30 years observed during March and May months of 33 year periods of time (Appendix 2). Less variable (CV < 20%) minimum temperature recorded over all months of the two periods. Time series trend observed minimum temperature over the two periods is presented below by Fig 2. The monthly minimum temperature trend analysis results revealed that the trend of minimum temperature observed during almost all months over both 30 (1987-2016) and 33 years (1987-2019) periods was increasing (Fig 2). The brown line in the legend represents the time series trend of observed monthly minimum temperature analyzed using NMA monthly minimum temperature datasets. Redline in the legend indicates the minimum temperature trend over the month (equal to the brown line in length up to 2016) estimated from NASA monthly minimum temperature datasets. The second red-line in the legend extending from the year 2016 to 2019 indicates trend



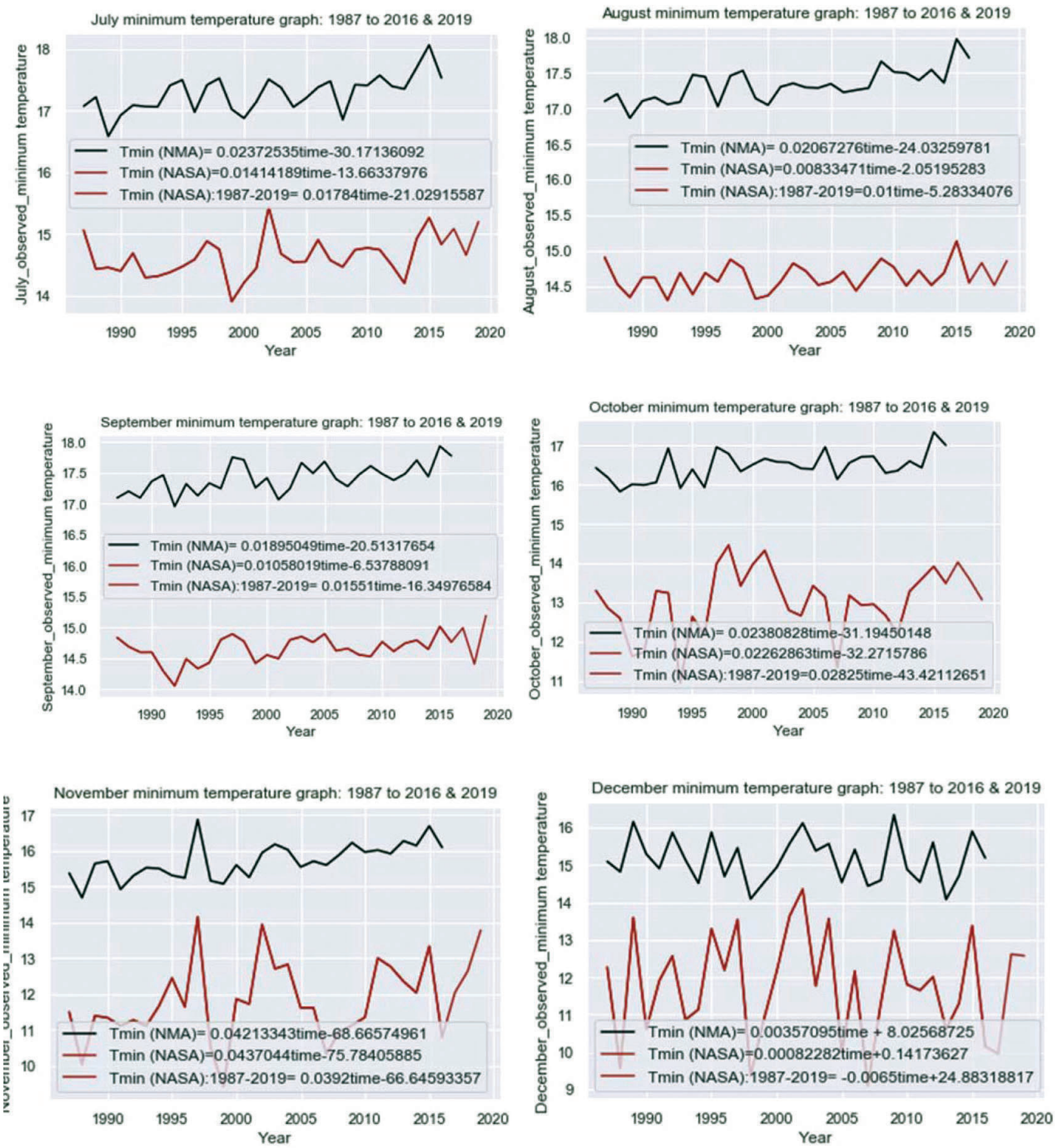


Fig. 2. Graphical representation of time series trends of observed monthly minimum temperature over the study area during the period 1987 to 2016 and 1987 to 2019.

of minimum temperature over the periods up to 2019.

The spatial features of monthly minimum temperature observed over the period 1987 to 2016 (30 years) are presented below with Table 2. The variation between stations regarding average monthly minimum temperature estimated to be non-significant during all months of the year starting from 1987 to 2016 (Table 2). During all remaining months of the year 1987 to 2016, the maximum, minimum temperature recorded at the Goben area or station. In contrast, Kuy found to be an area with the least minimum temperature (Table 2).

The spring season average minimum temperature prevailed over the 30 and 33 years period found to be relatively the highest but winter season observed minimum temperature was the lowest record (Appendix 1). Spring was the season with the maximum, minimum temperature, but that of winter season found to be the lowest one over the two periods (Appendix 1). The minimum temperature was increasing over the winter, spring, summer and

Table 2. Observed monthly average minimum temperature at 24 meteorological stations over the period of 1987 to 2016

Month	Min.	Max.	Mean	std	CV%	Sign.
Jan.	7.071 kuy	24.51Goben	15.3	4.9	32.1	0.3334
Feb.	8.1311 kuy	25.8021Goben	16.3	4.951403	30.442	0.33142
March	9.4kuy	27.3Goben	17.72	4.99	28.2	0.342
April	9.69kuy	27.273Goben	18.244	4.9136	26.93312	0.35
May	9.82kuy	24.81Goben	18.05743	4.5482	25.1872	0.39774
June	9.9434kuy	23.0778Goben	17.66627	4.5397	25.697	0.46547
July	10.04Alibo	22.7115Homi	17.274	4.33013	25.07	0.428852
Aug.	10.063kuy	22.7011Ehud Gebeya	17.32535	4.376	25.255	0.4191
Sept.	9.224kuy	23.088Goben	17.41352	4.62512	26.5605	0.434655
Oct.	7.1044kuy	23.16Goben	16.46857	4.777937	29.01247	0.37151
Nov.	5.962kuy	24.3641Goben	15.71133	5.2003	33.099	0.318994
Dec.	6.1639kuy	24.8744Goben	15.1381	5.262	34.75687	0.314423

autumn season of the periods of 30 and 33 years (Fig 3). There was a non-significant difference ($P>0.05$) among the 24 meteorological stations during the winter, spring, summer and autumn season regarding the observed minimum temperature (Table 3). The brown line in the legend represents the time series trend of observed seasonal minimum temperature analyzed using NMA minimum temperature datasets. Redline in the legend indicates the minimum temperature trend over the winter, spring, summer and autumn season (equal to the brown line in length up to 2016) estimated from NASA minimum temperature datasets. The red trend line in the legend extending from 2016 to 2019 indicates the trend of the winter, spring, summer and autumn minimum temperature over the periods up to 2019 (Fig.3). Belg (short rainy season) season observed average minimum temperature was the highest whereas Bega (dry season) season average minimum temperature found the lowest over the period 1987 to 2016 and 1987 to 2019 (Appendix 1). Belg, Kiremt and Bega minimum temperature spatial features over the period 1987 to 2016 (30 years) is presented below with Fig. 4, respectively. Times series trends of Belg, Kiremt and Bega season minimum temperature over the two periods shown by Fig. 4. The brown line in the legend represents the time series trend of observed seasonal minimum temperature analyzed using NMA minimum temperature datasets. Redline in the legend indicates the minimum temperature trend over the Belg, Kiremt and Bega season (equal to the brown line in length up to 2016) estimated from NASA minimum temperature datasets. The red trend line in the legend extending from 2016 to 2019 indicates the trend of Belg, Kiremt and Bega minimum temperature over the periods up to 2019 (Fig.4).

During the period 1987 to 2016, the mean annual minimum temperature of 16.9 oC was observed (Appendix 1). The less variable minimum temperature observed over the period with the lowest record of 16.341 °C and the highest minimum temperature of 17.45 °C as indicated in Appendix 1. Similarly, the less variable minimum temperature observed over the period 1987 to 2019, which was averagely 14.4 °C as understood from results of statistical analysis applied to NASA minimum temperature dataset over the stated period. The highest mean minimum temperature observed during the third decadal years (2007-2016), whereas the lowest

Table 3. Observed winter, spring, summer, autumn, *belg*, *Kiremt* and *bega* average minimum temperature at 24 meteorological stations over the period of 1987 to 2016

Season	Min.	Max.	Mean	Stdev	CV%	Sign.
Winter(DJF)	8.1829kuy	25.8079Goben	16.34213	4.93672	30.20855	0.33368
Spring(MAM)	9.8167kuy	25.0501Goben	17.9899	4.61365	25.646	0.39519
Summer(JJA)	9.8351kuy	22.7108Goben	17.337	4.4369	25.593	0.427058
Autumn(SON)	6.415kuy	24.1294Goben	15.77333	5.03674	31.932	0.329386
Belg (FMAM)	9.2705kuy	26.3Goben	17.5954	4.78338	27.18542	0.347321
Kiremt (JJAS)	9.8618kuy	22.8010Goben	17.4177	4.46086	25.61107	0.43637
Bega (ONDJ)	6.5803Kuy	24.225Goben	15.64568	4.98339	31.85155	0.328579

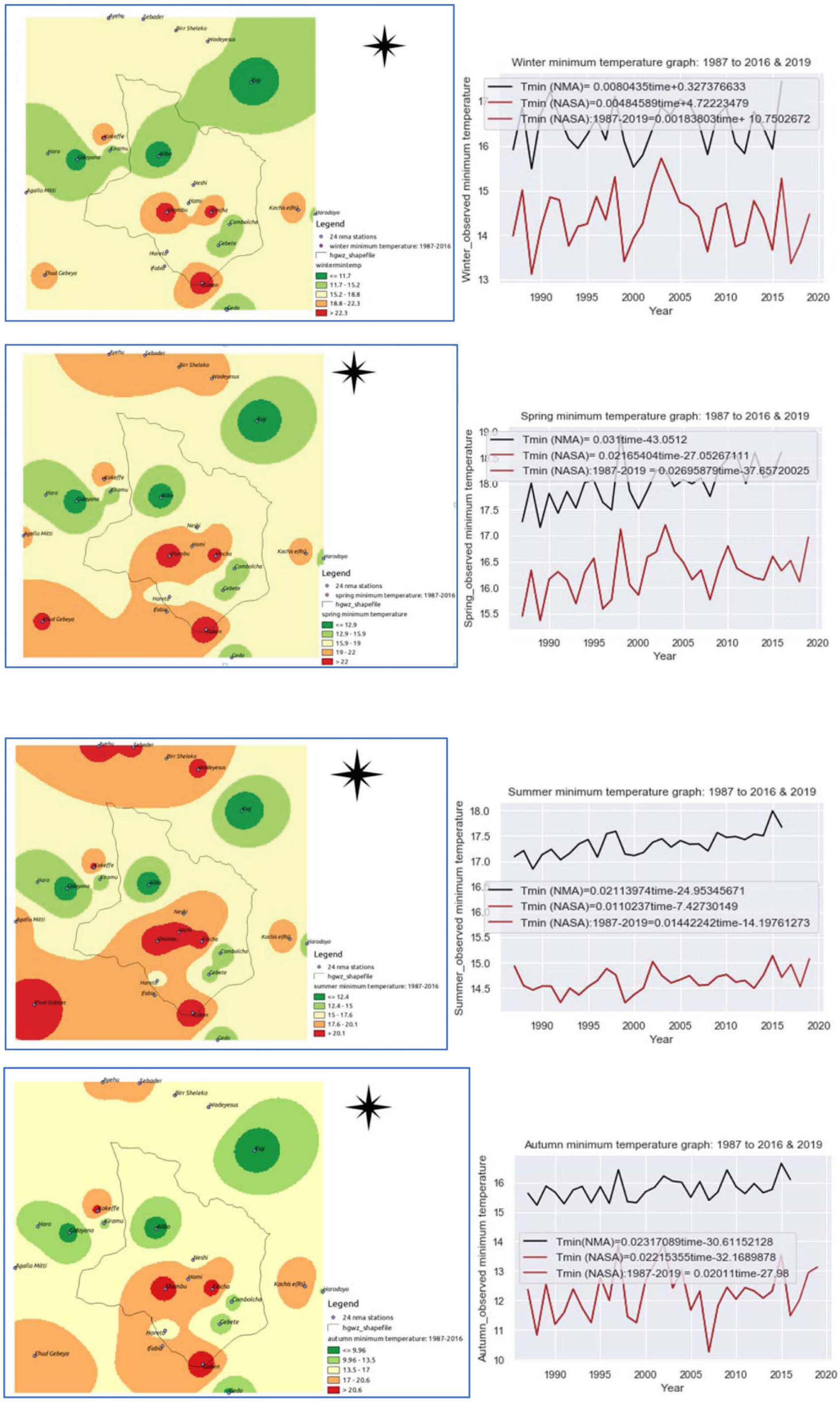


Fig. 3. Winter, spring, summer and autumn observed average minimum temperature spatial features and time series trend over the periods of the last 30 and 33 years.

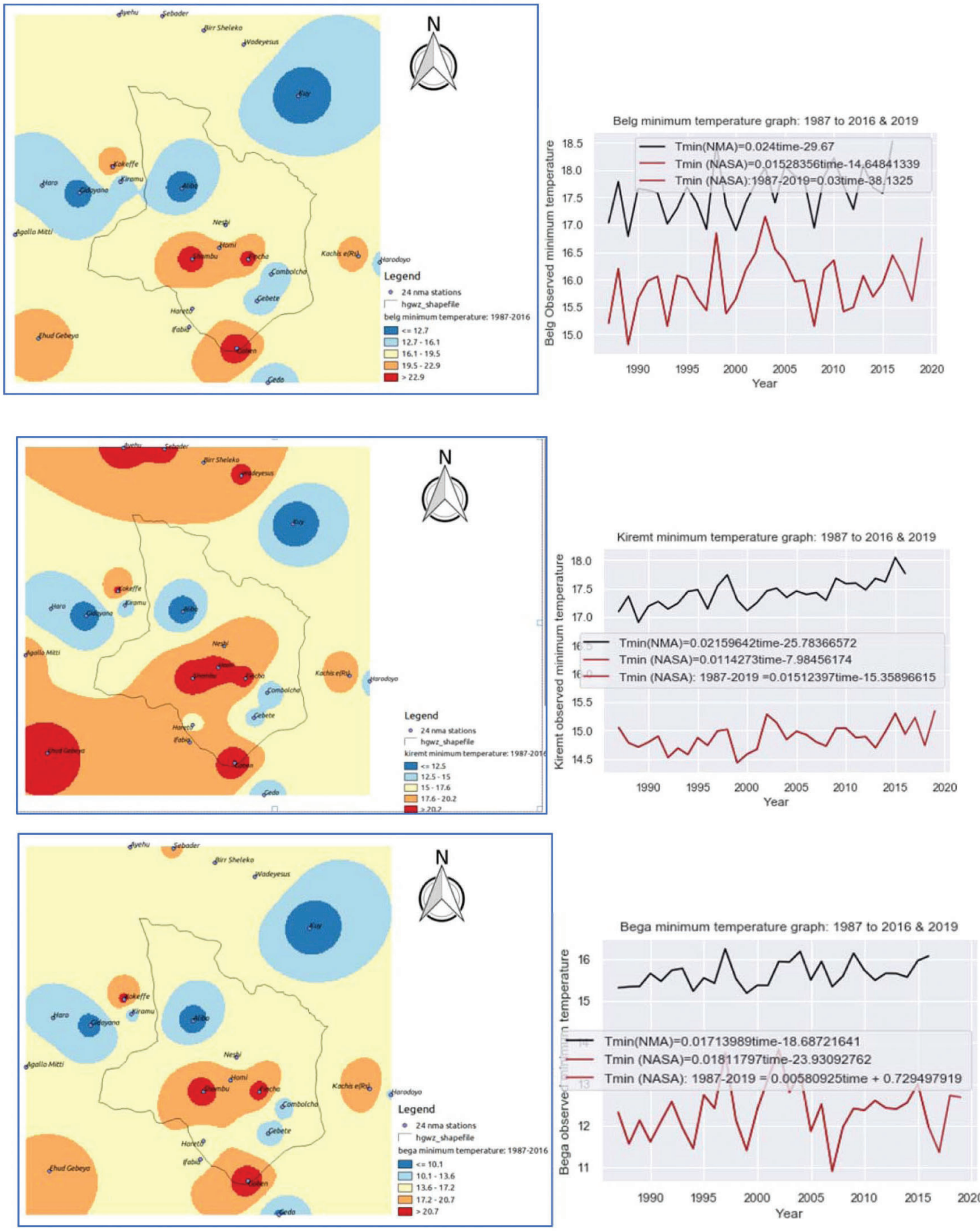


Fig. 4. The *Belg, Kiremt* and *Bega* minimum temperature spatial features and time series trends

observed during the first decadal years (1987-1996) (Appendix 1). The brown line in the legend represents the time series trend of observed seasonal minimum temperature analyzed using NMA annual and decadal minimum temperature datasets. Redline in the legend indicates the yearly and decadal minimum temperature trend (equal to the brown line in length up to 2016) estimated from NASA minimum temperature datasets (Fig. 5). The statistical analysis applied to annual and decadal observed minimum temperature throughout 1987 to 2016 (30 years) showed that Kuy is the area or sta-

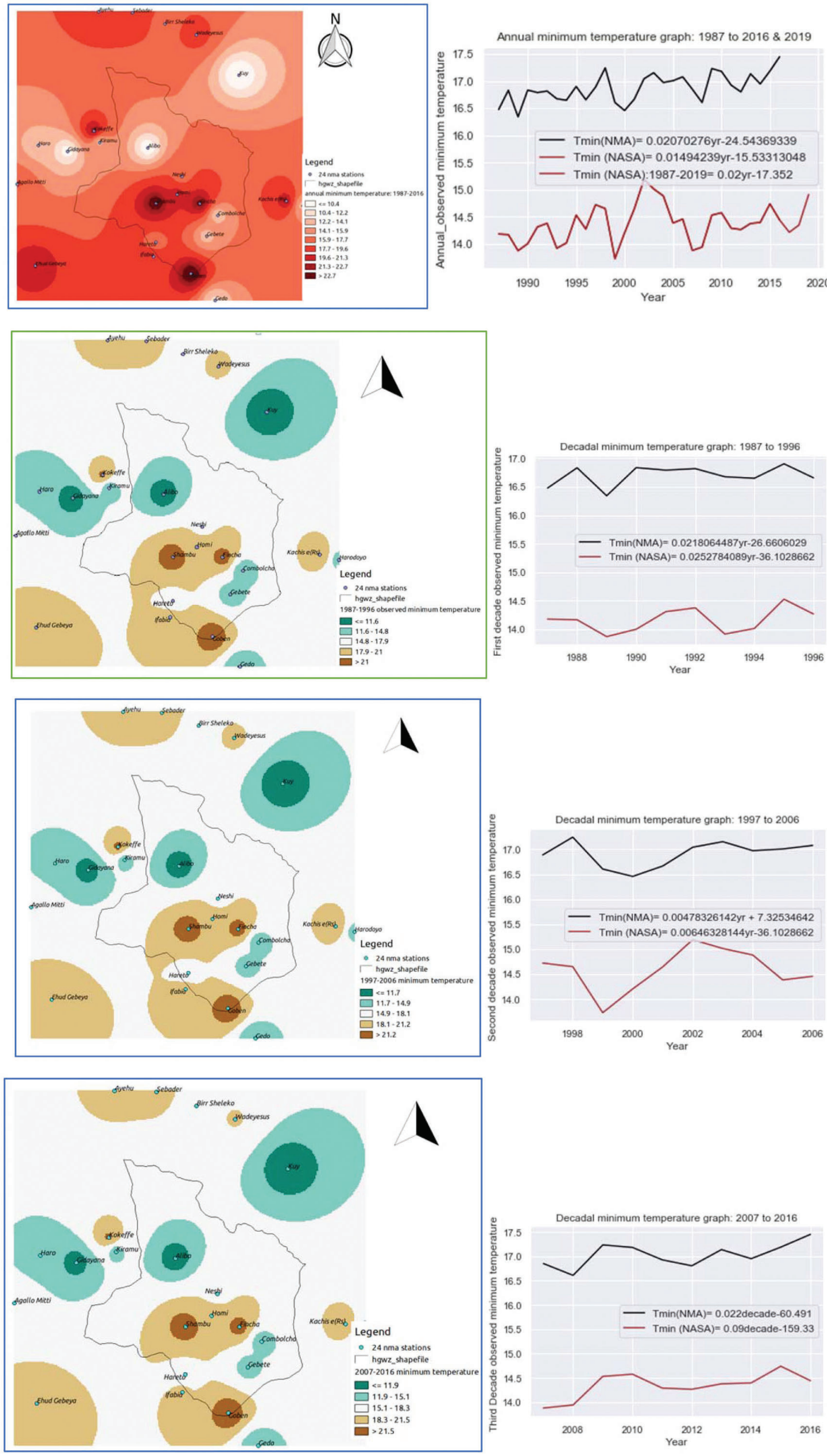


Fig 5. Annual and decadal minimum temperature spatial features and time series trends.

tion with the least minimum temperature whereas, Goben is the area or station with the highest observed minimum temperature (Table 4). The results showed that there was statistically non-significant variation in observed annual and the three consecutive decades minimum temperature among the 24 meteorological stations (P>0.05, Table 4).

Observed maximum temperature

Significantly different monthly maximum temperature was observed over the period from 1987 to 2016 (P-value = 0.02675) and 1987 to 2019 (P-value = 0.0195). Thirty years (1987-2016) monthly maximum temperature descriptive analysis applied to NMA dataset resulted in the highest mean maximum temperature recorded during March. February month of this time range found to be the second time with the highest average maximum temperature observed. Descriptive statistical analysis employed to the NASA maximum temperature dataset for the period 1987 to 2019 (33 years) produced similar results to that of the period 1987 to 2016 which indicate that the highest mean maximum temperature prevailed during the March month of the later period (33 years). The highest maximum temperature observed during the March month of the 30 years ranging from 1987 to 2016 (34.456317 °C) (Appendix 2). May month was the time when the highest maximum temperature recorded over the period from 1987 to 2019 (33.830484 °C) (Appendix 2). Similar to the observed monthly minimum temperature, less variable (CV<20%) monthly maximum temperature observed over all months of the 30 and 33 years period (Appendix 2). Spatial features and time series trend of observed mean maximum temperature presented below by a Fig 6. The red line in the legend represents the time series trend of observed monthly maximum temperature analyzed using

Appendix 1. Basicstatistics of observed monthly, three-monthly, four-monthly, annual, decadal and 30-years minimum temperature for the period 1987 to 2016 and 1987 to 2019

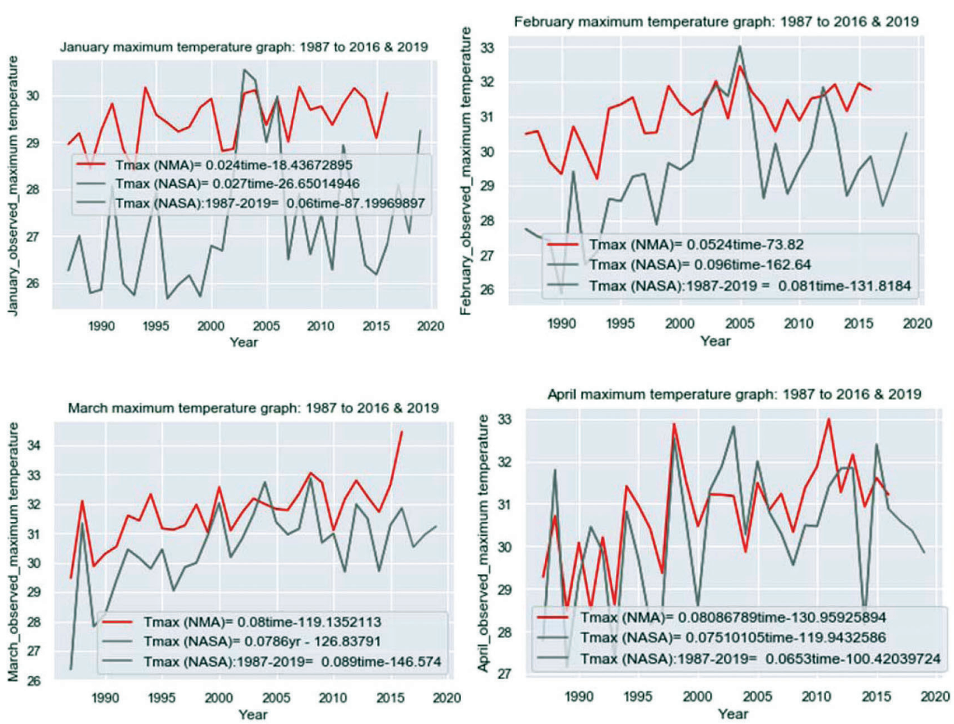
Month	1987 to 2016 (30 years)					1987 to 2019 (33 years)				
	Minimum Temperature					Minimum Temperature				
	Mean	Std	Min	Max	CV	Mean	Std	Min	Max	CV
Jan.	15.3	0.69	13.8	16.7	4.52	12.7	1.0	9.44	14.2	7.91
Feb.	16.3	0.73	14.8	17.5	4.51	14.4	0.8	12.8	16.3	5.77
Mar.	17.7	0.58	16.9	19.8	3.26	15.9	0.6	14.9	17.2	4.05
Apr.	18.2	0.53	17.3	19.4	2.89	16.6	0.7	14.8	17.9	3.92
May	18.1	0.51	17.1	19.3	2.84	16.6	0.7	15.4	18.3	3.94
June	17.7	0.31	17.1	18.2	1.74	15.6	0.3	15.0	16.0	2.14
July	17.3	0.30	16.6	18.1	1.74	14.6	0.3	13.9	15.4	2.26
Aug.	17.3	0.23	16.9	17.9	1.36	14.6	0.2	14.3	15.1	1.32
Sept.	17.4	0.24	16.9	17.9	1.37	14.7	0.2	14.1	15.2	1.57
Oct.	16.5	0.37	15.8	17.3	2.24	13.0	0.8	10.9	14.5	6.36
Nov.	15.7	0.49	14.7	16.9	3.17	11.8	1.1	9.41	14.2	9.35
Dec.	15.1	0.62	14.1	16.3	4.08	11.8	1.4	9.09	14.3	11.8
P_value	0.42					0.08				
Winter	15.6	0.39	14.9	16.2	2.54	12.9	0.7	11.4	14.4	5.01
Spring	18.0	0.45	17.2	19.2	2.52	16.4	0.5	15.2	17.4	3.07
Summer	17.4	0.26	16.8	18.1	1.52	14.9	0.2	14.4	15.5	1.65
Autumn	16.5	0.32	16.0	17.3	1.92	13.2	0.5	12.1	14.3	4.07
P_value	0.67					0.37				
Belg	17.6	0.5	16.8	18.5	2.60	15.9	0.5	14.8	17.2	3.33
Kiremt	17.4	0.24	16.9	18.1	1.38	14.9	0.2	14.4	15.3	1.51
Bega	15.7	0.3	15.2	16.3	1.9	12.3	0.7	10.9	13.8	6.85
P_value	0.28					0.15				
Annual	16.9	0.3	16.3	17.4	1.6	14.4	0.4	13.7	15.2	2.42
1987-1996	16.7	0.2	16.3	16.9	1.1	14.2	0.2	13.9	14.5	1.5
1997-2006	16.9	0.3	16.5	17.2	1.51	14.6	0.4	13.7	15.2	2.9
2007-2016	17.0	0.25	16.6	17.5	1.5	14.3	0.3	13.9	14.7	1.9
P_value	0.10					0.77				
1987-2016	16.9	0.3	16.341	17.45	1.6	14.4	0.35	13.73	15.2	2.44

NMA monthly maximum temperature datasets. The first brown line in the legend indicates the monthly maximum temperature trend over the months (equal to the brown line in length up to 2016) estimated from NASA monthly maximum temperature datasets. The second brown line in the legend extending from 2016 to 2019 indicates the trend of monthly maximum temperature over the periods up to 2019 (Fig. 6).

There were statistically non-significant differences (P>0.05) among the three monthly seasons (winter, spring, summer and autumn) and four monthly seasons (Belg, Kiremt and Bega) over the periods of 30 and 33 years as indicated in Appendix 2. Relatively the seasonal (three-monthly seasons) mean maximum temperature observed during the spring season (MAM maximum temperature) of the last 30 (30.732497°C) and 33 years (29.713636°C) are the highest records as indicated in Appendix 2. The Belg, Kiremt and Bega maximum temperature analysis showed that the highest mean maximum temperature observed during the Belg (short rainy season) season of the two periods when compared to Kiremt (long rainy season) and Bega (dry season) (Appendix 2). Further, the analysis results revealed that there were non-significant differences (P > 0.05) among the 24 meteorological stations concerning the records of maximum temperature during all three-monthly and four-monthly seasons of the year from 1987 to 2016 (30 years) (Table 6). The spatial analysis applied to Winter, Spring, Summer, Autumn, Belg, Kiremt and Bega seasons' maximum temperature resulted in features indicated by Fig 7, which processed (interpolated) from the time series points' records and projected by using QGIS version 3.4.8. Time-series trends of observed maximum temperature during both the three-and four-monthly seasons as presented by Fig. 7, with the spatial fea-

Table 4. Annual and decadal observed minimum temperature at 24 NMA meteorological stations over the period of 1987 to 2016

Time	Min.	Max.	Mean	Stdev	CV%	Sign.
Annual	8.5622kuy	24.43072Goben	16.88	4.66315	27.63	0.358735
1987-1996	8.5231kuy	24.14361Goben	16.6962	4.681	28.036	0.352212
1997-2006	8.5005kuy	24.4263Goben	16.91212	4.71712	27.892	0.3532
2007-2016	8.663kuy	24.72185Goben	17.0302	4.59764	26.997	0.372



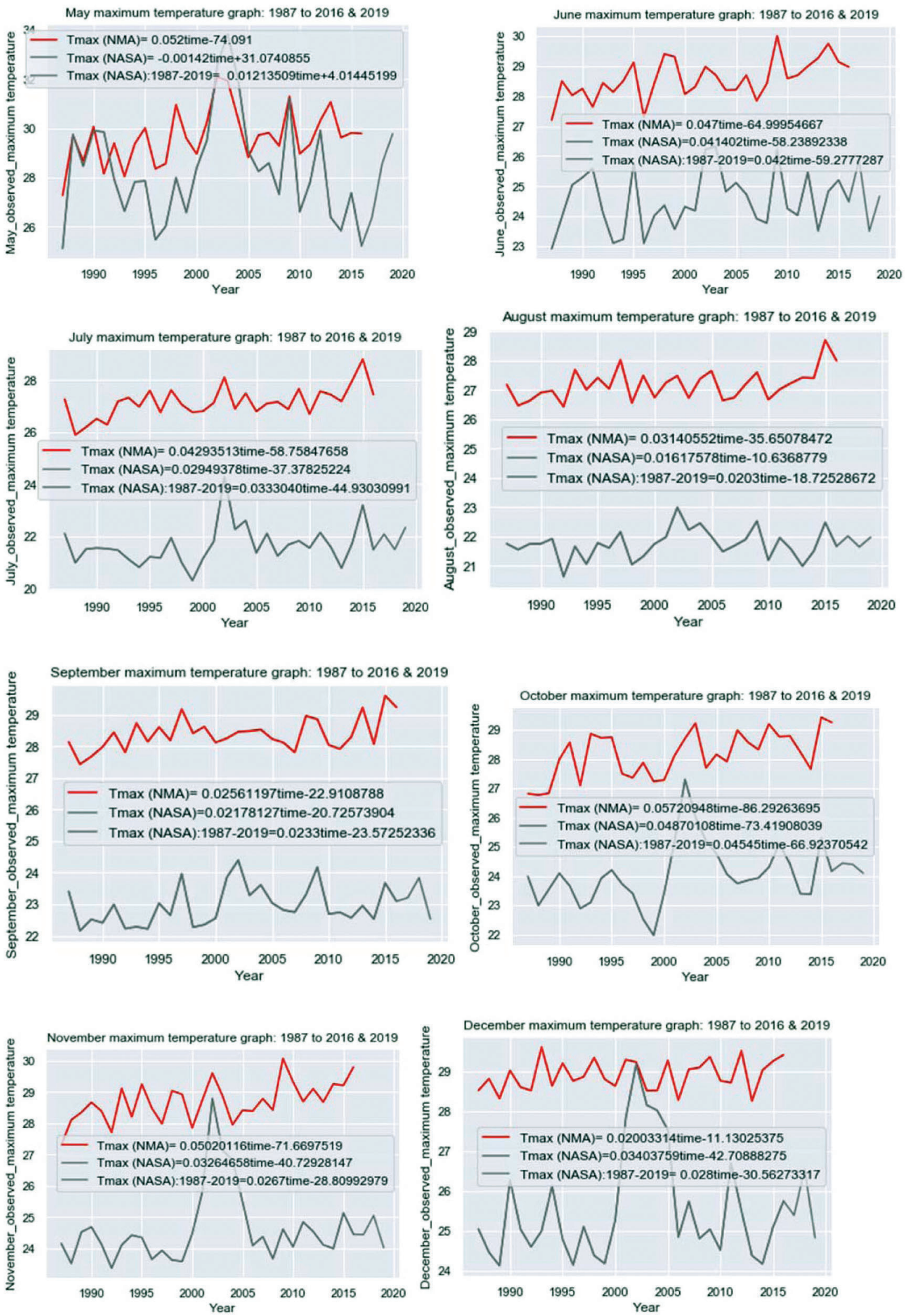


Fig. 6. Time series trend line graph of mean monthly maximum temperature

tures of the observed maximum temperature.

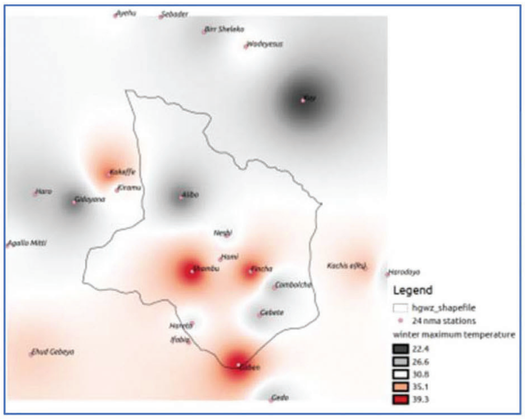
Observed time series mean maximum temperature during all seasons of the two indicated periods was varying with a very low rate and narrow range (Appendix 3). The CV (%) values for all seasons of the two periods are less than 5% which is less than 20% indicating the less variability (intra-season variability) of mean maximum temperature during the winter, spring, summer and autumn seasons over the two periods (Appendix 2). Belg, Kiremt and Bega season maximum temperature has been varying in a similar mode when compared to the winter, spring, summer and autumn seasons, i.e. less variability (CV < 20%, Appendix 2). On an annual basis,

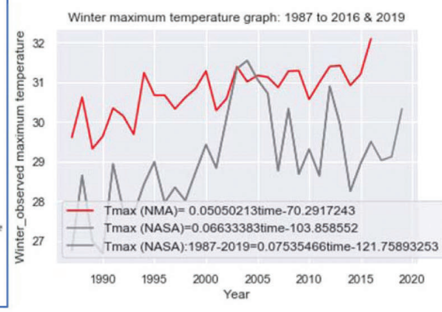
Appendix 2. Basic statistics of observed monthly, three-monthly, four-monthly, annual, decadal and 30-years maximum temperature for the period 1987 to 2016 and 1987 to 2019

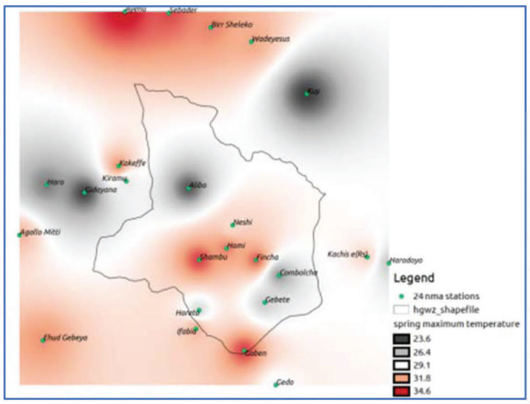
Month	1987 to 2016 (30 years)					1987 to 2019 (33 years)				
	Maximum Temperature					Maximum Temperature				
	Mean	Std	Min	Max	CV%	Mean	Std	Min	Max	CV%
Monthly										
Jan.	29.5	0.52	28.4	30.2	1.77	27.3	1.4	25.7	30.5	5.12
Feb	31.1	0.79	29.2	32.4	2.55	29.4	1.61	25.9	33.0	5.48
Mar	31.8	0.99	29.5	34.5	3.14	30.5	1.35	26.4	32.9	4.43
Apr.	30.8	1.14	28.5	32.9	3.7	30.3	1.53	27.2	32.8	5.04
May	29.7	1.11	27.3	32.1	3.74	28.3	2.12	25.1	33.8	7.47
Jun	28.6	0.66	27.2	30.0	2.29	24.5	0.97	22.9	26.3	3.94
July	27.1	0.59	25.9	28.8	2.17	21.7	0.74	20.3	24.3	3.42
Aug.	27.2	0.52	26.4	28.7	1.91	21.8	0.48	20.6	22.9	2.22
Sep.	28.4	0.50	27.4	29.6	1.78	22.9	0.61	22.2	24.4	2.67
Oct.	28.2	0.79	26.8	29.4	2.82	24.1	1.02	21.9	27.3	4.24
Nov.	28.7	0.63	27.3	30.1	2.20	24.6	1.13	23.4	28.8	4.6
Dec.	28.9	0.39	28.3	29.6	1.34	25.5	1.32	24.1	29.2	5.19
P-value	0.03					0.02				
Winter	29.8	0.39	28.8	30.4	1.32	27.4	1.22	25.8	30.2	4.46
Spring	30.7	0.88	28.7	31.9	2.87	29.7	1.3	26.4	32.8	4.39
Summer	27.6	0.47	26.9	28.9	1.72	22.7	0.62	21.7	24.5	2.75
Autumn	28.4	0.53	27.4	29.4	1.86	23.9	0.84	22.6	26.8	3.53
P-value	0.19					0.23				
Belg	30.8	0.80	29.1	31.8	2.6	29.6	1.26	26.7	32.6	4.3
Summer	27.8	0.5	27.1	29.1	1.63	22.7	0.6	21.8	24.5	2.53
Bega	28.8	0.42	27.9	29.6	1.46	27.4	1.05	23.9	28.4	11.0
P-value	0.55					0.79				
Annual	29.2	0.5	28.1	29.9	1.63	25.9	0.9	24.7	28.2	3.3
1987-1996	28.7	0.41	28.1	29.4	1.42	25.2	0.46	24.7	25.9	1.82
1997-2006	29.2	0.3	28.9	29.6	0.9	26.5	1.2	25.0	28.2	4.4
2007-2016	29.5	0.31	29.2	29.9	1.1	25.9	0.5	25.1	26.7	1.8
P-value	0.09					0.64				
1987-2016	29.2	0.5	28.1	29.9	1.7	25.9	0.9	24.7	28.2	3.5

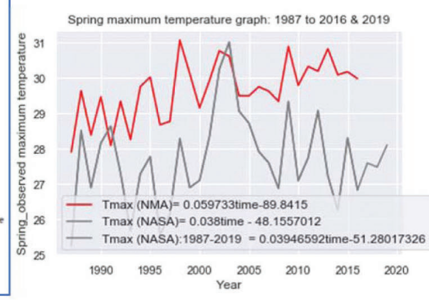
Table 6. Three-and four-monthly observed maximum temperature at 24 meteorological stations over the period of 1987 to 2016

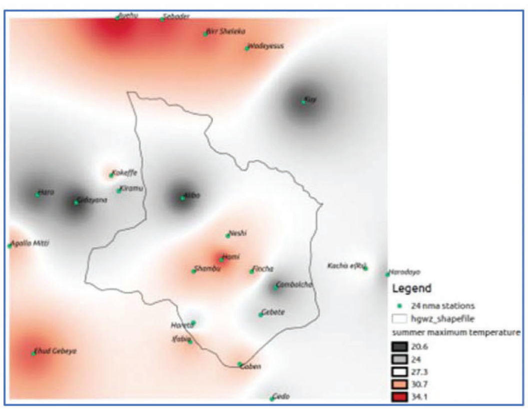
Season	Min.	Max.	Mean	Std	CV%	Sign.
Winter	22.4151 Kuy	39.28268 Shambu	30.61531	4.3541	14.22184	0.325486
Spring	23.6151 Kuy	34.57337 Ayehu	29.671	3.396337	11.447	0.599233
Summer	20.6196 Gidayanaa	34.07453 Ayehu	27.56177	4.109427	14.9099	0.695662
Autumn	21.22101 Kuy	34.31674 Shambu	28.59	3.458504	12.0986	0.41972
Belg	23.064 Kuy	37.953 Shambu	30.808	3.913787	12.7039	0.390502
Kiremt	21.0599 Gidayana	34.4397 Ayehu	27.8091	4.026654	14.47964	0.735462
Bega	21.4091 Kuy	35.2934 Shambu	28.8114	3.57771	12.41769	0.376325

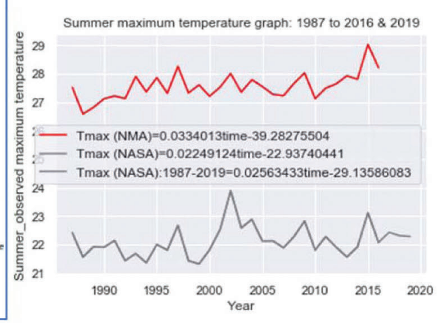

Legend
hgwz_shapefile
24 nma stations
winter maximum temperature
22.4
26.6
30.8
35.1
39.3

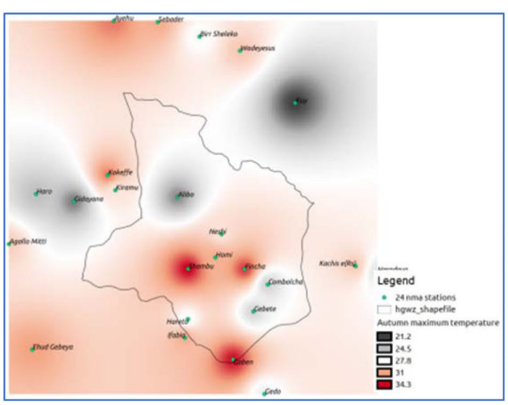

Winter maximum temperature graph: 1987 to 2016 & 2019
Winter_observed maximum temperature
Tmax (NMA)= 0.05050213time-70.2917243
Tmax (NASA)=0.06633383time-103.858552
Tmax (NASA):1987-2019=0.07535466time-121.75893253
Year

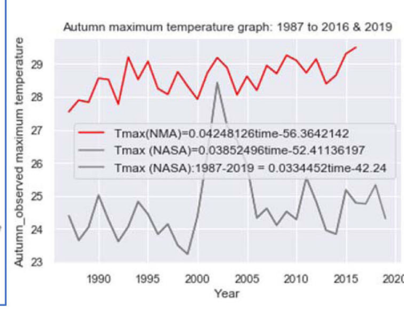

Legend
24 nma stations
hgwz_shapefile
spring maximum temperature
23.6
26.4
29.1
31.8
34.6


Spring maximum temperature graph: 1987 to 2016 & 2019
Spring_observed maximum temperature
Tmax (NMA)= 0.059733time-89.8415
Tmax (NASA)= 0.038time - 48.1557012
Tmax (NASA):1987-2019 = 0.03946592time-51.28017326
Year


Legend
24 nma stations
hgwz_shapefile
summer maximum temperature
20.6
24
27.3
30.7
34.1


Summer maximum temperature graph: 1987 to 2016 & 2019
Summer_observed maximum temperature
Tmax (NMA)=0.0334013time-39.28275504
Tmax (NASA)=0.02249124time-22.93740441
Tmax (NASA):1987-2019=0.02563433time-29.13586083
Year


Legend
24 nma stations
hgwz_shapefile
Autumn maximum temperature
21.2
24.5
27.8
31
34.3


Autumn maximum temperature graph: 1987 to 2016 & 2019
Autumn_observed maximum temperature
Tmax(NMA)=0.04248126time-56.3642142
Tmax (NASA)=0.03852496time-52.41136197
Tmax (NASA):1987-2019 = 0.0334452time-42.24
Year

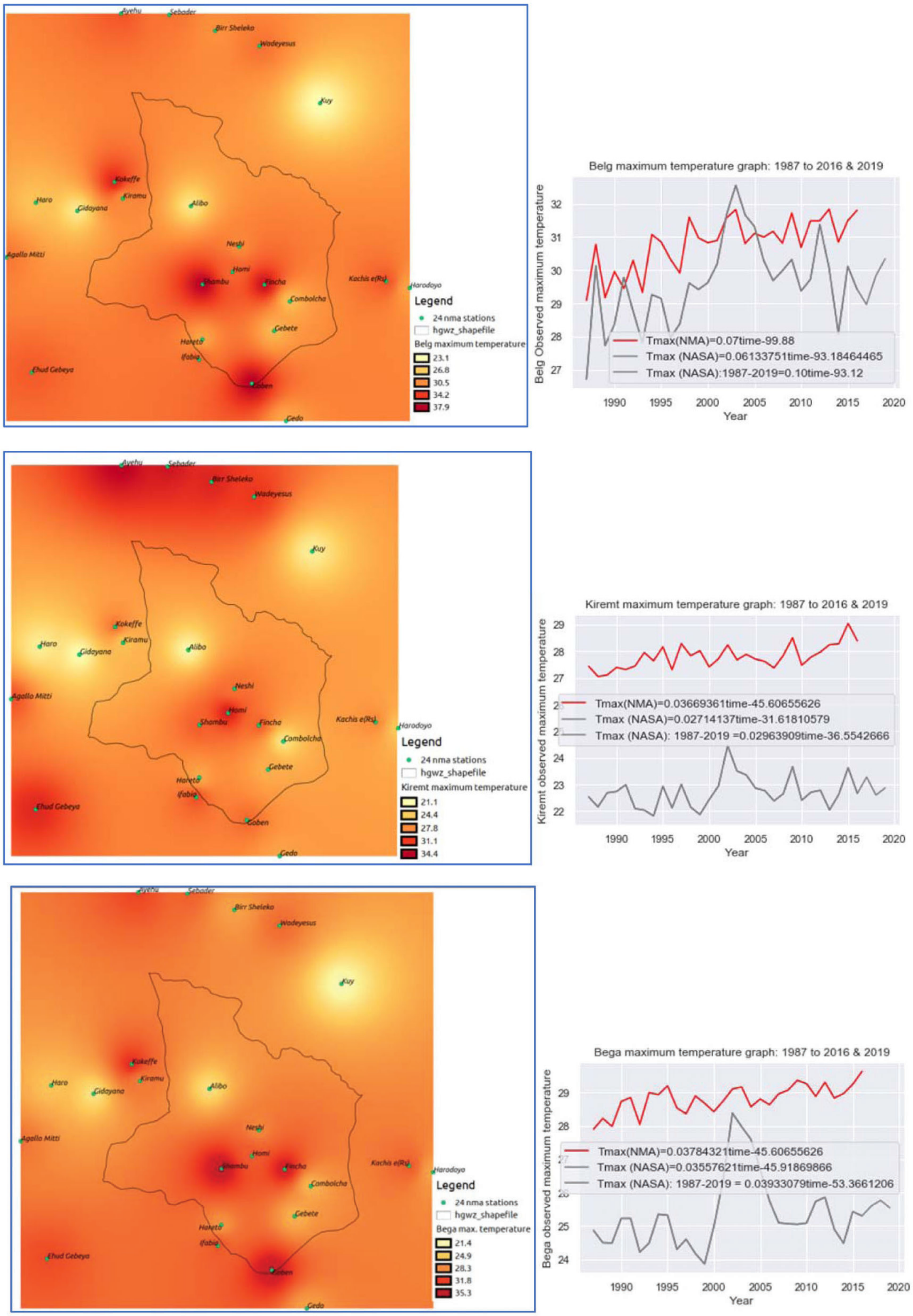


Fig. 7. GIS-based spatial plots and time series trends of observed maximum temperature over the winter, spring, summer, autumn, belg, kiremt and bega seasons

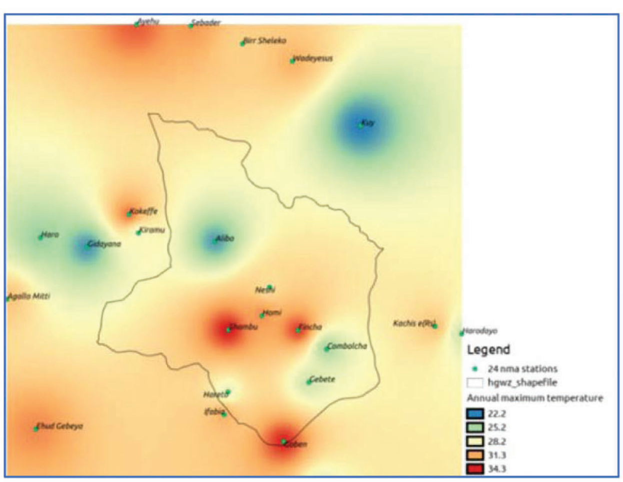
29.15oC mean maximum temperature observed over the periods of 1987 to 2016 (30 years) whereas; 25.9oC recorded during the period ranging from 1987 to 2019 (33 years). The highest mean maximum temperature observed during the third decadal years (2007-2016) whereas, the lowest observed during the first decadal years (1987-1996) as indicated in Appendix 2. Similar to the observed monthly and seasonal maximum temperature mode of variation, the variability of annual and decadal maximum temperature was statistically estimated to be less (CV< 20%, Appendix 2). The difference among the 24 meteorological stations regarding the observed annual maximum temperature estimated to be statistically non-significant (P > 0.05, Table 7). Also, the maximum temperature observed during the three consecutive decadal years was varying from station to station with a statistically non-significant difference (P>0.05, Table 7). The highest decadal mean maximum temperature recorded at Shambu station, whereas the lowest recorded at Kuy station (Table 7). Less variable (CV<20%) annual mean maximum temperature observed across stations (Table 7). Similarly, less variable (CV<20%) and non-significant (P > 0.05) mean maximum temperature recorded at 24 meteorological stations during the three consecutive decadal years of the period from 1987 to 2016 (30 years) (Table 7).

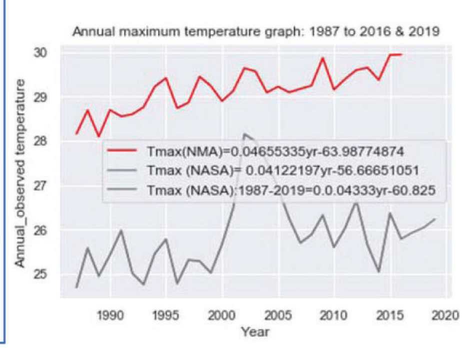
Observed average temperature

Average temperature dataset computed as the mean of the minimum and maximum temperature for different temporal scale subjected to a statistical investigation under this study. Statistically significant (P<0.05) difference evaluated between the months of the year ranging from 1987 to 2016 (30 years) and 1987 to 2019 (Appendix 3) in the observed average temperature observed over the two periods. March month was the time when the highest average temperature recorded over the period from 1987 to 2016 (30 years) whereas, April month found to be the time with the highest record of average temperature as indicated by the results of analysis applied to 33 years dataset for the period from 1987 to 2019 (Appendix 3). Less intra-month average temperature variability computed for all months of the two periods (Appendix 3). Increasing of average temperature valued during all months of the year 1987 to 2016 (30 years) as presented below by Fig 9. Similarly, rising trends of average temperature during all months of the period from 1987 to 2019 (33 years) observed as indicated by the long trend line (pink coloured line). Trends of the observed average temperature (NMA dataset) for the period 1987 to 2016

Table 7. Annual and decadal maximum temperature recorded at 24 meteorological stations during the period of 1987 to 2016

Time	Min.	Max.	Mean	Std	CV%	Sign.
Annual	22.187Kuy	34.2871Shambu	29.134	3.568174	12.24747	0.462167
1987-1996	22.0583Kuy	33.60523Shambu	28.68094	3.464452	12.0793	0.4223
1997-2006	22.006Kuy	34.433Shambu	29.2018	3.62575	12.41617	0.4737
2007-2016	22.497Kuy	34.823Shambu	29.51911	3.627564	12.28887	0.492





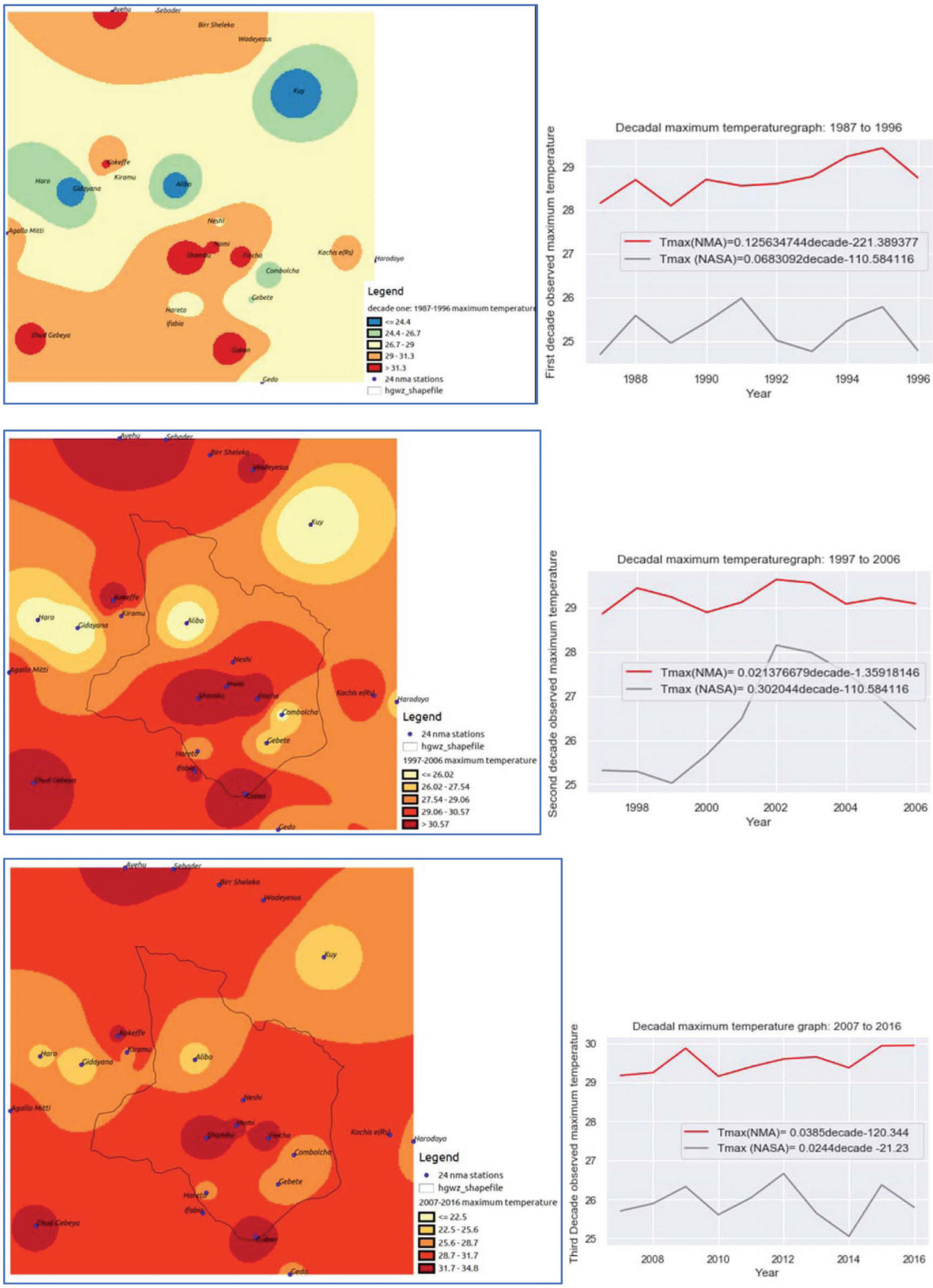


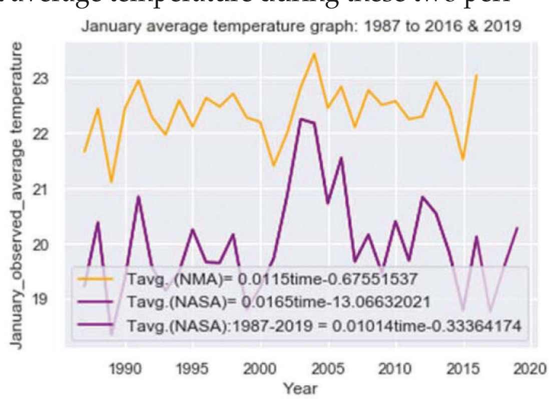
Fig. 8. GIS-based spatial plots and line graph representations of annual and decadal observed maximum temperature

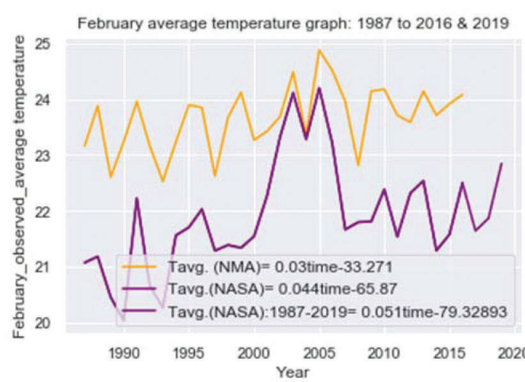
(yellow line), average temperature (NASA dataset) for the period 1987 to 2016 equivalent to NMA dataset (pink line up to 2016) and average temperature over the period 1987 to 2019 (pink line extended from 2016 to 2019).

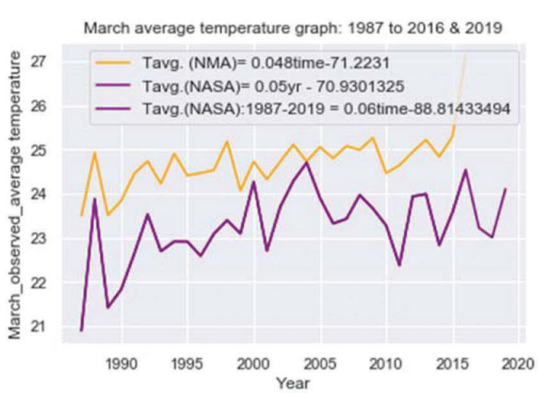
There was non-significantly different ($P>0.05$) average temperature observed during the winter, spring, summer and autumn seasons (Appendix 3). The seasonal analysis results indicated that relatively the highest average temperature prevailed during the spring month, whereas the lowest observed during the autumn season of the period from the year 1987 to 2016. The results showed less intra-season variability (CV<20%) of observed average temperature during these seasons of the period 1987 to 2016 as well as 1987 to 2019 (Appendix 3). Increasing of average temperature during these seasons observed over the two periods (Fig 10). Similar to the variation of average temperature over the three-monthly seasons (winter, spring, summer and autumn), a statistically non-significant variation ($P>0.05$) in average temperature over the four-monthly seasons (Belg, Kiremt and Bega) of the period of 30 and 33 years (Appendix 3). Belg (short rainy season) season found to be the season with the highest average temperature during these two periods or years (Appendix 3). Belg, Kiremt and Bega season average temperature has been varying with less intra-season variability over the periods of 30 and 33 years. Time series trend analysis applied to Belg, Kiremt and Bega season average temperature datasets form NMA and NASA for the period of 30 and 33 years indicated an increasing trend of the average temperature over the Belg, Kiremt and Bega seasons (Fig 10). Annually 23.014 °C and less variable (inter-annual variability) average temperature observed from 1987 to 2016 (30 years). Analysis result revealed that 20.132 °C and less variable (inter-annual variability) recorded average temperature from 1987 to 2019 (33 years). Increasing of annual average temperature over the series of years within the range of 30 and 33 years period was evaluated. The statistical time series trend analysis produced similar results that shown increasing of average temperature over the periods of three recent and consecutive decadal years belong to the range of time from 1987 to 2016 (Fig. 11).

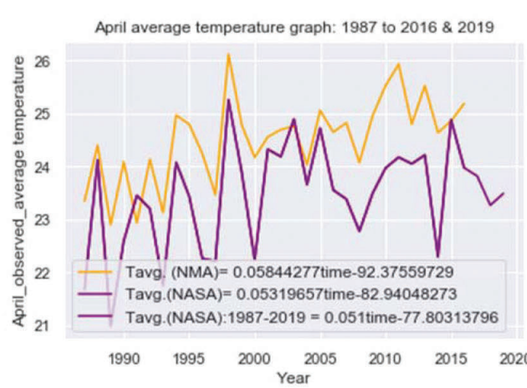
Discussion

The temporal variability and trends of observed minimum, maximum and average temperature dur-









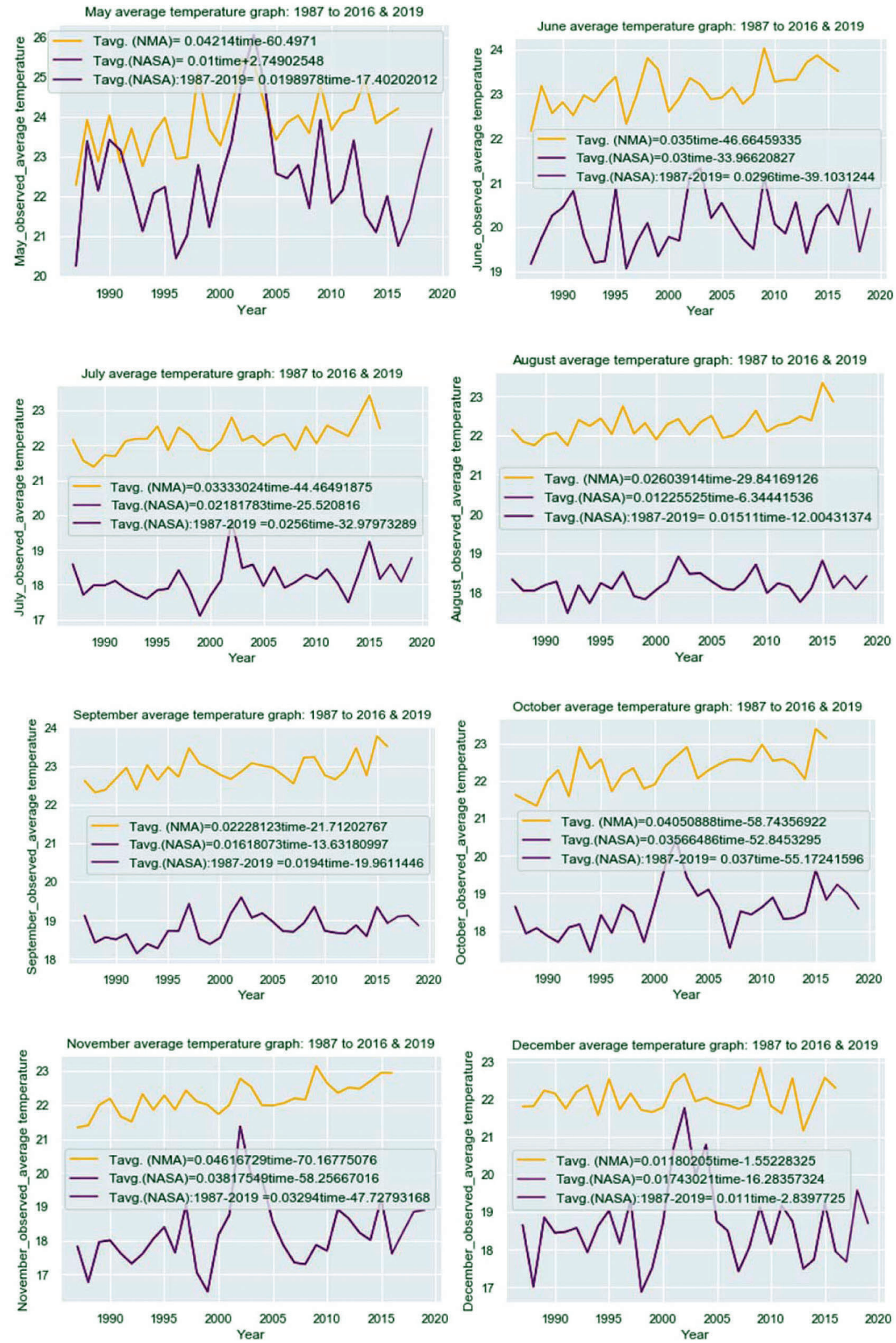
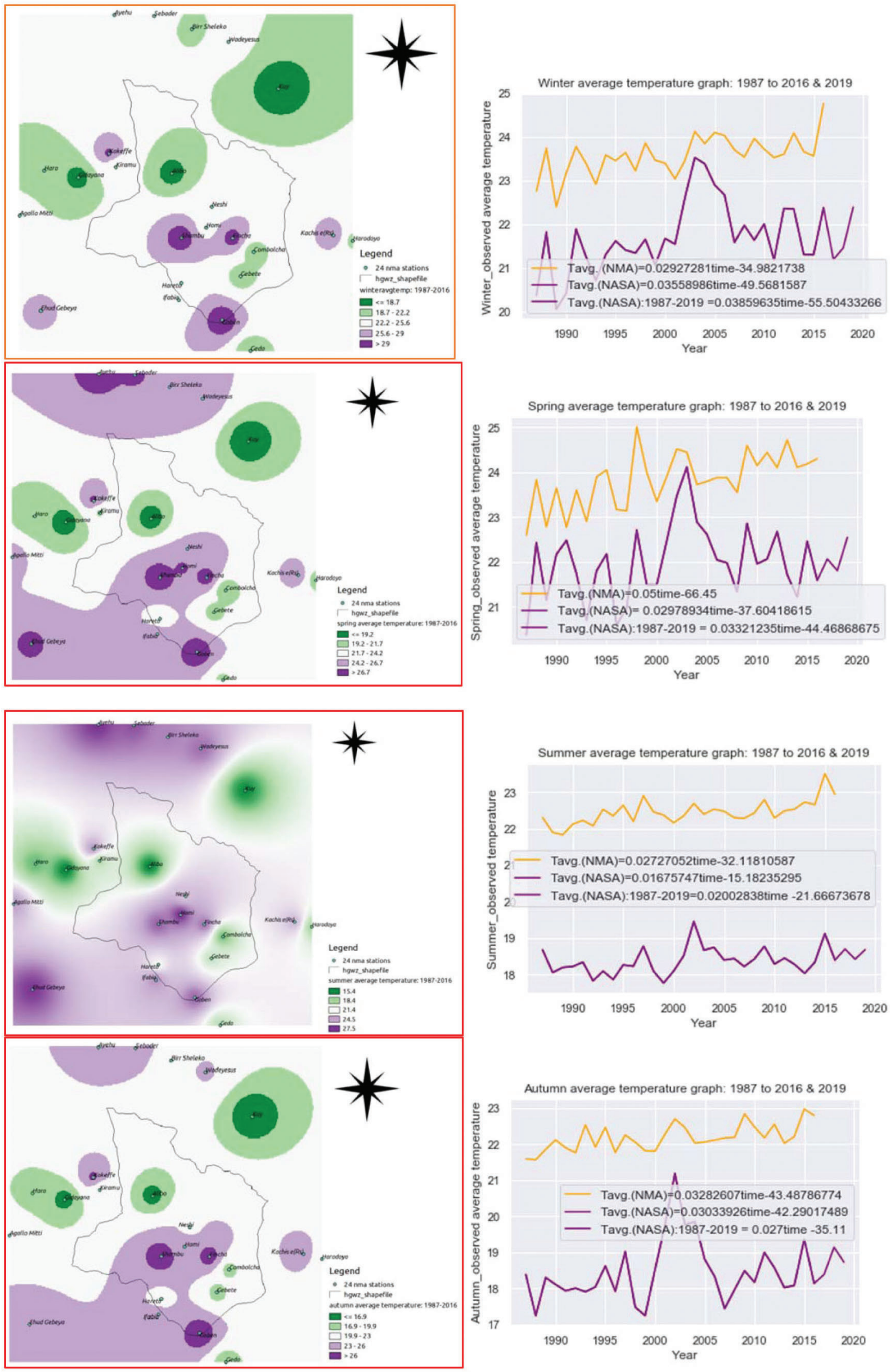


Fig. 9. Graphical representations of time series trends of monthly average temperature over the period of 30 and 33 years.


Winter average temperature graph: 1987 to 2016 & 2019
Winter_observed average temperature
Tavg. (NMA)=0.02927281time-34.9821738
Tavg.(NASA)=0.03558986time-49.5681587
Tavg.(NASA):1987-2019 =0.03859635time-55.50433266
Year
Spring average temperature graph: 1987 to 2016 & 2019
Spring_observed average temperature
Tavg.(NMA)=0.05time-66.45
Tavg.(NASA)= 0.02978934time-37.60418615
Tavg.(NASA):1987-2019 = 0.03321235time-44.46868675
Year
Summer average temperature graph: 1987 to 2016 & 2019
Summer_observed temperature
Tavg.(NMA)=0.02727052time-32.11810587
Tavg.(NASA)=0.01675747time-15.18235295
Tavg.(NASA):1987-2019=0.02002838time -21.66673678
Year
Autumn average temperature graph: 1987 to 2016 & 2019
Autumn_observed average temperature
Tavg.(NMA)=0.03282607time-43.48786774
Tavg.(NASA)=0.03033926time-42.29017489
Tavg.(NASA):1987-2019 = 0.027time -35.11
Year
Legend
24 nma stations
hgwz_shapefile

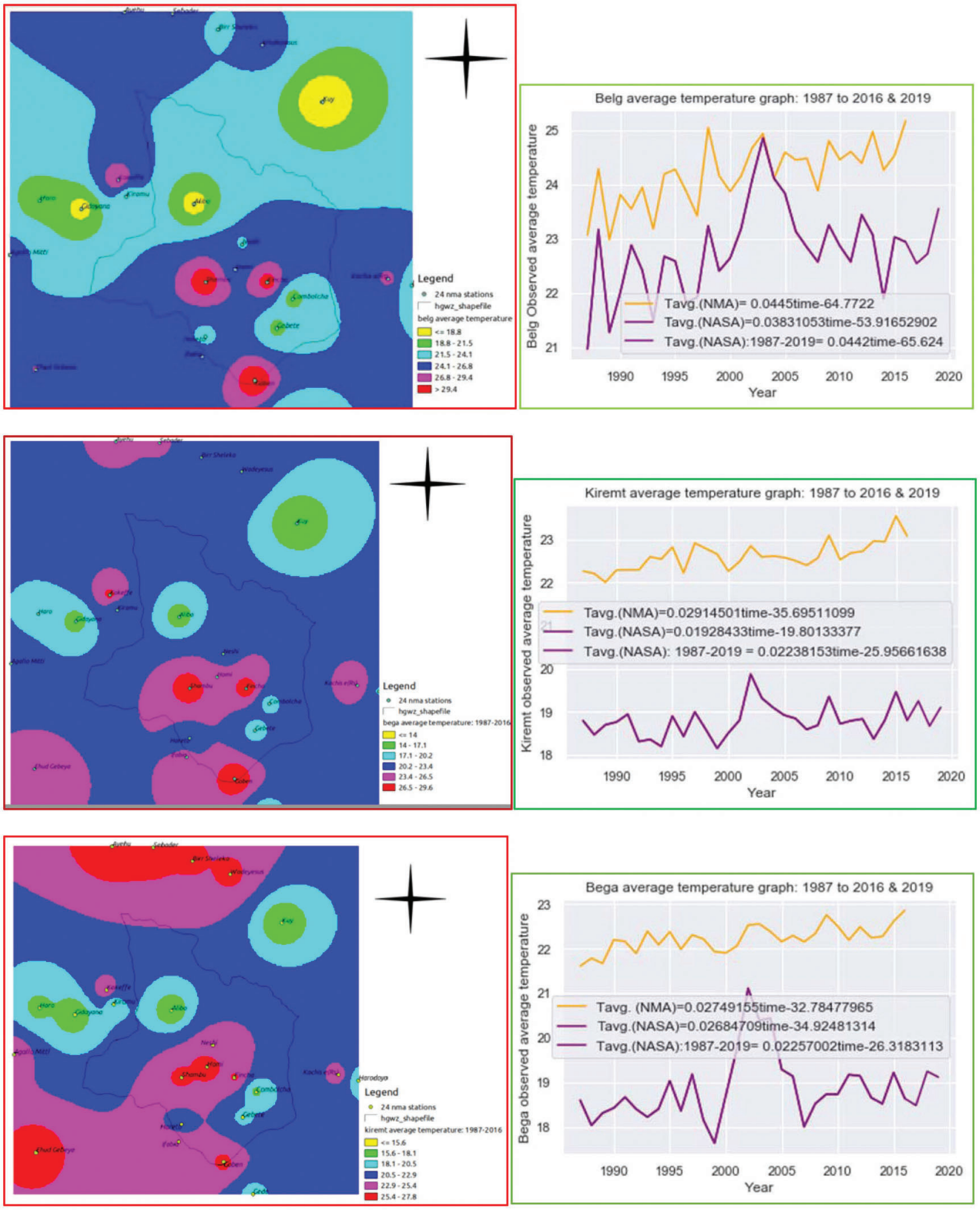


Fig. 10. Graphical representations of time series trends of 3-monthly and 4-monthly seasons' average temperature over the period of 30 and 33 years.

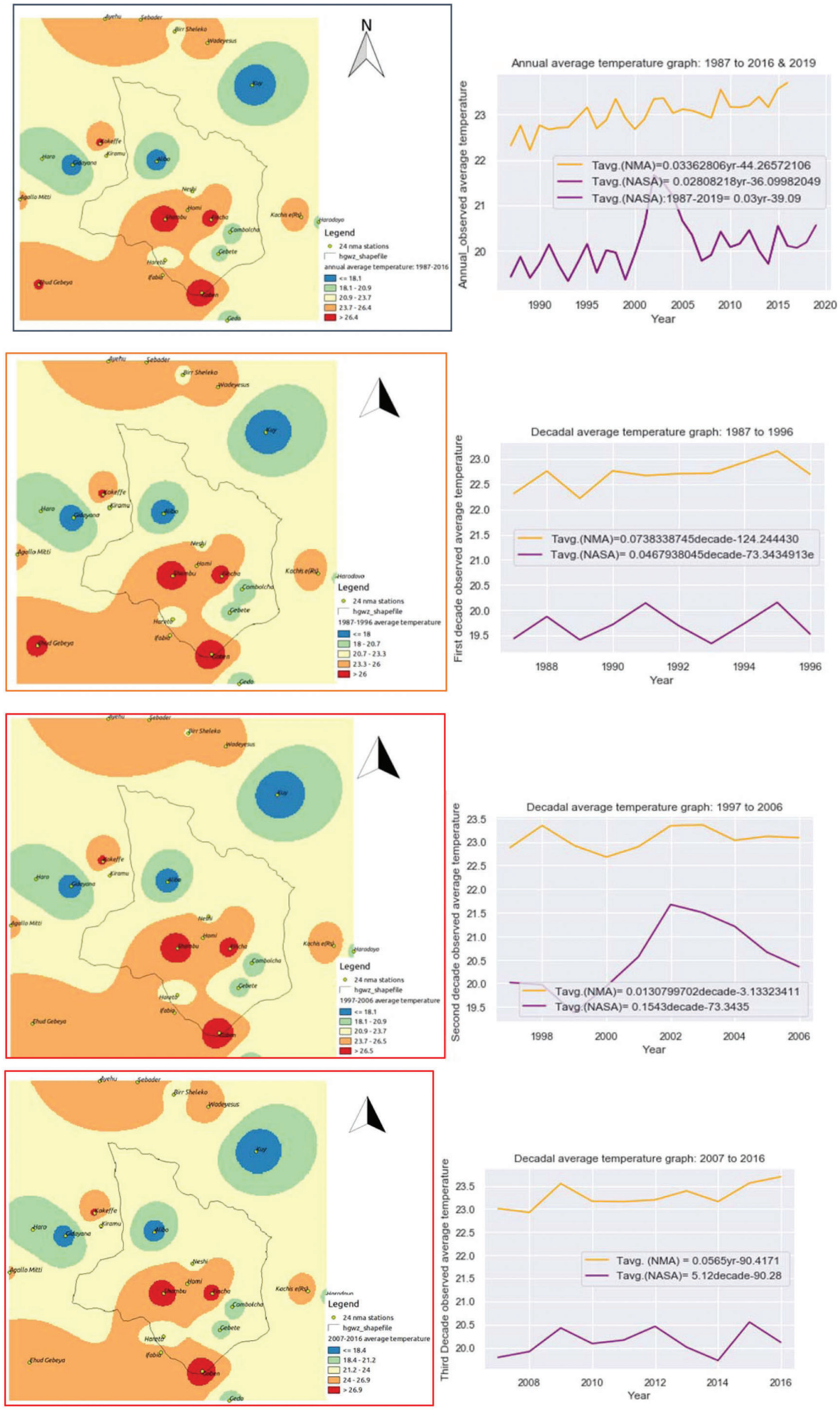


Fig. 11. Graphical representationsof time series trends of annual and three-consecutive decadal years average temperature from 1987 to 2016.

ing the last 33 years can be linked to the change in the prevalence patterns of temperature over a changing series of time series. In this study, it is highly expected that with the shifting of each time scale i.e months, seasons, years and decades, there were changes in the climatic processes and systems that might have been caused by natural and anthropogenic factors. This inturn might have led to a change in the features of the observed minimum, maximum and average temperature. In line with this, in the paper of Fitsum *et al.* (2017), it is stated that temporal climate variation over different parts of Ethiopia is the result of the macro-scale pressure systems and moisture flows, which are related to the changes in air pressure systems over different time scales. The seasonal and annual minimum, maximum and average temperature variations over the study area at different time scales, might be due to the changes in these pressure systems over time. The spatial variability of minimum, maximum and average temperature over different time scales might be due to altitudinal and location differences, which can drive spatial variation of these temperature variables over a period of time. As concluded in previous studies, owing to the irregular terrain (landscape), the distribution of temperature greatly differs even in a smaller geographic area like the study area. According to paper by Fitsum *et al.* (2017), it is stated that the spatial variations in temperature are influenced by changes in the intensity, position, and direction of movement of the air pressure systems over the country. Also, in this paper, it is clearly stated that the spatial distribution of climatic temperature in Ethiopia is significantly influenced by complex topography.

Ethiopia lies in the eastern horn of Africa at ap-

Appendix 3. Basic statistics of observed monthly, three-monthly, four-monthly, annual, decadal and 30-years average temperature for the period 1987 to 2016 and 1987 to 2019

Month	1987 to 2016 (30 years)					1987 to 2019 (33 years)				
	Average Temperature					Average Temperature				
	Mean	Std	Min	Max	CV%	Mean	Std	Min	Max	CV%
Jan.	22.4	0.5	21.1	23.4	2.25	19.9	0.91	18.3	22.2	4.56
Feb.	23.7	0.58	22.5	24.9	2.45	21.9	0.99	20.0	24.2	4.51
Mar	24.7	0.65	23.5	27.1	2.65	23.3	0.85	20.9	24.7	3.7
Apr.	24.5	0.81	22.9	26.1	3.28	23.5	1.01	20.98272	25.2	4.31
May	23.9	0.77	22.3	25.5	3.23	22.4	1.32	20.2	26.1	5.86
Jun.	23.1	0.46	22.2	24.0	1.98	20.1	0.63	19.1	21.3	3.12
July	22.2	0.42	21.4	23.4	1.87	18.2	0.51	17.1	19.9	2.82
Aug	22.3	0.34	21.7	23.3	1.54	18.2	0.3	17.5	18.9	1.66
Sept.	22.9	0.35	22.3	23.8	1.52	18.8	0.35	18.1	19.6	1.87
Oct.	22.3	0.49	21.3	23.4	2.23	18.6	0.66	17.4	20.4	3.55
Nov	22.2	0.46	21.3	23.1	2.06	18.2	0.97	16.5	21.4	5.33
Dec	22.0	0.39	21.2	22.8	1.75	18.7	1.07	16.9	21.8	5.73
P-Value	0.03					0.01				
Winter	20.1	0.82	19.1	22.1	1.24	20.1	0.8	19.1	22.1	3.98
Spring	23.0	0.9	20.9	25.1	2.6	23.1	0.85	20.9	25.1	3.7
Summer	18.8	0.41	18.1	19.9	1.55	18.8	0.41	18.1	19.9	2.2
Autumn	18.5	0.62	17.5	20.5	1.72	18.5	0.6	17.5	20.5	3.3
P-value	0.12					0.13				
Belg	24.2	0.6	22.9	25.2	2.4	22.8	0.82	20.9	24.9	3.62
Summer	22.6	0.33	22.0	23.5	1.45	18.8	0.4	18.2	19.9	1.99
Bega	22.2	0.3	21.6	22.9	1.34	18.9	0.73	17.6	21.1	7.7
P-value	0.22					0.35				
Annual	23.0	0.35	22.2	23.7	1.51	20.1	0.6	19.3	21.7	2.8
Decadal										
1987-1996	22.7	0.3	22.2	23.2	1.2	19.7	0.3	19.3	20.2	1.5
1997-2006	23.1	0.23	22.7	23.4	1.00	20.5	0.75	19.4	21.7	3.64
2007-2016	23.3	0.3	22.9	23.7	1.1	20.1	0.3	19.7	20.6	1.8
P-value	0.12					0.66				
1987-2016	23.0	0.35	22.2	23.7	1.51	20.1	0.6	19.3	21.7	2.44

proximately 3 to 15° N latitude and 33° to 48° E longitude, which has an implication on atmospheric circulation. The country's topography is composed of a massive highland complex of mountains and dissected plateaus divided by Great Rift Valley running generally southwest to northeast. The seasonal and annual minimum, maximum and average temperature variations are the result of the macro-scale pressure systems and monsoon flows, which are related to the changes in the pressure systems (Fitsum *et al.,* 2017). The most important weather systems that cause temperature variations over Ethiopia include the Sub-Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and Somalia Jet (NMA 1996b). The Tropical Easterly Jet (TEJ) and the Tibetan anticyclone are two important upper-level atmospheric features. The strength and position of these atmospheric systems vary from year to year and, so, also the temperature activity. Regional and global weather systems affecting the Kiremt (JJAS) season include the (ITCZ), the Maskaran High Pressure in the Southern Indian Ocean, the Helena High Pressure Zone in the Atlantic, the Congo air Boundary, the monsoon depression and monsoon trough, the monsoon clusters and the Tropical Easterly Jet (Kassahun 1999).

Conclusion

There was non-significant difference among the months of the year 1987 to 2016 and 1987 to 2019. The mean minimum temperature observed over the period 1987 to 2016 (30 years) and 1987 to 2019 (33 years) was relatively maximum during April and May months of the two periods. The lowest monthly minimum temperature was observed during the January month of the two periods, whereas the highest minimum temperature over the period of 30 years was observed during March and May months of 33 year periods of time. Less variable minimum temperature was recorded over all months of the two periods. The trend of observed minimum temperature during almost all months over both 30 and 33 year periods of time was increasing. There was non-significant difference in observed monthly minimum temperature among 24 meteorological stations. The spring season average minimum temperature prevailed over the 30 and 33 years period was found to be relatively the highest but winter season observed minimum temperature was the lowest record. Minimum temperature was increasing over the winter, spring, summer and autumn season of the periods of 30 and 33 years. There was non-significant difference in observed minimum temperature among the 24 meteorological stations during the winter, spring, summer and autumn season. Belg (short rainy season) season observed average minimum temperature was the highest, whereas Bega (dry season) season average minimum temperature found the lowest over the period 1987 to 2016 and 1987 to 2019. Less variable annual minimum temperature was observed over the period with the lowest record of 16.341 °C and maximum minimum temperature of 17.45 °C. Similarly, less variable annual minimum temperature was observed over the period 1987 to 2019, which was averagely 14.4 oC. The highest mean minimum temperature was observed during the third decadal years (2007-2016), whereas the lowest was observed during the first decadal years (1987-1996). The statistical analysis applied to annual and decadal observed minimum temperature over the period of 1987 to 2016 (30 years) showed that Kuy is the station with the least minimum temperature whereas, Goben is the station with the highest observed minimum temperature. There was statistically non-significant variation in observed annual and the three consecutive decades minimum temperature among the 24 meteorological stations. Significantly different monthly maximum temperature was observed over the period from 1987 to 2016 and 1987 to 2019. During the last 30 year period (1987-2016), the highest mean maximum temperature was recorded during the March month. Similarly, the highest mean maximum temperature prevailed during the March month of during the period of 1987 to 2019. The highest maximum temperature was observed during the March month of the 30 years period ranging from 1987 to 2016. May month was the time when the highest maximum temperature recorded over the period from 1987 to 2019. Less variable (CV<20%) monthly maximum temperature was observed over all months of the 30 and 33 years period. There were statistically a non-significant differences (P>0.05) among the winter, spring, summer, autumn, belg, kiremt and Bega seasons over the periods of 30 and 33 years. The highest mean maximum temperature was observed during the Belg (short rainy season) season of the two periods when compared to Kiremt (long rainy season) and Bega (dry season). There was a non-significant difference in seasonal observed maximum temperature among the 24 meteorological stations. The CV (%) values for all seasons of the two periods are less than 5% which is less than 20% indicating the less variability (intra-season variability) of mean maximum temperature during the winter, spring, summer and autumn seasons over the two periods. Belg, Kiremt and Bega season maximum temperature has been varying in similar mode, when compared to the winter, spring, summer and autumn seasons i.e less variability (CV < 20%. On average, 29.15 °C annual maximum temperature was observed over the periods of 1987 to 2016 whereas, 25.9 °C was recorded during the period ranging from the year 1987 to 2019. The highest mean maximum temperature was observed during the third decadal years whereas, the lowest was observed during the first decadal years (1987-1996). There was non-significant difference (P>0.05) in annual maximum temperature among the 24 meteorological stations. Also maximum temperature observed during the three consecutive decadal years was varying from station to station with statistically non-significant difference (P > 0.05). The highest decadal mean maximum temperature recorded at Shambu station whereas, the lowest was recorded at Kuy station. Less variable (CV < 20%) annual mean maximum temperature was observed across the 24 meteorological stations. Less variable (CV < 20%) and non-significant (P>0.05) mean maximum temperature was observed at 24 meteorological stations during the three consecutive decadal years of the period from 1987 to 2016.

Statistically significant (P<0.05) difference evaluated among the months of the year ranging from 1987 to 2016 and 1987 to 2019 in the observed average temperature. March month was the time when the highest average temperature observed over the period from 1987 to 2016 whereas, April month found to be the time with the highest record of average temperature observed during the last 33 years period ranging from 1987 to 2019. Increasing of average temperature valued during all months of the year 1987 to 2016. Similarly, increasing trends of average temperature during all months of the period from 1987 to 2019 was observed. There was non-significant difference in observed average temperature during the winter, spring, summer and autumn seasons. The highest average temperature prevailed during the spring month whereas, the lowest was observed during the autumn season of the period from the year 1987 to 2016. Less intra-season variability (CV < 20%) of observed average temperature during these seasons of the period 1987 to 2016 as well as 1987 to 2019. Increasing of average temperature during these seasons observed over the two periods. There was statistically non-significant variation in average temperature among the Belg, Kiremt and Bega seasons during the period of the last 30 and 33 years. Belg (short rainy season) season found to be the season with the highest average temperature during these two periods. Belg, Kiremt and Bega season average temperature has been varying with less intra-season variability over the periods of 30 and 33 years. Increasing trend of the average temperature was observed over the Belg, Kiremt and Bega seasons. Annually 23.014 °C and less variable (inter-annual variability) average temperature observed over the period of 1987 to 2016. Analysis result revealed that 20.132 °C and less variable (inter-annual variability) observed average temperature over the period of 1987 to 2019. Increasing of annual average temperature was observed over the series of years within the range of 30 and 33 years. Increasing trend of average temperature was observed during the periods of three recent and consecutive decadal years belong to the range of time from 1987 to 2016.

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