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Research Article

Analyzing Spatio-temporal Climate Variability Using Geospatial Technology: A Case of North Shewa, Oromia, Ethiopia

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Abstract

Climate change has been one of the most environmental problems facing the world today. Many studies were made on the issue of climate change in different parts of the countries, based on rainfall and temperature data. There was still a wide zone variation among the study area and some lapse in it. Hence, this study aims at analyzing climate variability based on temperature, rainfall and satellite image. Gridded rainfall and temperature data, and satellite image for 30 years, were used for analysis. The overall average rainfall in the last 30 years was 1036.50 mm with standard deviation of + 27.27 mm and coefficient of variation 2.63%. The annual rainfall and pattern show a considerable fluctuation, one year there is a slight positive anomaly and on the other year shows negative anomalies. Based on drought index classification, the statistical result revealed that in the area extremely dry was observed in 2002- 2004. In the year 2000, 2001 and 2011 severely dry was observed. Moderate drought was occurred in 2005 and 2015. No drought (nearly normal) that was observed in the rest observation. The total average rainfall of Kiremt season between 1990 and 2020 was found to be 762.28 mm with +18.74 mm standard deviation and coefficient of variation 2.46%. The mean maximum temperature of the study area over thirty years' time ranging from 1990 to 2020 was 26.03°C with standard deviation +1.25°C and coefficient of variation 4.80%. From the result, there was linear correlation between mean annual rainfall and calculated NDVI value. The r^2 value was 0.8749. Regarding to the graph there was negative correlation (-0.88 correlation coefficient) of mean annual temperature and mean annual NDVI value of the year 1990 to 2020, with 0.766 value of r^2. From the RSCCI, in thirty years observation there was 0.013% decrement in area of dega region from 1990 to 2020, and increment of woinadega and kola by 0.004% and 0.01% respectively. The highest proportion of the area falls within dega (49.93%) of the total area. The second highest (30.54%) area falls within woinadega and kola occupied small portion (19.53%) of the study area. Based on the finding of this study, possible to predict that the study area climate would project to dega (49.53%), woinadega (30.66%) and kola (19.81%) agro-ecology for the next thirty years (2050).

Keywords

Climate Variability, Spatial, Temporal, Remote Sensing Climatic Compound Index

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1. Introduction

Climate change has been one of the most talked issues, particularly since the start of the twenty centuries. The most important climate quantities are most often surface variables such as temperature, precipitation and wind. According to World Meteorological Organization (WMO), over a long period, more than several years, the climate is the statistical description in terms of the mean and variability of relevant quantities, and it is the duration over years and decades, usually over 30 years.

Ethiopia is one of the developing nations which enjoy diversified climatic conditions that range from semi-arid and desert to humid and warm types across its different parts [1]. To this end, there are different ways of classifying the country’s climate systems into several agro-ecological zones (AEZs). Across its AEZs, there was a wide variation in mean annual rainfall and temperature [2].

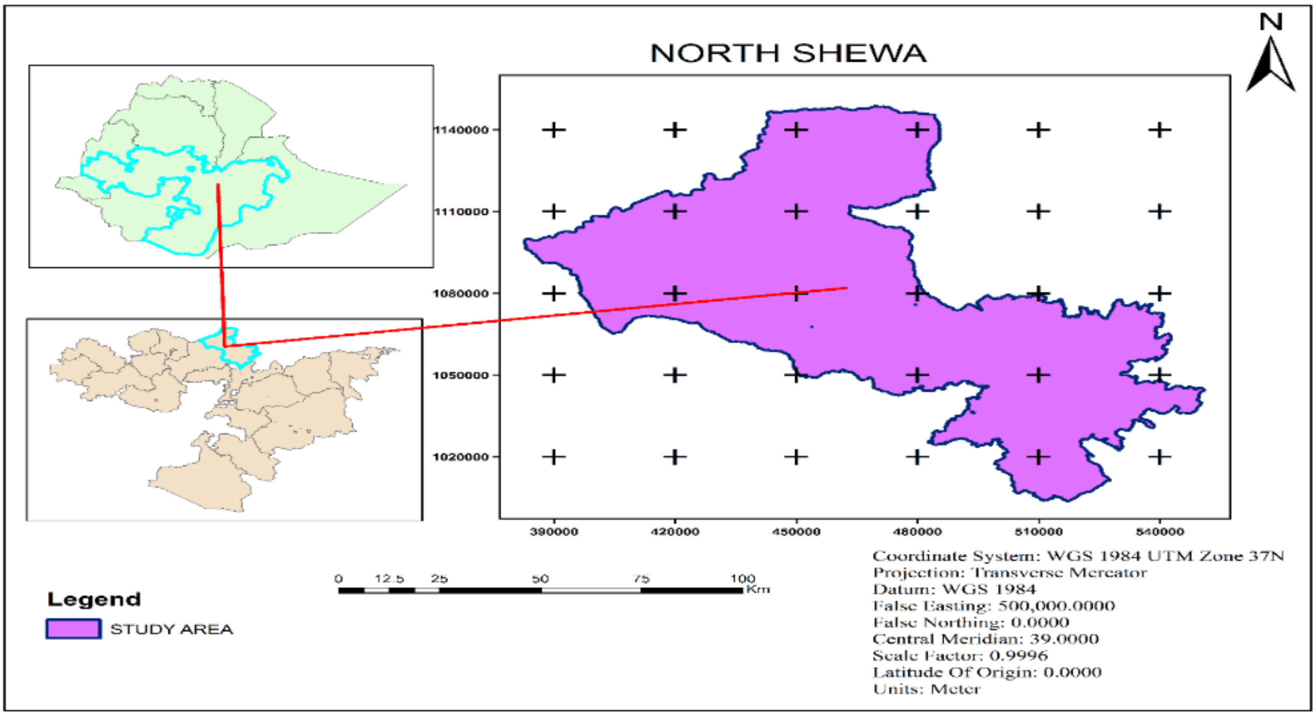
Many studies were made on the issue of climate change and variability in different parts of the countries, based on rainfall and temperature data. There was still a wide zone variation among study area in mean annual rainfall and temperature since the system was done based on interpolation. Therefore, there was some lapse in it [3]. This has been an era of information and technology which makes accessibility of spatial data for scientists and researchers on a broad scale. Access to aerial and satellite imagery is very helpful to study the climatic condition of an area.

Hence, this study was attempted to analyze the Spatio-temporal variability of climate of North Shewa zone by using satellite image. Therefore, this study was a remarkable piece of work which clearly portrays the prevailing situation taking into consideration relevant climatic factors such as, rainfall, temperature and satellite images.

North Shewa zone has faced various problems resulted from climate change. Study done by Dereje et al. [4], denoted that an upward trend of 0.07°C/annum in mean annual maximum temperature at Kola AEZ [5]. It also showed an upward trend of 0.06/year for both Dega and Woinadega AEZs. Mean annual minimum temperature exhibited an upward trend of 0.03°C/year at Kola, Woinadega, and Dega, signifying a 1.05°C increase between 1979 and 2013. The reduced precipitation and rise in temperature could trigger wide-ranging influences on agricultural practices and crop production of smallholder farmers.

2. Materials and Methods

North Shewa Administrative Zone is located in the Oromia National Regional State of Ethiopia. Its latitudinal and longitudinal locations extend from 9°08′52"-10°35′17"N and 37°56′13"-39°34′47"E, respectively.



Data Source

Figure 1. *Location of Study Area.*

Table 1. Data source.

No	Data required	Source	Data type	Year	Data format
1	Rainfall	National Metrological Agency	Secondary	1990-2020	Csv
2	Temperature	National Metrological Agency	Secondary	1990-2020	Csv
3	Satellite image	USGS	Secondary	1990-2020	TIFF

Table 2. List of software.

No	Software	Version	Purpose
1	Arc GIS	10.8	Storing, managing, and analyzing spatial information and produce map
2	ERDAS IMAGINE	2015	Processing and analyzing satellite images
3	SPSS	22	Management and statistical analysis of data
4	ENVI	5.3	Processing and analyzing satellite images

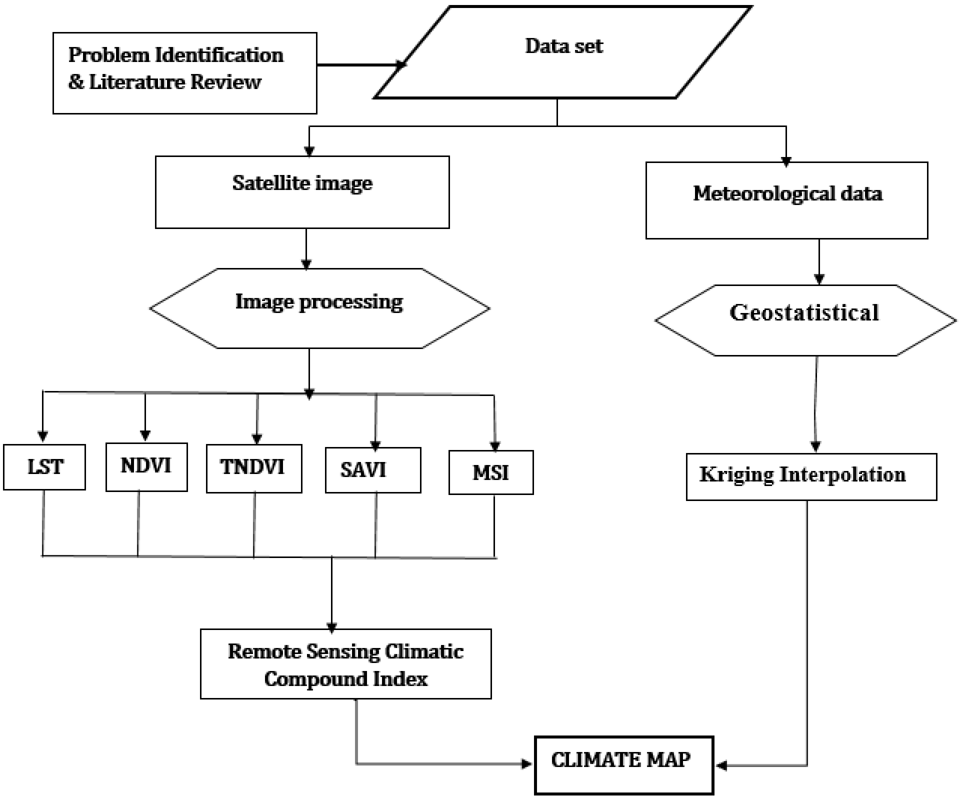


Figure 2. Methodological Scheme of the Study.

Method of Data Analysis

Inter-annual Fluctuation of Rainfall

$$SRA = \frac{Rt - Rm}{\sigma} \quad (1)$$

Where: SRA is standardized rainfall anomaly, R_t: is annual rainfall in a given year, R_m: is long term mean annual rainfall over a period of observation i.e., 1990 to 2020 and σ: is standard deviation of each year annual rainfall over the period of observation (1990 to 2020).

Coefficient of Variation (CV): Coefficient of Variation is a statistical measure of how the individual data value varies *from the mean value.*

$$CV = \frac{\sigma}{X} * 100 \quad (2)$$

Where, CV is the coefficient of variation, σ is the standard deviation and x is the mean.

Precipitation Concentration Index: -

$$PCI_{Annual} = \frac{\sum_{I=1}^{12} PI^2}{(\sum_{I=1}^{12} PI)^2} * 100 \quad (3)$$

$$\mathrm{PCI_{Seasonal}} = \frac{\sum_{i=1}^{12} \mathrm{pi}^2}{(\sum_{i=1}^{4} \mathrm{pi})^2} * 100 \quad (4)$$

Where, pi is the monthly precipitation in month i

Temperature Anomalies

$$STA = \frac{\mathrm{Tt-Tm}}{\sigma} \quad (5)$$

Where: STA is standardized temperature anomaly, $Tt_:$ is annual maximum/minimum temperature in year t, T_m: is long term mean annual maximum/minimum temperature over a period of observation and σ: is standard deviation of maximum/minimum annual temperature over the period of observation.

Land Surface Temperature

In the first step, the digital number of the image is converted into spectral radiance.

$$\mathrm{L\lambda = Lmin + (Lmax - Lmin) * \frac{DN}{255}} \quad (6)$$

Where, L_λ =Spectral radiance, Lmin is the minimum radiance (Watts/ (m^2.srad.μm), Lmax is the maximum radiance (Watts/ (m^2.srad.μm).

In the second step, spectral radiance is converted into sensor radiance value by using Eq.

$$\mathrm{TOA = \frac{Lmax\lambda\ - Lmin\lambda}{Qcalmax - Qcalmin} * (Qcal - Qcalmin) + \ Lmin\lambda} \quad (7)$$

Where, T_{OA} = Top of atmospheric, Q_{cal} is the DN value of pixel, Q_{calmax} is the maximum DN value of pixels, Q_{calmin} is the minimum DN value of pixels.

In step 3, sensor effective radiance is converted into sensor brightness value by using Eq.

$$\mathrm{BT = \frac{K2}{\ln(\frac{K1}{TOA}+1)}} \quad (8)$$

Where, B_T refers to the effective at satellite brightness temperature in Kelvin, K1 (Watts/(m^2.srad.μm)) and K2 (Kelvin) are the calibration constants and T_{OA} is the spectral radiance.

$$T \circ C \ = T\ (K) - 273.15 \quad (9)$$

The first to retrieve LST for Landsat 8 OLI band data, are converted to radiance using the radiance rescaling factors provided in the metadata file by using Eq.

$$\mathrm{L\lambda \ = \ ML * Qcal \ + AL} \quad (10)$$

Where, L_λ temperature of atmosphere spectral radiance.

ML band-specific multiplicative rescaling factor from the metadata (radience multi band X where X is the band number), AL band-specific additive rescaling factor from the metadata (radience_add_band_X, where X is the band number), Qcal quantized and calibrated standard product pixel values (DN).

In the second step, convertion of OLI band data from spectral radiance to brightness temperature using the thermal constants provided in the metadata file using Eq.

$$\mathrm{BT = \frac{K2}{\ln(\frac{K1}{L\lambda}+1)}} \quad (11)$$

Where, BT at satellite brightness temperature (K), L_λ temperature of atmosphere spectral radiance, K1 and K2 band-specific thermal conversion constants from the metadata.

For obtaining the results in Celsius, the radiant temperature is revised using eq.

$$T \circ C \ = T\ (K) - 273.15 \quad (12)$$

In the third step, calculate the NDVI

$$NDVI = Float \frac{\mathrm{(Band\ 5\ -\ Band\ 4)}}{\mathrm{Float(Band\ 5\ +\ Band\ 4)}} \quad (13)$$

In the fourth step compute the proportion of vegetation $P_{v:}$

$$\mathrm{Pv = Square\left(\frac{(NDVI\ -\ NDVImin)}{(NDVImax\ -\ NDVImin)}\right)} \quad (14)$$

Fifth step: Depending on the fractional vegetation cover (FVC) for a given pixel. The land surface emissivity (ε) is calculated using Eq (15) as proposed by [6].

$$\epsilon = 0.004 * \mathrm{Pv} + 0.986 \quad (15)$$

Final step, calculate the land surface temperature using mono window algorithm. A comparative analysis has been done to assess land surface temperature.

$$LST = \frac{\mathrm{BT}}{(1\ +\ \mathrm{W}\ *\ (\frac{\mathrm{BT}}{\mathrm{P}}) * \ln(\varepsilon)} \quad (16)$$

Where, B_T brightness (at-satellite temperature), W wavelength of emitted radiance (11.5μm),

P =14,380 (constant)

Normalized Difference Vegetation Index

$$NDVI = \frac{\mathrm{NIR\ -\ RED}}{\mathrm{NIR\ +\ RED}} \quad (17)$$

$$Yi = \sum_{i=1990}^{2020} \frac{Xi}{N} \quad (18)$$

Where, Yi = overall mean NDVI

Xi = is the average NDVI value of a given year

N= total observation year

Adjusted-Soil Vegetation Index

$$SAVI = \left(\frac{NIR - R}{(NIR + R)} + L\right) * (1 + L) \quad (19)$$

Where, NIR is the reflectance value of the near infrared band, RED is reflectance of the red band, and L is the soil brightness correction factor.

Moisture stress index

$$MSI = \frac{RSWIR}{NIR} \quad (20)$$

Where, RSWIR Remote sensing short wave infrared, NIR near infrared.

Transformed normalized difference vegetation

$$TNDVI = \sqrt{\frac{NIR-RED}{NIR-RED}} + 0.5 \quad (21)$$

Regression Analysis

$$r = \frac{n\sum(xy)-(\sum x)(\sum y)}{\sqrt{[n\sum(x^2)-(\sum x^2)][n(\sum y^2)-(\sum y)^2]}} \quad (22)$$

Where, n is the number of data pairs.

Remote sensing climatic compound index (RSCCI)

$$RSCCI = \frac{LST+NDVI+SAVI+MSI+TNDVI}{5} \quad (23)$$

3. Result and Discussion

Annual Patterns of Rainfall

The annual total rainfall of the study area varies temporally and spatially. Generally, the result showed that the mean annual rainfall distribution across all the three observation varies both in space and time.

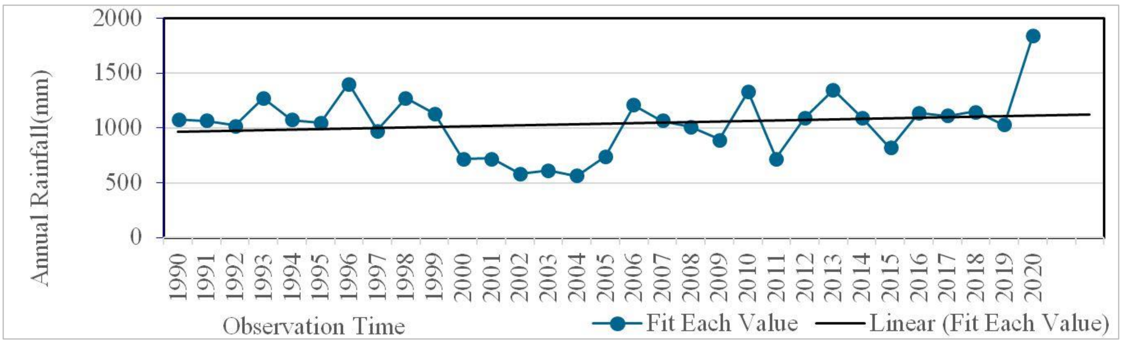


Figure 3. *Total mean annual rainfall trends in the study area between 1990 and 2020.*

Generally, as Figure 3 depicts, the annual rainfall pattern shows a considerable fluctuation, one year there is a slight positive anomaly and on the other year shows negative anomalies.

Table 3. *Annual mean rainfall (mm), SD (mm) and CV (%).*

Year	Maximum	Minimum	Mean	SD	CV (%)
1990-2000	1405.63	720.27	1096.75	18.00	2
2000-2010	1333.83	561.15	872.48	27.31	3.13
2010-2020	1842.5	722.33	1134.26	30.38	2.68

Interannual Fluctuation of Rainfall

The statistical result revealed that in the area extremely dry was observed in 2002, 2003 and 2004. Severely dry was observed in the year 2000, 2001 and 2011 severely dry was observed. Moderate drought occurred in 2005 and 2015. In the rest observation, drought was not prevailed in the area (nearly normal).

The result of standardized rainfall anomalies indicated that the inter-annual variability of rainfall shows lack of annual total rainfall trends for the period from 1990 to 2020.

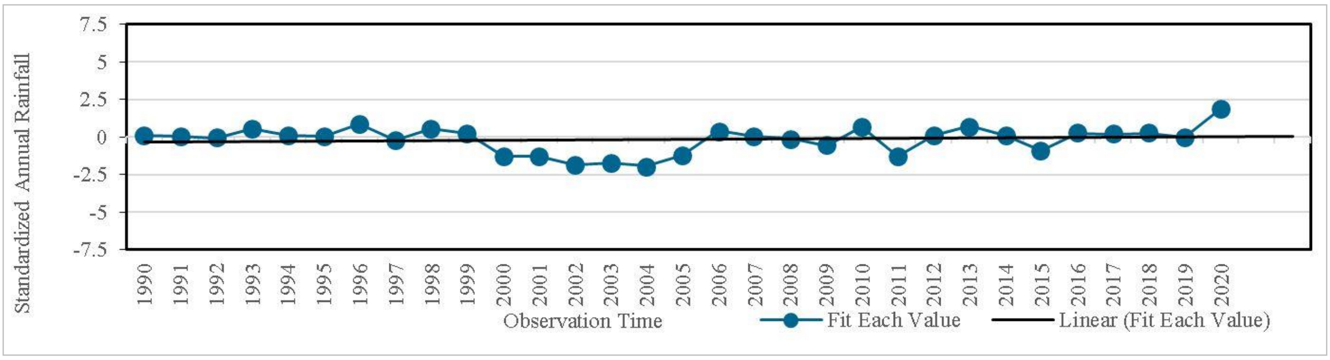


Figure 4. Standardized annual rainfall anomaly in the study site during the observation year b/n 1990 and 2020.

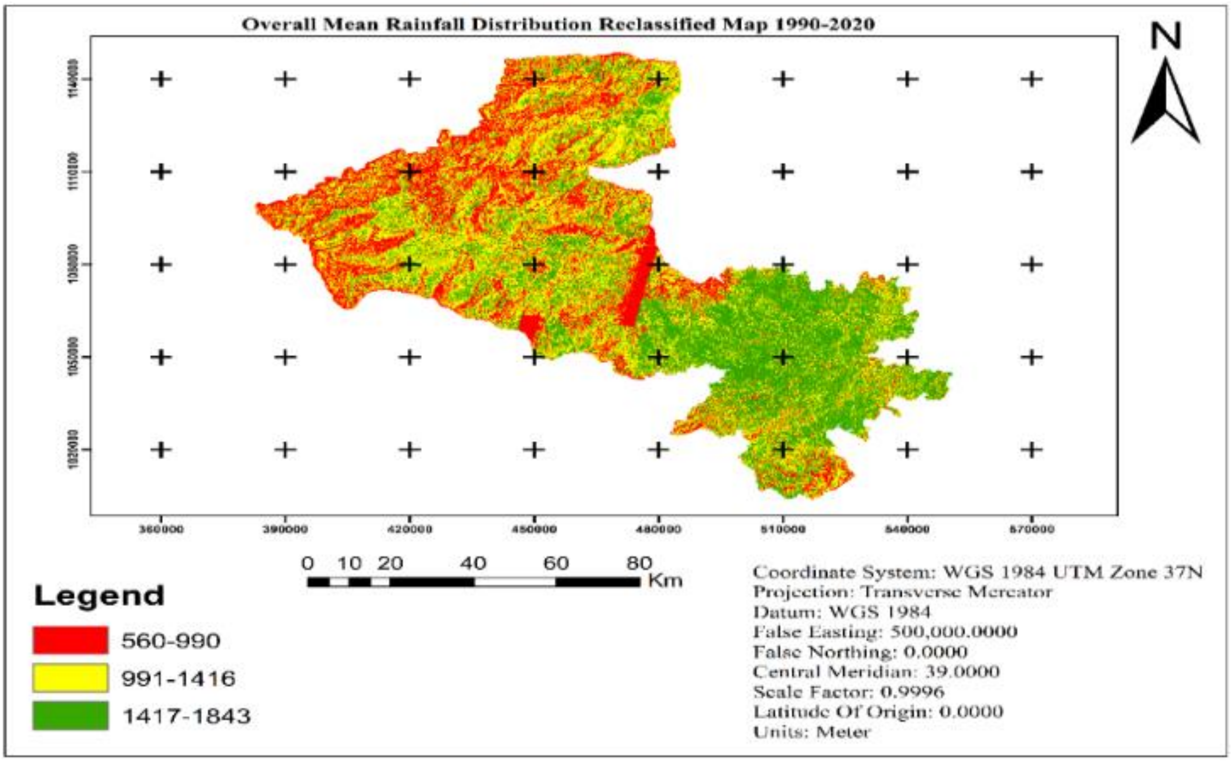


Figure 5. The Overall Mean Rainfall Distribution Reclassified Map 1990-2020.

Kiremt Season Rainfall

The study area received its maximum rainfall during Kiremt season that extends from June to September.

Table 4. Kiremt season mean rainfall (mm), SD (mm) and CV (%).

Decades	Mean Rainfall (mm)	SD	CV
1990-2000	814.60	12.50	0.015344
2000-2010	643.61	21.37	0.0332
2010-2020	823.40	17.59	0.021359

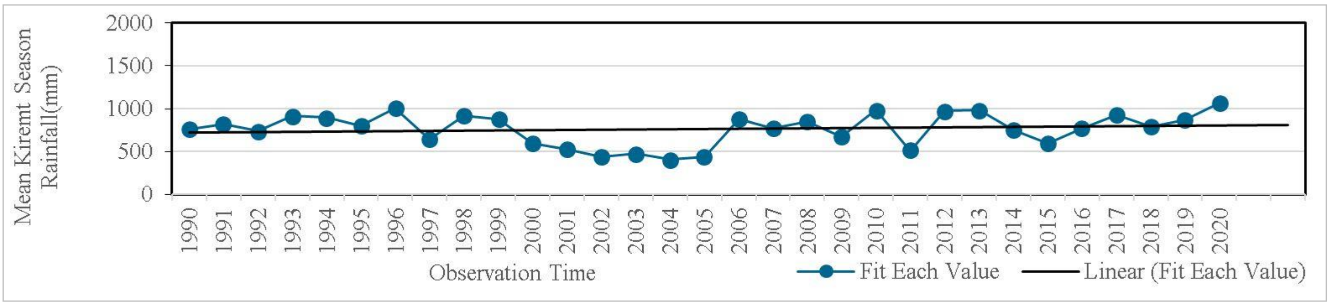


***Figure 6**. Trend of rainfall during kiremt season b/n 1990 and 2020.*

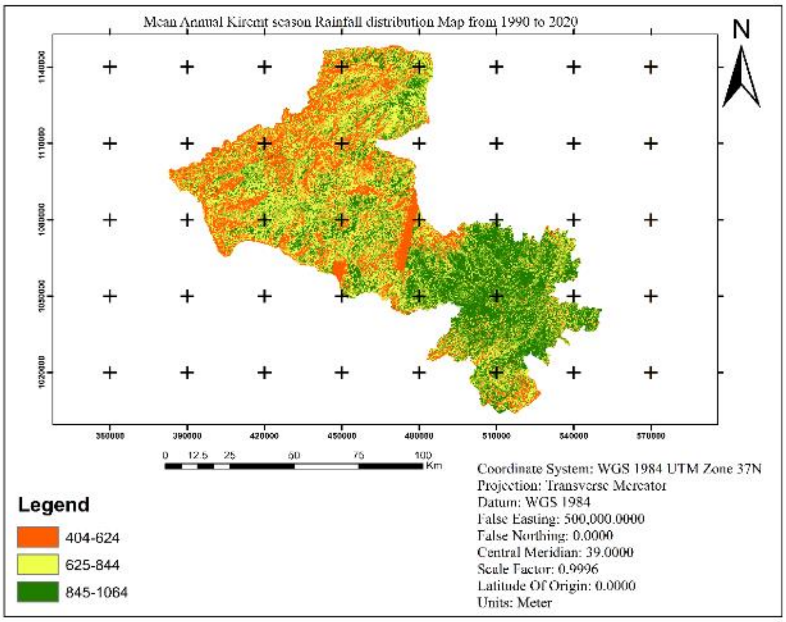


***Figure 7**. Mean Annual Kiremt rainfall distribution between 1990 and 2020.*

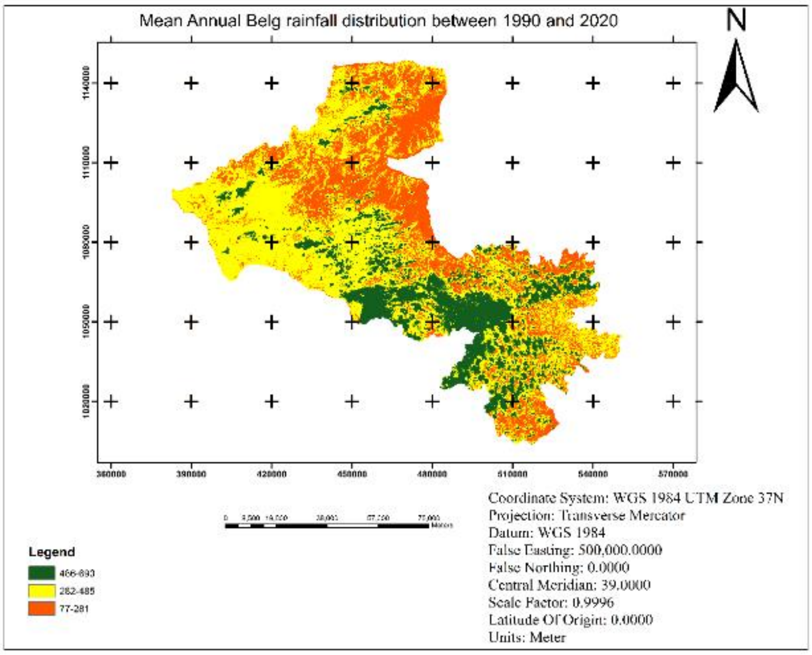


***Figure 8**. Mean Annual Belg rainfall distribution between 1990 and 2020.*

Table 5. Belg season mean rainfall (mm), SD (mm) and CV (%).

Decades	Mean Rainfall (mm)	SD	CV
1990-2000	201.48	7.33	0.04
2000-2010	171.94	9.00	0.05
2010-2020	246.95	17.40	0.07

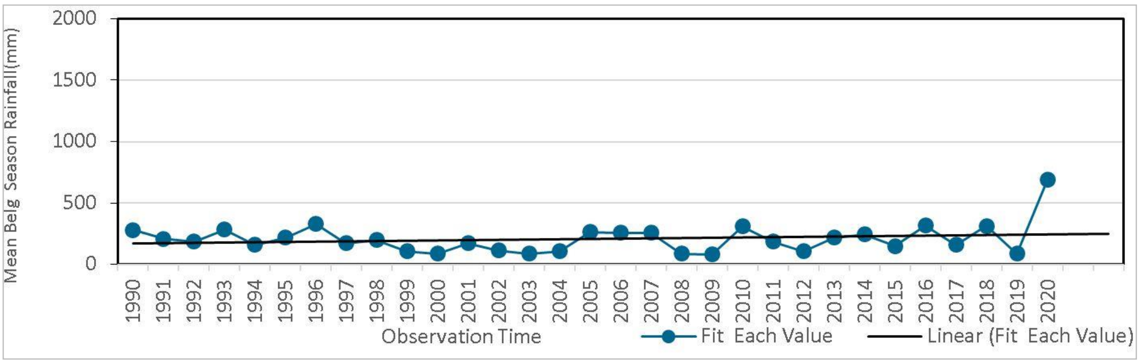


Figure 9. Shows trend of rainfall distribution in belg season from 1990 to 2020.

Bega Season Rainfall

The result of the analysis across the observation (1990-2020) demonstrated that the study area received a mean rainfall of 67.90 mm during the beg a season having a standard deviation of +4.27 mm and coefficient of variation 0.062876 (6.29%) (Figure 10). In thirty years, period of Bega rainfall distribution, the maximum rain was recorded in 1997 which is 165.17 mm, whereas the mean minimum rainfall was 14.85 mm which happened in 2012.

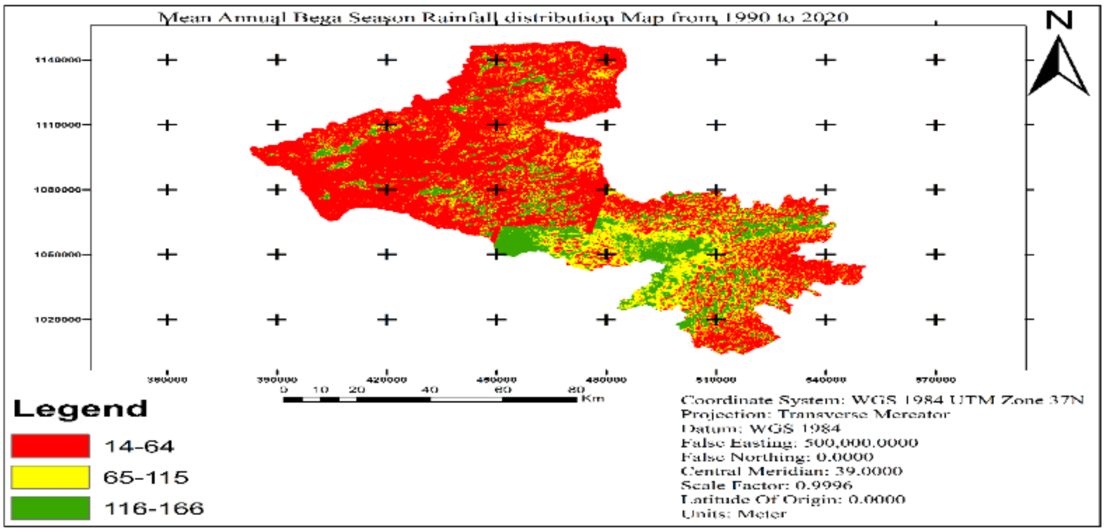


Figure 10. Mean annual Bega season rainfall distribution between 1990 and 2020.

Table 6. Bega season mean rainfall (mm), SD (mm) and CV (%).

Decades	Mean Rainfall (mm)	SD	CV
1990-2000	80.67	5.23	0.06

Decades	Mean Rainfall (mm)	SD	CV
2000-2010	56.93	3.38	0.06
2010-2020	64.81	3.93	0.06

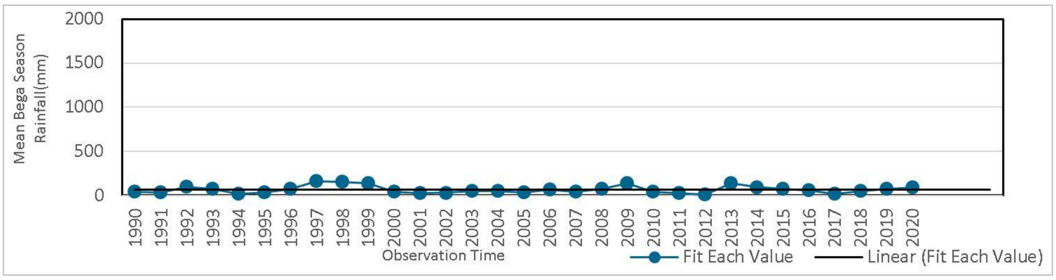


Figure 11. *Shows trend of rainfall distribution in Bega season from 1990 to 2020.*

Table 7. *Annual and seasonal PCI values of rainfall distribution pattern (1990-2020).*

PCI	Annual (%)	Kiremt (%)	Belg (%)	Bega (%)
<10	-	64.52	19.35	16.13
10 - 15	38.71	22.58	54.84	19.35
16 -20	61.29	12.90	19.35	22.58
>20	38.71		6.45	41.94

Table 7, depicts frequency and percentage of annual and seasonal PCI values rainfall distribution for the years ranging from 1990 to 2020. It shows irregular distributions in the annual rainfall pattern. While higher frequency of irregular distributions in the annual rainfall pattern (61.29%), moderate rainfall distribution (38.71%) and more strong irregularity was observed (38.71%) and it was illustrating a more or less uniform and moderate pattern in Kiremt rainfall. It further shows that uniform precipitation distribution (16.13%), moderate (19.35%), irregular distribution (22.58%) and strong irregularity (41.94%) of bega rainfall pattern. Also, it revealed that uniform precipitation distribution (19.35%), moderate (54.84%), irregular distribution (19.35%) and strong irregularity (6.45%) of belg rainfall.

Spatial and Temporal Variability of Maximum and Minimum Temperature

The analysis revealed that the mean maximum temperature of the study area over thirty years period varies from time to time.

Table 8. *Decadal mean minimum and mean maximum temperature, SD and CV.*

Year	Mean (°C)		SD (°C)		CV (%)	
	Max	Min	Max	Min	Max	Min
1990-2000	25.71	11.69	1.03	0.38	4	3.23
2001-2010	25.86	11.94	1.26	0.40	4.86	3.33
2011-2020	26.55	11.84	1.41	0.32	5.32	2.68

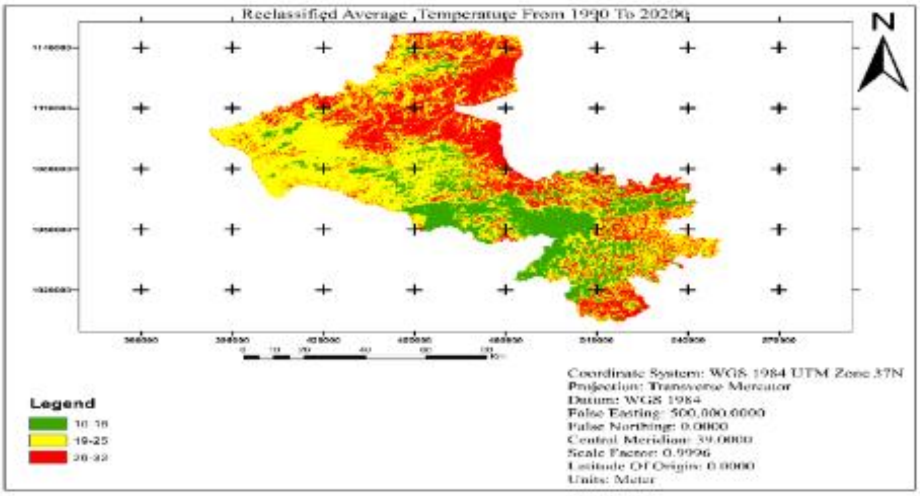


Figure 12. *Reclassified average temperature between 1990 and 2020.*

In the study area, the mean annual maximum temperature reached its highest level 27.66°C, 27.2°C, 27.12°C in the year 2002, 2003 and 2004 respectively. But the lowest temperature was found to be 11.69°C registered in 1996.

Inter-annual Temperature Fluctuation

Inter-annual/annual variation of maximum and minimum temperatures expressed in terms of normalized temperature anomalies averaged. Figures 13 and 14 clearly exhibits that there has been a warming trend in the mean annual maximum temperature over the past 30 years and it has increased by 0.84°C. This clearly shows that there has been a relatively increasing and declining trend in the mean.

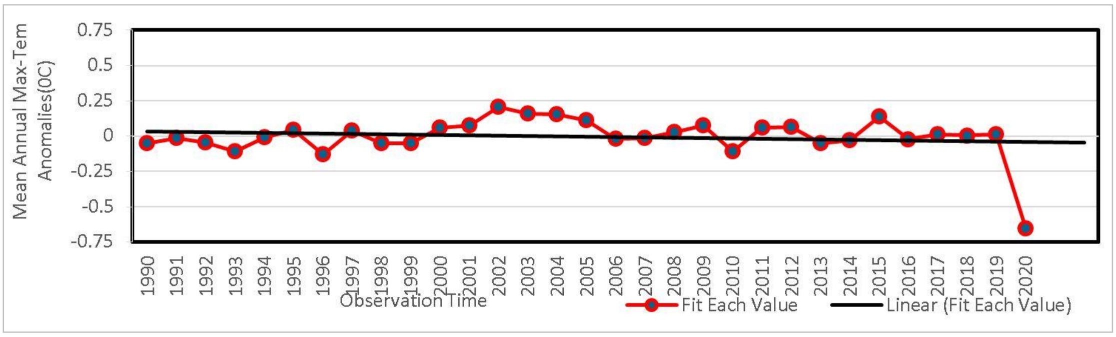


Figure 13. *Mean maximum temperature variability and trend over the study area.*

On the other hand, as depicted in Figure 14, the mean annual minimum temperature over the past thirty years demonstrated that there has been a slight rise and decline unlike the average annual maximum temperature.

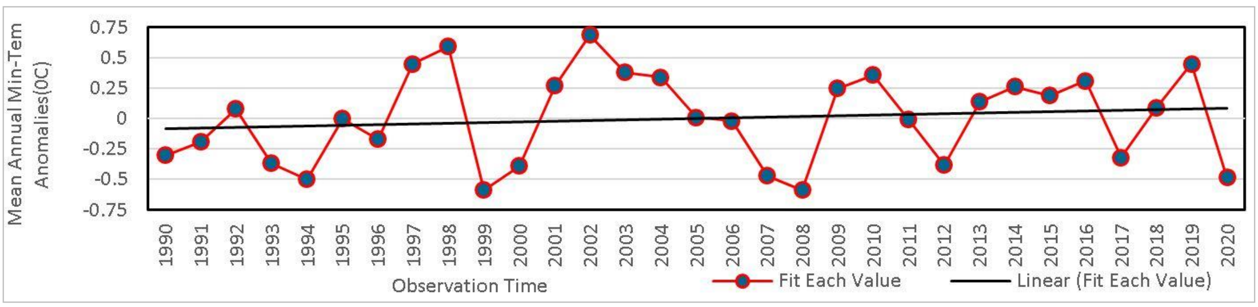


Figure 14. *Mean minimum temperature variability and trend over the study area.*

Correlation between mean annual NDVI and average annual Rainfall

From annual quantitative analysis of vegetation coverage, both the highest and the lowest vegetation coverage were manifested in the year 1990 and 2004 which is 21.30% and 5.29% respectively.

Table 9. *Vegetation Coverage and Coefficient of Variation.*

Vegetation Coverage per decade			
Decade	**1990-2000**	**2001-2010**	**2011-2020**
CV	0.05-0.17	0.17- 0.21	0.12 -0.17
Vegetation Coverage (%)	5.29-16.60	16.60-21.30	11.72 -16.55

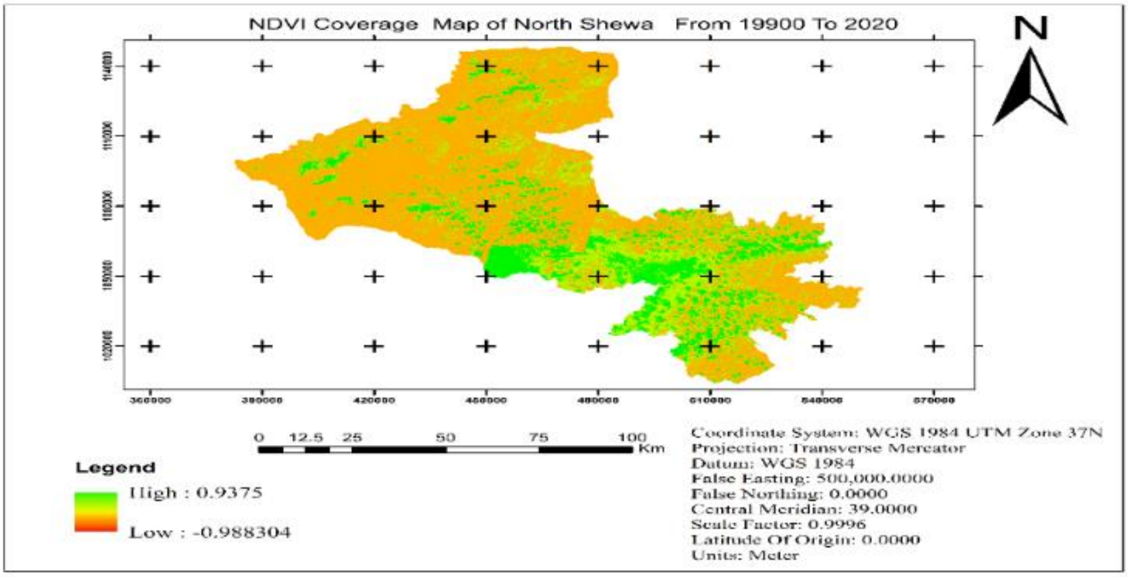


Figure 15. *Depicts the overall average annual NDVI distribution 1990 to 2020.*

From the result, it was possible to deduced that there was linear correlation between mean annual rainfall and calculated NDVI value. The r^2 value was 0.8749 r^2 adjusted is 0.871, and the P value is significant at 0.002 since the threshold for statistical significance level is 0.05. The high value of r^2 shows that the time-series NDVI datasets derived from satellite image was a way forward in the direction of advancement in data availability.

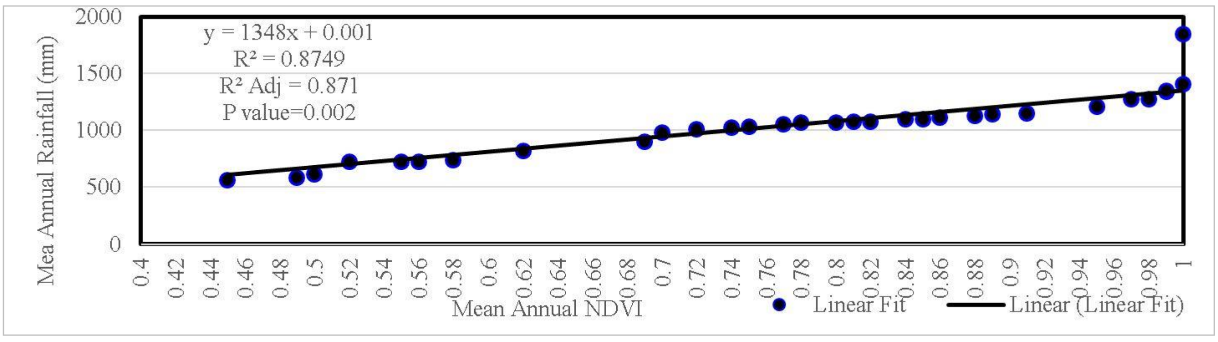


Figure 16. *Shows the correlation b/n mean annual rainfall and mean annual NDVI.*

Correlation between mean annual NDVI and average annual temperature

Regarding to the graph (Figure 17), the correlation of mean annual temperature and mean annual NDVI value of the year 1990 -2020, the result explained that mean annual temperature is negatively correlated (-0.88 correlation coefficient) with NDVI values of the area, which is 0.766 value of r^2. Increase in temperature was not coincides with an increase in NDVI.

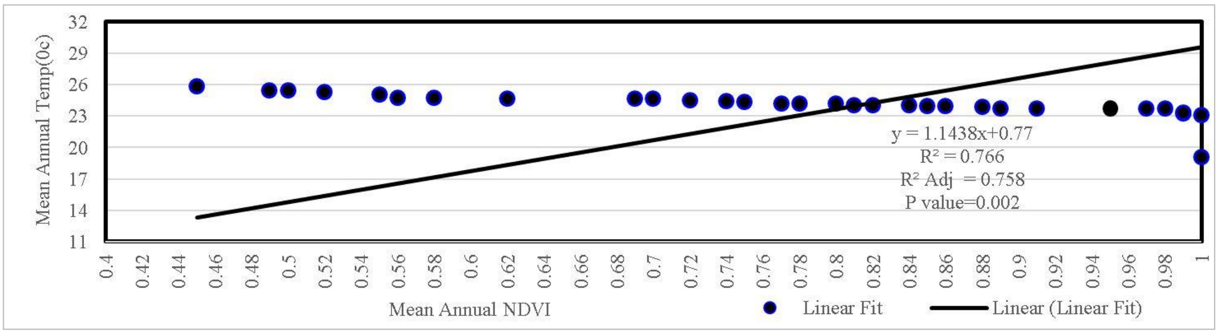


Figure 17. *Shows the correlation b/n mean temperature and mean NDVI.*

Traditional Agroecological climatic classification of Study area using RSCCI

North Shewa zone has been classified into three agro-ecological climatic zones as, dega, woinadega and kola.

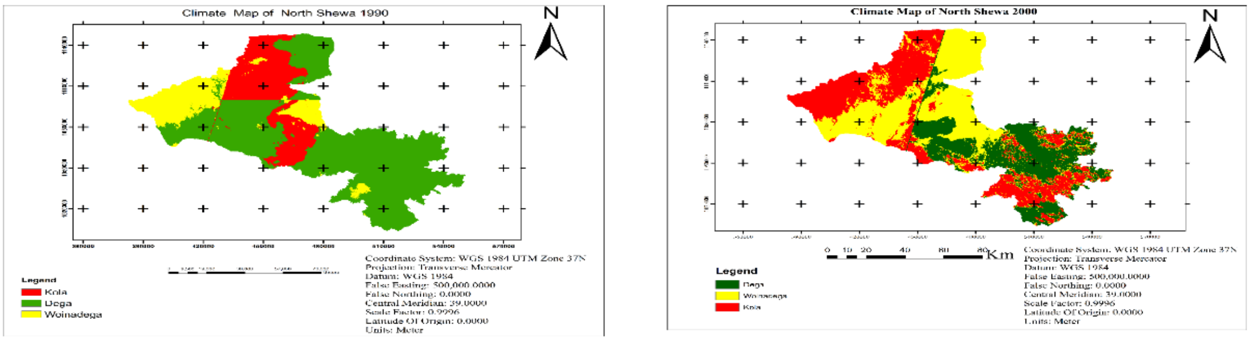


Figure 18. *The climatic classification using RSCCI for year 1990 and 2000.*

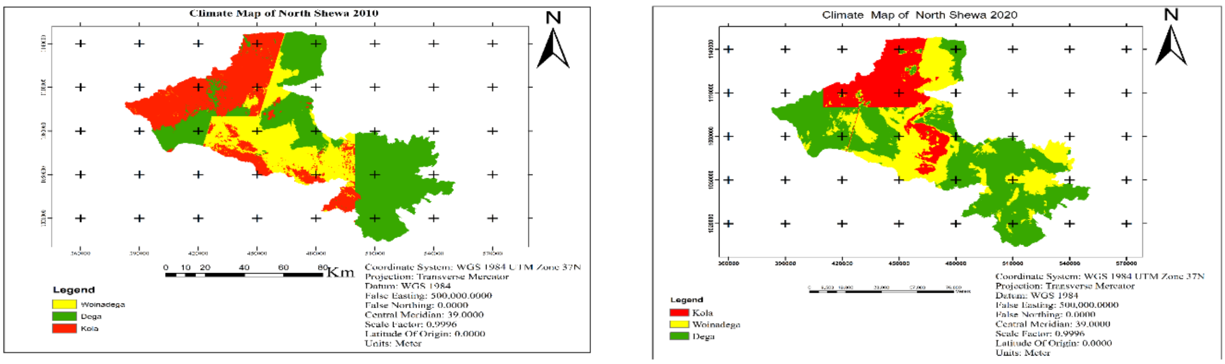


Figure 19. *The climatic classification using RSCCI for year 2010 and 2020.*

Table 10. Area of agro-ecological climatic classification calculated from RSCCI.

Classes	1990		2000		2010		2020	
	Area (hect)	%	Area (hect)	%	Area (hect)	%	Area (hect)	%
Dega	468379.6	50.33	335034.4	36.00	373688	40.15	464659.6	49.93
Woina-dega	283120.8	30.42	373688	40.15	355003.8	38.14	284270.7	30.54
Kola	179190.21	19.25	221968.2	23.85	201998.8	21.70	181760.3	19.53

Discussion

The aim of study was attempted to analyze the spatio-temporal climate variability of study area (1990-2020) using satellite image, temperature and rainfall. The time series analysis of total annual rainfall was done to reveal the general trends of rainfall amounts over the study area. The statistical result revealed that in the area extremely dry was observed in 2002, 2003 and 2004. The results obtained PCI, shows high uniform (64.52%) rainfall distribution during kiremt season than other seasons and annual. Supporting this finding research conducted by [6, 9]. shows 81.6% and 14.2% of the total rainfall was gained in kiremt and belg season respectively in the study area. There has been a warming trend in the mean annual maximum temperature over the past 30 years and it has increased by 0.84°C. Results obtained by [7, 8, 10].; the mean annual maximum temperature showed 0.5°C increase per decade (1981- 2010).

There was linear correlation between mean annual rainfall and calculated NDVI value, and negative correlation with temperature. Similarly, [11, 12]., report shows linear correlation between mean annual rainfall and calculated NDVI value (r^2 =0.35). The highest proportion of the area falls within highland (Dega) of the total area. In agreement with the present study, earlier studies have shown, [5, 13]. report designate that the Dega occupies over 50% of the total area of the zone.

Conclusions

It was concluded from the results of this research that distinguished climatic change has been observed within the boundaries of north Shewa zone in a time span of thirty years from 1990 to 2020. The result shows there was a considerable spatial variation of rainfall and temperature in the study area. The findings of the study revealed that there is a fluctuation of rainfall and temperature in the study area. From the Remote Sensing Climatic Compound Index model there was 14.33% and 4.15% reduction and increased in area of dega region from 1990 to 2000, and from 2000 to 2010 respectively. There was 9.78% increment in area of dega region from 2010 to 2020. In thirty years observation there was 0.013% decrement in area of dega region from 1990 to 2020 and increment of Woinadega and kola by 0.004% and 0.01% respectively. Based on the finding of this study, possible to predict that the study area climate would projected to dega (49.53%), woinadega (30.66%) and kola (19.81%) agro-ecology for the next thirty years (2050).

Recommendations

On the basis of the findings in this study, the researcher makes the following recommendations.

1) Strengthen of further research on the impact of climate change and variability on different socio-economic activities of the societies is very essential.
2) Creation of awareness and public participation on:
   a) Adverse effects climate elements,
   b) Climate change policies,
   c) Environmental and drought monitoring systems and improve the disaster related risk reduction capacity (adaptation and mitigation mechanisms).

Abbreviations

AEZs	Agro Ecological Zones
CSA	Central Statistical Agency
DN	Digital Number
ENVI	Environment for Visualization of Image
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
GIS	Geographic Information System
MSI	Moisture Stress Index
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
RS	Remote Sensing
RSCCI	Remote Sensing Climate Compound Index
SAVI	Adjusted-Soil Vegetation Index
SPSS	Statistical Package for Social Sciences
TM	Thematic Mapper
TNDVI	Transformation Normalized Difference Vegetation Index
USGS	United States Geological Survey
WMO	World Meteorological Organization

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Data Availability Statement

The adequate resources of this article are publicly accessible.

The data and materials used for analysis in this manuscript are available at the corresponding author. It is possible to reasonably request the corresponding author. Also, all secondary and primary data used for the research are available in the hands of researchers.

Conflicts of Interest

This article has no conflicts of interest.

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