World Applied Sciences Journal 38 (6): 453-464, 2020
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2020.453.464

Scientific Analysis of Variability and Time Series Trends of Observed Annual and Decadal Temperature over Northwestern Ethiopia Since 1987

[1]Belay Ejigu Feke, [2]Tadesse Terefe, [3]Kassahun Ture and [4]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
[3]Addis Ababa University Institute of Environmental Science, Addis Ababa, Ethiopia.
[4]Jimma University College of Agriculture and Veterinary Medicine,
Department of Natural Resources Management, Jimma, Oromia, Ethiopia

Abstract: Climate variability and change are among the major environmental challenges of the 21st century. Climate change is a global concern as it severely affects the livelihoods of the world community in general and agricultural production and food security of the farming community in particular. This scientific analysis investigated the variability and time-series trends of observed temperature over the past periods. Dataset for statistical analysis were obtained from the National Meteorology Agency of Ethiopia and National Aeronautics and Space Administration. All statistical tests and analyses were conducted using Python 3.7.4. A less variable annual minimum temperature was observed over the period with the lowest record of 16.341°C and a maximum-minimum temperature of 17.45°C. Increasing of annual and decadal average temperature was observed over the series of years within the range of 30 years.

Key words: Temperature · Variability · Trend · Linear Regression

INTRODUCTION

The issue of climate variability has become more threatening not only to food security and sustainable development of any nation, but also to the totality of human existence. As has been indicated by Tripathi and Mishra [1], climate variability and change is a reality. It has happened, it is happening and it will continue to happen. In its wake it is affecting livelihood systems. Climate change is a global concern as it severely affects the livelihoods of the world community in general and agricultural production and food security of the farming community in particular. It could have an adverse effect on various biophysical and economic activities like agriculture, water resources, forestry, human health, biodiversity and wildlife. Its consequences are severe in developing countries in which agriculture is the primary source of livelihood [2].

Climate variability refers to variations in the mean state and other statistics of the climate on both temporal and spatial scales beyond the individual weather events [3]. While climate change is a change in climate over comparable time periods (a decade or more), which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere [3]. Climate change is caused by the release of greenhouse' gases into the atmosphere. These gases accumulate in the atmosphere, which results global warming. The changes in global climate-related parameters such as temperature, precipitation, soil moisture and sea level. However, the reliability of the predictions on climate change is uncertain. There are no hard facts about what will definitely be the result of increases in the concentration of greenhouse gases within the atmosphere and no firm timescales are known. Agriculture is one sector, which is important to consider in terms of

Corresponding Author: Belay Ejigu, Jimma University College of Agriculture and Veterinary Medicine, Department of Natural Resources Management, Jimma, Oromia, Ethiopia.

climate change. The agriculture sector both contributes to climate change, as well as will be affected by the changing climate [4].

Climate variability and change are among the major environmental challenges of the 21st century. Successive reports of the Intergovernmental Panel on Climate Change [5] and various other studies [6-13] show that climate change is having multifaceted effects on human societies, multilevel sectors and the environment. Scientific evidence indicates that anthropogenic factors are the major contributors to the prevailing global climate change [14]. The atmospheric concentration of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide has substantially increased over time. For example, the carbon dioxide concentration has increased from 280 ppm (pre-industrial level) to about 394 ppm in 2012; a 41% increase due to human activities. The global average temperature has increased by 0.74 o C in the last century and is projected to increase with 1.1-5.8 o C by the end of this century and the rainfall patterns will change with an increased frequency of extreme events [15, 16].

Climate variability and change impacts directly or indirectly on all economic sectors to some degree, but agriculture is among the sectors most sensitive and inherently vulnerable to climate variability [17-20] and climate change is most likely to increase this vulnerability [21]. The impacts of increased temperature from global warming and changes in rainfall patterns resulting from climate change are expected to reduce agricultural production and put further pressure on marginal land [22]. Many studies [5, 18, 23- 25] conclude that the strongest impact of climate change on the economic output of agriculture is expected for Sub-Saharan Africa, which implies that the challenge to deal with the negative impacts of climate change will be largest in the poorest and already most food insecure regions.

Smallholder farmers in Sub-Saharan Africa are already challenged by the current climate variability [8] and with a business-as-usual development, climate change is expected to pose challenges beyond the current experiences [26]. Despite growing efforts to reduce GHG emissions, more frequent climatic extremes are now inevitable [16] and put agricultural adaptation and risk management strategies in the spotlight. Because agricultural production remains the main source of income for most rural communities, particularly in developing nations, adaptation of the agricultural sector to the adverse effects of change will be imperative to protect the livelihoods of the poor and to ensure food security. Adaptation can greatly reduce the climate vulnerability of rural communities by making them better able to adjust to climate variability and change and helping them cope with adverse consequences [16]. Thus, adaptation research needs to be enhanced from local to global scales to identify appropriate adaptation strategies and to support the adaptation process through policies guided by scientific evidence. 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 variability and trends of observed temperature that prevailed since 1987 over the northwestern parts of Ethiopia.

MATERIALS AND METHODS

Description of the Study Area: This investigation study was 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°10' North and 9°50' North and Longitude 36°00' East and 36°50' East direction. Nonetheless, the scope 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. This was not to limit the climatic (temperature) analysis to the political boundary of the area. The study area has a total land coverage of 8, 097 km2 [27]. 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 [28], 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. 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 [29]. The average altitude of Horro Guduru Wollega Zone ranges from 860 to 2657 meters above sea level [29]. Mixed crop-livestock agriculture is the main 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*) [30].

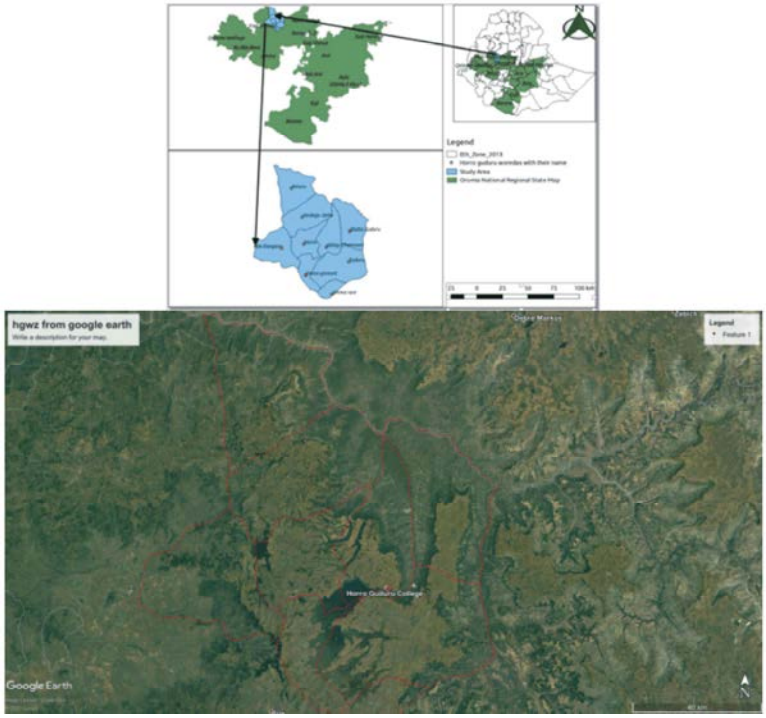

Fig. 1: Map of the study area

Climatic seasons of the study area categorized in to two classes. These are three-monthly and four-monthly seasons. Three-monthly seasons include winter or locally *Bega* (December-January), spring (March-May), summer (June-August) and autumn (September-November). Four-monthly seasons include locally known as *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 [31, 32].

Data Type and Sources: Observed temperature data for Spatio-temporal variability and time series trend analysis have been obtained from different sources. 4km by 4km resolution gridded daily minimum, maximum and average temperature data was obtained from National Meteorological Agency (NMA) of Ethiopia. Daily average temperature data was 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 were used as a sources of time series rainfall dataset (daily) for the statistical analysis applied.

Statistical Data Analysis: All statistical analysis was employed using Python3 integrated in jupyter notebook platform implementing the functionality of Python3 multiple codes, built-in and external and/or user defined functions, modules, packages and libraries. Observed minimum, maximum and 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 seasonal analysis applied to four three-monthly seasons and three four-monthly seasons separately. A number of techniques have been developed for the analysis of temperature, which generally fall in to variability and time series trend analysis categories. Total, average (mean), minimum, maximum, Coefficient of Variation (CV %), slope (m) and P are computed statistical values used for the interpretation of the Spatio-temporal variability and trend analysis results. These values are also computed for the time series observed minimum, maximum and average temperature dataset at each NMA station to describe and investigate the spatial variation on the basis of 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 Coefficient of Variation (CV). CV was calculated to evaluate the variability of the temperature. A higher value of CV is the indicator of larger variability and vice versa which is computed as:

$CV = \sigma/\mu * 100$

where CV is the coefficient of variation; σ is the standard deviation and μ is the mean minimum, maximum and average temperature. According to Hare [33], CV is 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 are performed through applying parametric test method. Linear regression analysis was performed to detect the Spatio-temporal trend of observed minimum, maximum and average temperature prevailed over the study area. Linear regression model was developed using the functionality of 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 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). In fact, other strong Python libraries such as Statsmodels, etc can be utilized to perform any regression modeling to develop equation that determine dependent variables from independent variable/s considered. Time series trend detection was performed using the following Python3 codes and procedural steps:

Step 1: Validation of data sets for regression analysis.

Step 2: Calling of 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 was computed of Scikit-learn. Similar values of these two statistics can be generated of both Python3 libraries, but in case of Statsmodels the constant should be added to the model manually with code 'sm.add_constant(x), which is not automatic as of Scikit-learn. Statsmodels also helps us to determine which of our variables are statistically significant through the p-values. To do these, the following codes were used:

- Import statsmodels.api as sm
- Model = sm.OLS(y, x)
- Results = model.fit()
- Print(results.summary())

Step 7: Predicting of dependent variable (minimum, maximum and average temperature) from 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 AND DISCUSSION

Observed Minimum Temperature: During the period 1987 to 2016 mean annual minimum temperature 16.9°C was observed (Table 1). Less variable minimum temperature was observed over the period with the lowest record of 16.341°C and maximum-minimum temperature of 17.45°C as indicated in Table 1. 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) (Table 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. Red line in the legend indicates the annual and decadal minimum temperature trend (equal to the brown line in length up to 2016) estimated from NASA minimum temperature datasets (Fig. 2).

Observed Maximum Temperature: On the annual basis, 29.15°C mean maximum temperature was observed over the periods of 1987 to 2016 (30 years) The highest mean maximum temperature was observed during the third decadal years (2007-2016) whereas, the lowest was observed during the first decadal years (1987-1996) as indicated in the Table 3. 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%, Table 3).

Observed Average Temperature: Annually 23.014°C and less variable (inter-annual variability) average temperature observed over the period of 1987 to 2016 (30 years). Analysis result revealed that 20.132°C and less variable (inter-annual variability) observed average temperature over the period of 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 an increase in average temperature over the periods of three recent and consecutive decadal years belong to the range of time from 1987 to 2016 (Fig. 4).

The temporal variability and direction of changing of observed minimum, maximum and average temperature during the past 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 years and decades, there were changes in the climatic processes and systems that might have been caused by natural and anthropogenic factors. This in turn 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 Bekele *et al.* [33], 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 annual and decadal 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 Bekele *et al.* [33], it is stated that the spatial variations in temperature are influenced by changes in the intensity,

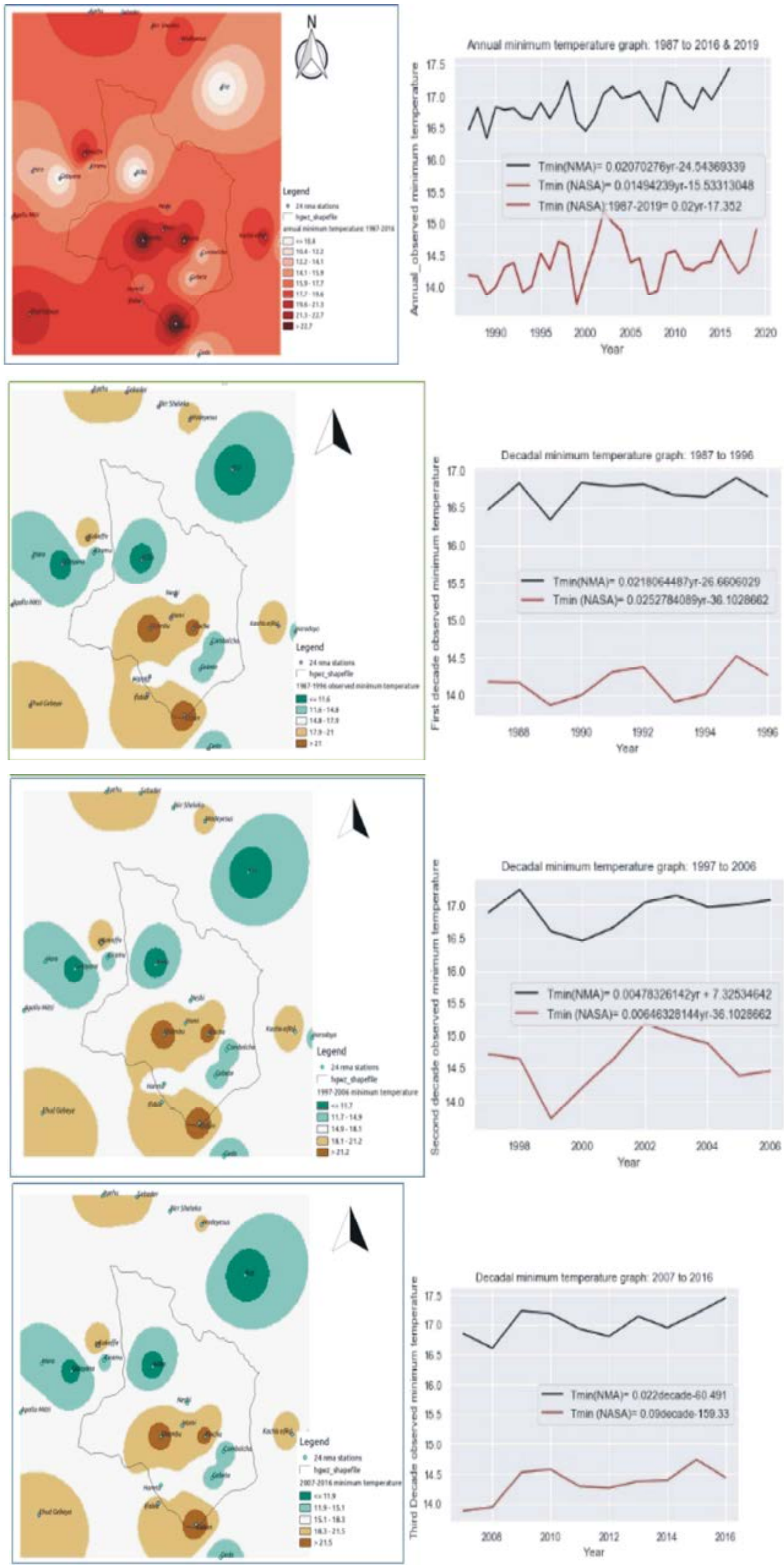

Fig. 2: Annual and decadal minimum temperature spatial features and time series trends

Table 1: Basic statistics of observed annual and decadal minimum temperature for the period 1987 to 2016

	1987 to 2016 (30 years)				
	Minimum Temperature				
Month	Mean	Std	Min	Max	CV
Annual	16.9	0.3	16.341	17.45	1.6
1987-1996	16.7	0.2	16.341	16.901	1.1
1997-2006	16.9114	0.3	16.46	17.2443	1.512433
2007-2016	17.030312	0.25	16.605	17.45	1.5
P-value	0.102033				

Table 2: 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	8.5622 kuy	24.43072 Gobe_ _n	16.88	4.66315	27.63	0.358735
1987-1996	8.5231 kuy	24.14361 Goben	16.6962	4.681	28.036	0.352212
1997-2006	8.5005 kuy	24.4263 Goben	16.91212	4.71712	27.892	0.3532
2007-2016	8.663 kuy	24.72185 Goben	17.0302	4.59764	26.997	0.372

Table 3: Basic statistics of observed annual and decadal maximum temperature for the period 1987 to 2016

	1987 to 2016 (30 years)				
	Maximum Temperature				
Month	Mean	Std	Min	Max	CV%
Annual	29.15	0.5	28.1	29.95	1.634
1987-1996	28.7	0.41	28.1	29.42	1.42
1997-2006	29.22	0.3	28.9	29.64	0.9
2007-2016	29.5332	0.310233	29.2	29.95	1.1
P-value	0.091				

Table 4: 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	22.187 Kuy	34.2871 Shambu	29.134	3.568174	12.24747	0.462167
1987-1996	22.0583 Kuy	33.60523 Shambu	28.68094	3.464452	12.0793	0.4223
1997-2006	22.006 Kuy	34.433 Shambu	29.2018	3.62575	12.41617	0.4737
2007-2016	22.497 Kuy	34.823 Shambu	29.51911	3.627564	12.28887	0.492

Table 5: Basic statistics of observed annual and decadal average temperature for the period 1987 to 2016

	1987 to 2016 (30 years)				
	Average Temperature				
Month	Mean	Std	Min	Max	CV%
Annual	23.014	0.35	22.22	23.7	1.51
1987-1996	22.7	0.3	22.22	23.2	1.2
1997-2006	23.1	0.2312	22.7	23.4	1.0023
2007-2016	23.3	0.3	22.93	23.7	1.1
P-value	0.121038				

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 temperature in Ethiopia is significantly influenced by complex topography. The annual and decadal 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 [33]. 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)

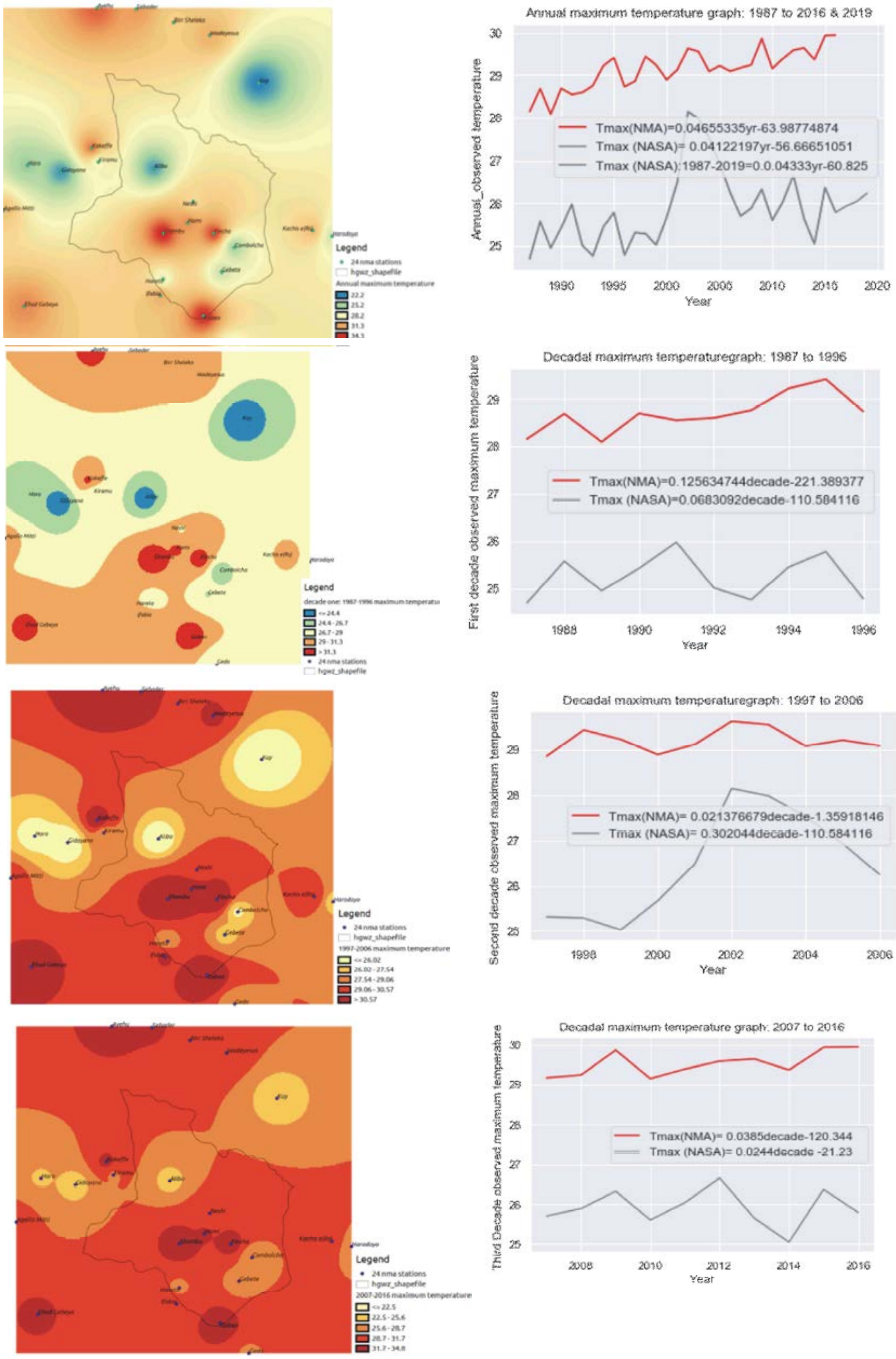

Fig. 3: GIS-based spatial plots and line graph representations of annual and decadal observed maximum temperature

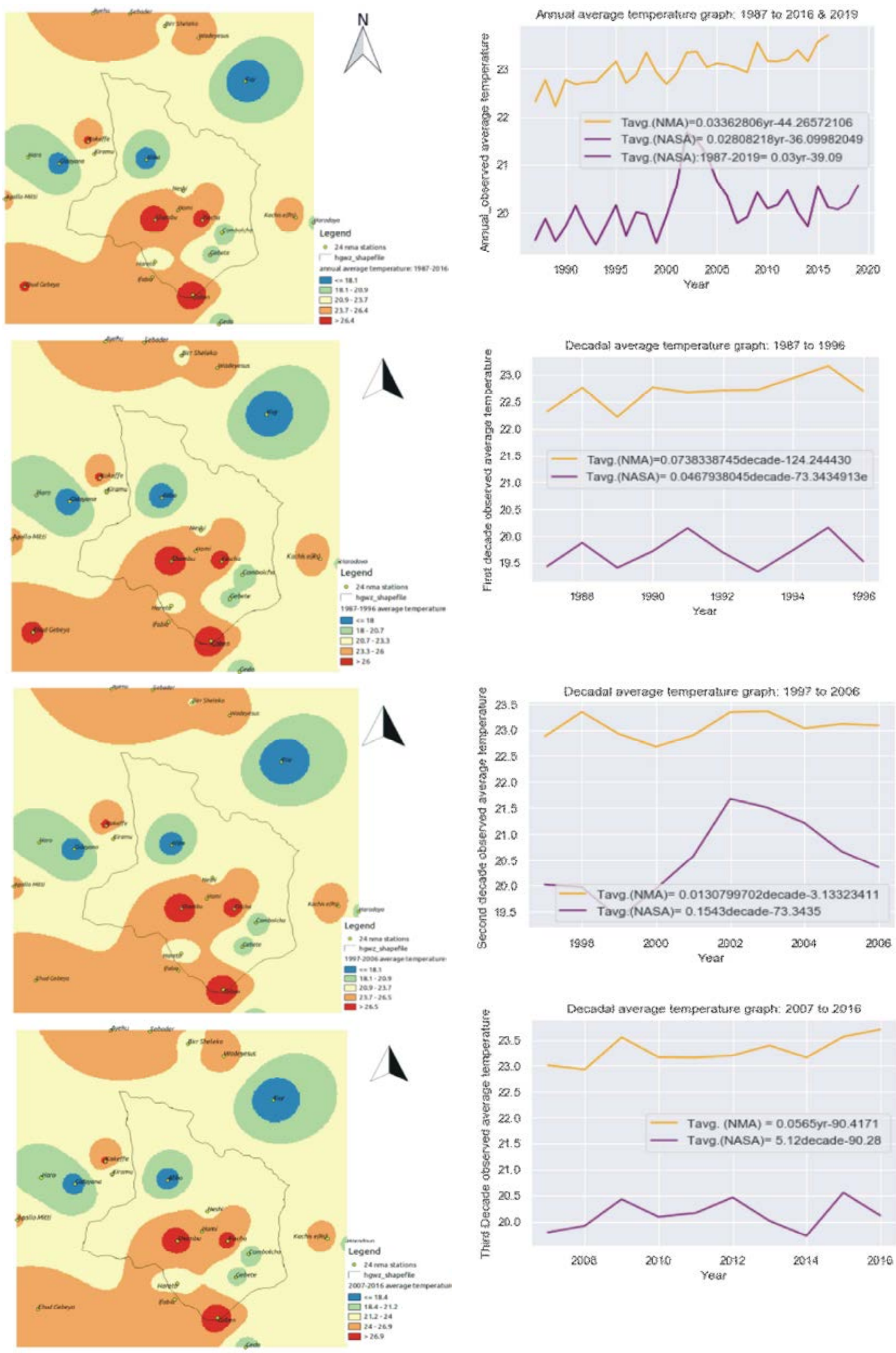

Fig. 4: Graphical representations of time series trends of annual and three-consecutive decadal years average temperature from 1987 to 2016

and Somalia Jet [34]. 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. Territorial and worldwide weather condition 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 [35].

CONCLUSION

The less variable annual minimum temperature was observed over the period with the lowest record of 16.341°C and a maximum-minimum temperature of 17.45°C. Similarly, the less variable annual minimum temperature was observed over the period 1987 to 2019, which was averagely 14.4°C. 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). 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 a 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). 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 oC 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. An 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.

REFERENCES

1. Tripathi, A. and A.K. Mishra, 2017. Knowledge and Passive Adaptation to Climate Change: An Example from Indian Farmers. Climate Risk Management, 16: 195-207.
2. World Bank, 2008. World Development Report 2008: Agriculture for development. Washington DC: World Bank.
3. IPCC (Intergovernmental Panel on Climate Change), 2014. AR5 IPCC Whats in it for Africa.
4. Cumhur, Aydinalp and Malcolm S. Cresser, 2008. The Effects of Global Climate Change on Agriculture. American-Eurasian J. Agric. & Environ. Sci., 3(5): 672-676. Idosi Publications.
5. IPCC, 2007. Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the of the IPCC.
6. Leemans, R. and B. Eickhout, 2004. Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. Global Environmental Change, 14: 219-228.
7. Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences, 104: 19680-19685.
8. Cooper, P.J.M., K.P.C. Rao, P. Singh, J. Dimes, P. Traore, P. Dixit and S.J. Twomlow, 2009. Farming with current and future climate risk: Advancing a'Hypothesis of Hope'for rainfed agriculture in the semi-arid tropics. Jounal of SAT Agricultural Research, 7: 1-19.
9. Schlenker, W. and D.B. Lobell, 2010. Robust negative impacts of climate change on African agriculture. Environmental Research Letters, 5: 014010.
10. Thornton, P.K., P.G. Jones, P.J. Ericksen and A.J. Challinor, 2011. Agriculture and food systems in Sub-Saharan Africa in a 4°C+ world. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 369: 117-136.
11. Rajani Srivastava, 2013. Effect of Global Warming on Agricultural Systems. American-Eurasian J. Agric. & Environ. Sci., 13(5): 677-682. Idosi Publications
12. Yibrah Gebremedhin and Araya Alemie Berhe, 2015. Impact of Climate Change on Potato Yield (*Solanum tuberosum* L.) At Mekelle Areas, in Northern Ethiopia. World Journal of Agricultural Sciences, 11(2): 62-69. Idosi Publications.
13. Abul Khayer, Fatiha Sultana Eti, Md. Mohibul Hasan, Md. Khairul Bashar Biplob, Rabiul Haq Chowdhury, M. Anwar-Ul-Alam and A.B.M. Alauddin Chowdhur, 2019. Factors Affecting Agriculture in Response to Climate Change in Bangladesh. Middle-East Journal of Scientific Research, 27(2): 106-113. Idosi Publications.

14. Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe and G. Myhre, 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
15. Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy and A. Noda, 2007. Global climate projections. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Ed.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp: 747-845.
16. IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp: 582.
17. Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, 2007. Africa. In: Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change [Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.(eds.)], Cambridge University Press, Cambridge UK, pp: 433-467.
18. Müller, C., W. Cramer, W.L. Hare and H. Lotze-Campen, 2011. Climate change risks for African agriculture. Proceedings of the National Academy of Sciences, 108: 4313-4315.
19. Wheeler, T. and J. Von Braun, 2013. Climate Change Impacts on Global Food Security. Science, 341: 508-513.
20. Karim Omar, 2014. Assessing the Conservation Status of the Sinai Primrose (Primula boveana). Middle-East Journal of Scientific Research, 21(7): 1027-1036. Idosi Publications.
21. Thornton, P.K., P.G. Jones, G. Alagarswamy, J. Andresen and M. Herrero, 2010. Adapting to climate change: agricultural system and household impacts in East Africa. Agricultural Systems, 103: 73-82.
22. Van De Steeg, J., M. Herrero, J. Kinyangi, P. Thornton, K. Rao, R. Stern and P. Cooper, 2009. The influence of climate variability and climate change on the agricultural sector in East and Central Africa-Sensitizing the ASARECA strategic plan to climate change. Research Report 22, ILRI, pp: 85. ISBN 92-9146-23-1. Nairobi, Kenya.
23. Challinor, A., T. Wheeler, C. Garforth, P. Craufurd and A. Kassam, 2007b. Assessing the vulnerability of food crop systems in Africa to climate change. Climatic Change, 83: 381-399.
24. Hellmuth, M.E., A. Moorhead, M.C. Thomson and J. Williams, 2007. Climate risk management in Africa: Learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA.
25. Jones, P.G. and P.K. Thornton, 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environmental Science Policy, 12: 427-437.
26. Cairns, J.E., J. Hellin, K. Sonder, J.L. Araus, J.F. MacRobert, C. Thierfelder and B. Prasanna, 2013. Adapting maize production to climate change in Sub-Saharan Africa. Food Security, 5: 345-360.
27. CSA, 2011. Federal Democratic Republic of Ethiopia Central statistical Agency Statistical Abstract, Addis Ababa, Ethiopia.
28. Beyene, B., D. Hundie and G. Gobena, 2015. Assessment on dairy production system and its constraints in Horro guduru Wollega Zone, Western Ethiopia. Science, Technology and Arts Research Journal, 4(2): 215-221.
29. CSA, 2014. Agricultural sample survey: Report on farm management practices for private peasant holdings, 3, Addis Ababa, Ethiopia.
30. NMSA (National Meteorological Services Agency), 1996. Assessment of drought in Ethiopia Meteorological Research Report Series, Addis Ababa, 1(2): 259.
31. Korecha, D. and A. Barnston, 2007. Predictability of June–September rainfall in Ethiopia. American Meteorological Society, 135: 625-650.

32. Hare, W., 2003. Assessment of Knowledge on Impacts of Climate Change, Contribution to the Specification of Art, 2 of the UNFCCC. WBGU.
33. Fitsum Bekele, Nega Mosisa and Dejen Terefe, 2017. Analysis of Current Rainfall Variability and Trends over Bale-Zone, South Eastern Highland of Ethiopia. SF J Global Warming 1:2.
34. NMSA (National Meteorological Services Agency), 1996b. Assessment of drought in Ethiopia: Meteorological Research Report Series, Addis Ababa, 1(2): 259.
35. Kassahun Bokretsion, 1999. Ye'ayer Mezabat'na tinbi'ya k'Itiopia Antsar (Climate Change and Forecast in Ethiopia, in Amharic). Paper Presented at a Meeting organized by the DPPC on Climate Change, Drought and Disaster Prevention in Ethiopia, Addis Ababa, Ethiopia.