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Research Article

Rainfall and Temperature Climatology over Amhara Region

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Abstract

Studying spatial variations in rainfall and temperature is crucial for assessing climate-related changes and designing future water resource management strategies and agricultural planning. This study aims to analyze the climate parameters in the Amhara region of Ethiopia. Rainfall, maximum, and minimum temperatures data spanning from 1991 to 2020 were obtained from CHIRPSv2.0 and ERA5. The results showed that Amhara region had received mostly *Bega*, *Belg*, and *Kiremt* and annually 100-250 mm, 150-300mm, 800-1000 mm, and 1000-1300 mm rainfall, respectively. Climatologically Amhara region received a high amount of rainfall from June to September. Based on the annual rainfall cycle, *Bega* is the dry period over Amhara region. The results also showed that the mean maximum temperatures in *Bega*, *Belg*, *Kiremt*, and annually over Amhara region were 23-27°C, 27-30°C, 21-27°C, and 23-27°C, respectively. The study also revealed that minimum temperatures across Amhara ranged from 9-15°C for *Bega*, 12-18°C for *Belg*, 15-18°C for *Kiremt*, and 9-15°C annually. Based on these findings, we recommend that the Forecast and Early Warning, and Development Meteorology team use this recent climatology to give a seasonal climate forecast easily for various sectors to support the development of climate-resilient agricultural practices and water resource management strategies.

Keywords

Climatology, Rainfall, Temperature, CHIRPS v2.0, ERA5, Amhara

1. Introduction

Climate is a major factor for sustainable development, but autonomous climate cycles caused by natural climate variability disturb social, economic, and ecological systems [1]. Humans also influence regional, sub-regional, and global climate patterns [2-4]. Continued high rates of population growth, industry, transportation, growing reliance on fossil fuel-driven growth technologies, and the effects of land use, such as urbanization, agriculture, livestock, and deforestation, are the main causes of global climate change [5]. Although climate change is global, potential changes and variability are not expected to be uniform around the world, and there can be dramatic variations from region to region [6, 7].

Two of the most extreme and potentially disastrous effects of climate change and variability in East Africa are changes in temperature and the frequency, intensity, and predictability of precipitation [8, 9]. According to Kisaka and Michael [10, 11], changes in regional precipitation will ultimately have an impact on the spatial and temporal patterns of water resources. This could result in decreased agricultural production and productivity, widespread food shortages, and food insecurity [12]. There are a number of studies that assessed the spatial and temporal fluctuations of rainfall and temperature in different

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parts of Ethiopian. However, the results of these studies reveal a range of outcomes, some of which have even been contradictory. Additionally, the majority of investigations employed scant data from meteorological stations, particularly in the Amhara region. Thus, using those stations to make generalizations about the entire Amhara region is challenging. This study closes this gap by presenting a more thorough examination of temperature and precipitation with respect to annual and seasonal fluctuations, using one hundred twenty one sample points of CHIRPSv2.0 and ERA5 data. To that end, analyzing and assessing the climatology of rainfall and temperature through scientific investigations is crucial in order to help researchers, policymakers and developers to make more informed decisions, at regional and/or local levels [13]. Access to information aids in formulating suitable strategies, such as selecting appropriate crops or varieties, determining the optimal planting time, and implementing effective land management techniques, all tailored to the specific location and seasonal climate conditions of the region. Therefore, the objective of this study is to assessment and assessing the spatial variability of monthly, seasonal and annual rainfall and temperature using dense CHIRPS v2.0 and ERA5 data respectively, over Amhara region for the period 1991-2020.

2. Materials and Methods

2.1. Description of the Study Area

The Amhara region is one of Ethiopia's highest regions, encompassing thirteen administrative zones and the area located between $8^0$45'N and $13^0$45'N latitude and $35^0$46' and $40^0$25'E (Figure 1). The total area of the study area is estimated at 156, 960 km^2. The climatic conditions in the Amhara region are categorized based on altitude: *Kola* (hot zone) below 1500 masl (31% of the region), *Woyina Dega* (warm zone) between 1500-2500 masl (44% of the region), and *Dega* (cold zone) between 2500-4620 masl (25% of the region) [14]. Based on annual rainfall distribution, eastern Amhara region is characterized by bimodal rainfall patterns, whereas western Amhara region is characterized by unimodal rainfall patterns. Three distinct rainfall seasons occur in this study area: the main rainy season called, *Kiremt* (June-September), which accounts for 70% of the rainfall [15]. The dry period, which cover from October to January, are locally known as *Bega*. The second rainy season is cover from February to May, are locally known as *Belg* [16-18]. According to Seleshi and Zanke [18] and Ayalew [14], the *Kiremt* and *Belg* seasons account for 74.3% and 5-30% of the annual rainfall, respectively, in the Amhara Regional State of Ethiopia. In contrast, in the northern and northeastern regions of western Amhara, the *Kiremt* season contributes more than 90% [9]. The long-term average annual rainfall in the eastern Amhara region, it ranges from 516.9 mm to 1,342 mm [6], while in the western Amhara region varies from 600 to 2,300 mm [9]. Likewise, the annual mean temperature in the region typically ranges between 15°C and 21°C, although it can rise to as high as 27°C in valleys and other marginal areas [14].

Economic activity

Agriculture continues to be the main economic sector in the region. Generally speaking, it makes up 55.8% of the area GDP on average, and 88.7% of the population makes their living from agriculture and related industries [14]. It is the main supplier of food, raw materials, and revenue from exports for the nearby industries. The area is home to a variety of flora and fauna species due to its unique agro-ecology.

Population

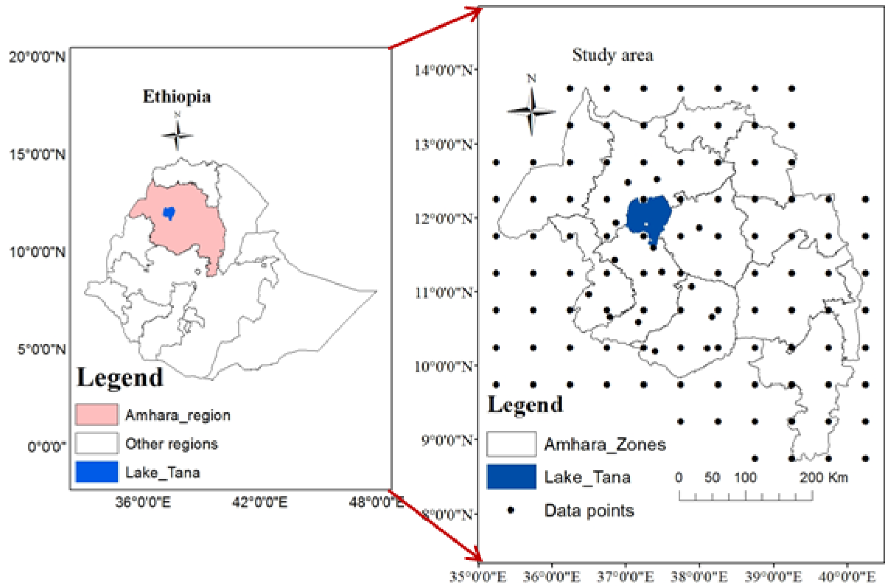


Figure 1. Study area and data points.

The region's population makes up about 25.5% of the nation's overall population, while it only makes up 15.4% of the country's total area [4]. Therefore, the population of the region would double in 25 years if the current pace of population growth continues. In terms of the distribution of settlements, the vast majority of people, or around 89% of the total population, live in rural areas and work primarily in agriculture. Compared to the lowlands, the highlands are more densely populated. Looking at the population's age distribution, 80.6 percent of people are under 14, and 6.2 percent of people are 65 years of age or older. As a result, the age dependency ratio reaches 86.8%. This merely demonstrates that there is an additional person to shoulder the socioeconomic burden for each individual.

2.2. Data Types and Sources

2.2.1. Satellite Precipitation Product

Satellite precipitation products are obtained from different institutions and organizations and are freely available. There are different sources of uncertainty in precipitation estimates from satellite-based products. The common sources of errors can generally be associated with data processing, discrete sampling, radiance measurements, retrieval algorithms, and the view of the sensors [19].

The CHIRPSv2.0 (ftp://chg ftpout. geog. ucsb. edu/pub/org/chg/products/CHPclim/) is a high-resolution satellite precipitation dataset for nearly 40 years developed by the Climate Hazards Center (CHC). The CHIRPS covers 50° S to 50° N latitudes and all longitudes with a spatial resolution of 0.05° [20]. The performance of rainfall products has been evaluated in different areas of the world for different applications. Literatures showed that different researchers used different number of stations, study time period, evaluation approach, and also type of continuous and categorical statistical indices used as well as study area coverage and evaluation timescale. For instance, a study by Ageet [21] and Aniley [22] evaluate the performance of CHIRPS v2.0 with other datasets over Equatorial East Africa and over Ethiopia, respectively. They conclude CHIRPS has better performance and greatest skill in detecting rainfall events measured in volumetric rainfall. Furthermore, Belay [23] evaluated the multi-source satellite rainfall product of CHIRPSv2.0 to assess the spatio-temporal rainfall variability in data scarce regions of Beles River Basin. The analyzed result showed a slight overestimation of daily, monthly and annual rainfall for the low land region and underestimation for the high land region. The author concludes that the performance of CHIRPSv2.0 rainfall varies spatially within a small basin level.

The CHIRPSv2.0 dataset can be downloaded daily data in NetCDF format and extracted based on station latitude and longitude by using the R statistical package for the time period 1991-2020. After extracting the CHIRPSv2.0 data, the One hundred twenty one grid points were purposely selected based on the fair distribution of the grid points in the study area (Figure 1).

2.2.2. Reanalysis Data

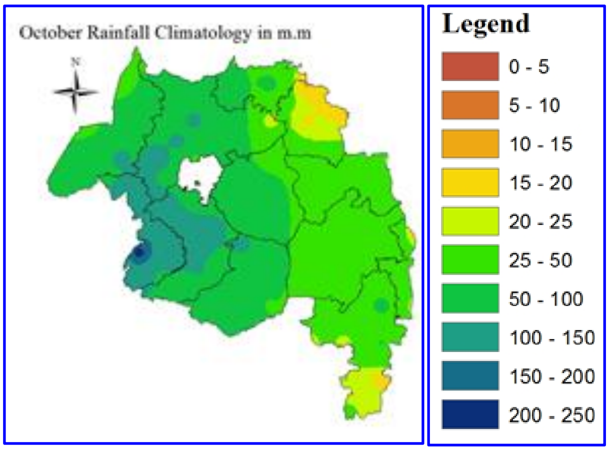
Additionally, for this study, the temperature time series data used for the daily maximum and minimum temperature came from reanalysis products from 1991 to 2020. The European Center for Medium-Range Weather Forecasts (ECMWF) has released the global atmospheric reanalysis dataset ERA5. This dataset makes data from weather balloons, satellites, and ground stations. With long-term (1950-present) global coverage of meteorological data, ERA5 offers a horizontal resolution of 0.25° latitude-longitude. Recent climate studies in Africa [24, 25], Asia [26-28], and on the global scale [29, 30] have found that ERA5 performs the best. ERA5 has several key improvements over previous global reanalysis products; better temporal and spatial resolutions are one of its primary advantages. Every data point is connected to precise latitude and longitude coordinates, arranging the data on a standard grid. The ERA5 temperature data is commonly recorded in degrees Celsius and is available at various pressure and surface levels. The ERA5 daily maximum and minimum temperature data at a height of 2 meters was obtained from the Copernicus Climate Change Service website: https://climate.copernicus.eu/climate-reanalysis and downloaded in the NetCDF format and converted to CSV format using the Climate Data Tool (CDT) package in R software. To assess the spatial variability of temperature, One hundred twenty one grid points were purposively selected, ensuring a fair distribution of grid points across the study area.

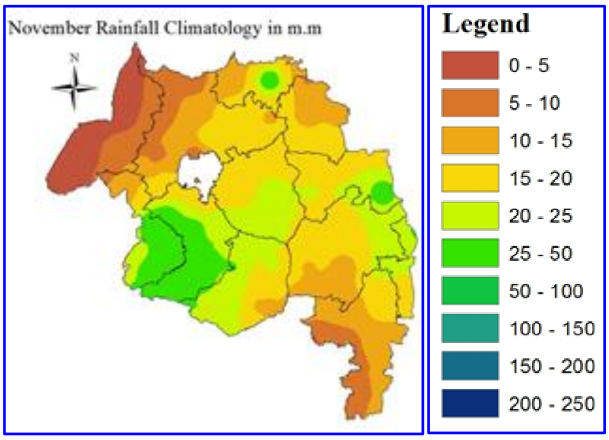
3. Results and Discussions

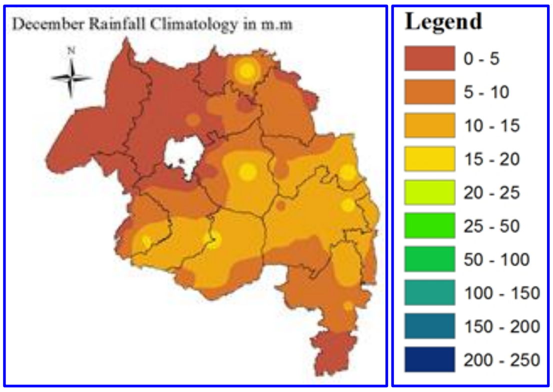
3.1. Climatology of Rainfall

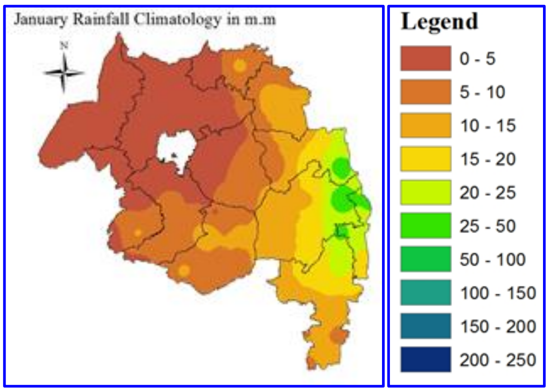
3.1.1. Rainfall Climatology During *Bega* Season

The mean *Bega* season rainfall in the Amhara region is distributed geographically between 25 mm and 250 mm. The Figure shows that western, central and eastern parts of the Amhara region are received the maximum amounts of rainfall (100 mm-250 mm. However, the northern and northeastern parts of the study area received low amounts of rainfall (25mm-100 mm) (Figure 2). The results are little bit contradict with those of Alemu and Bawok [31] who discovered that most of Amhara region had less than 150 mm during *Bega* season. This may be due season classification.









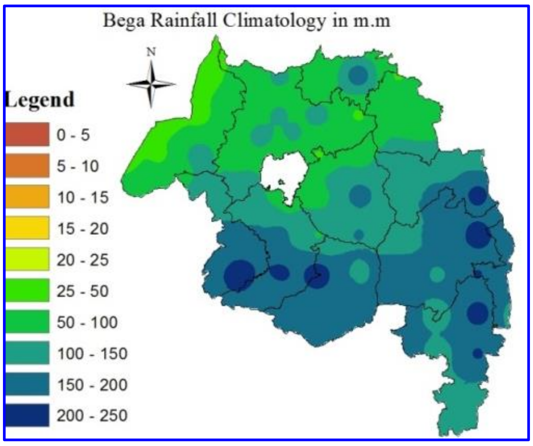
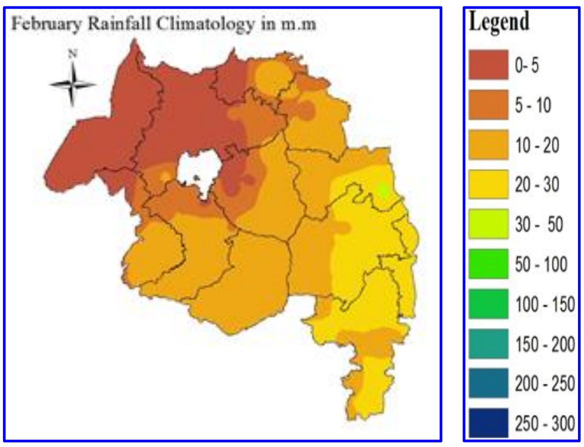


Figure 2. *Rainfall climatology for Bega season.*

Bega season predominantly falls under the influence of hot, dry days and cool nights [18, 32]. Those dry air masses originate from the Saharan anticyclone and Siberia high-pressure systems. Most of the highland regions have occasional frost in addition to early morning frost. Occasionally, however, low-pressure systems that originate in the Mediterranean migrate southward and combine with tropical systems, disrupting northeasterly winds and causing unseasonal rainfall in northwest Ethiopia.

3.1.2. Rainfall Climatology During *Belg* Season

The long-term mean *Belg* season rainfall in the Amhara region is distributed geographically between 50 mm and 300 mm. The Figure shows that western, central and eastern parts of the Amhara region are received the maximum amounts of rainfall (150 mm-300 mm. However, the northern and northeaster parts of the study area received low amounts of rainfall (50-150 mm) (Figure 3). The results align with those of Fazzini [33] who discovered that most of the Amhara region had less than 100 mm - 200 mm during *Belg* season. However, Fazzini [33] report that the northern part of the Amhara region receives less than 100 mm. But, in this study including northern, most of the Amhara region had received more than 100 mm during *Belg* season.



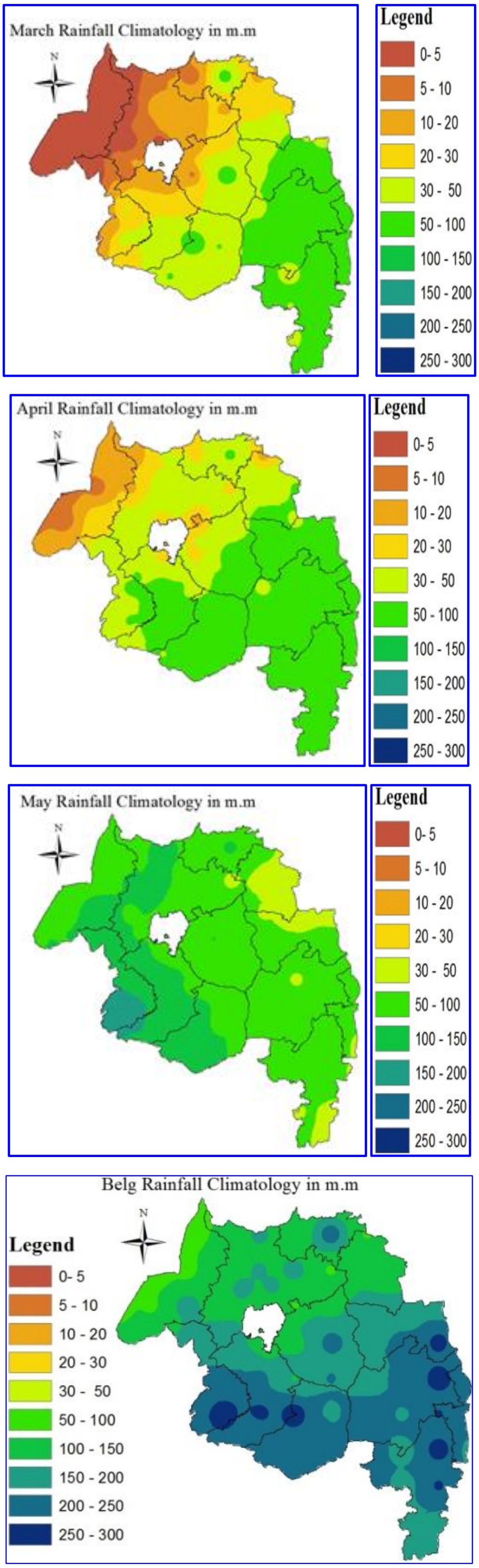
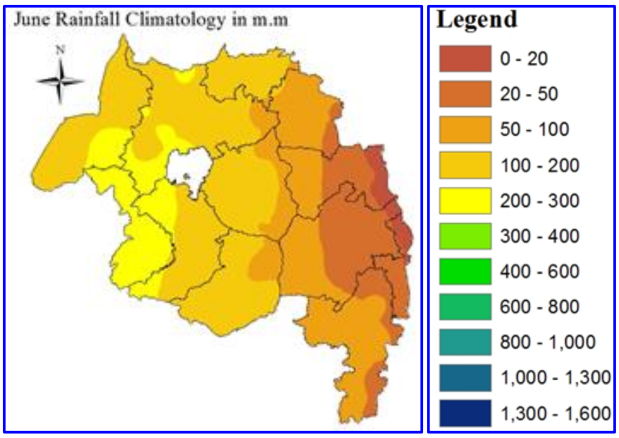


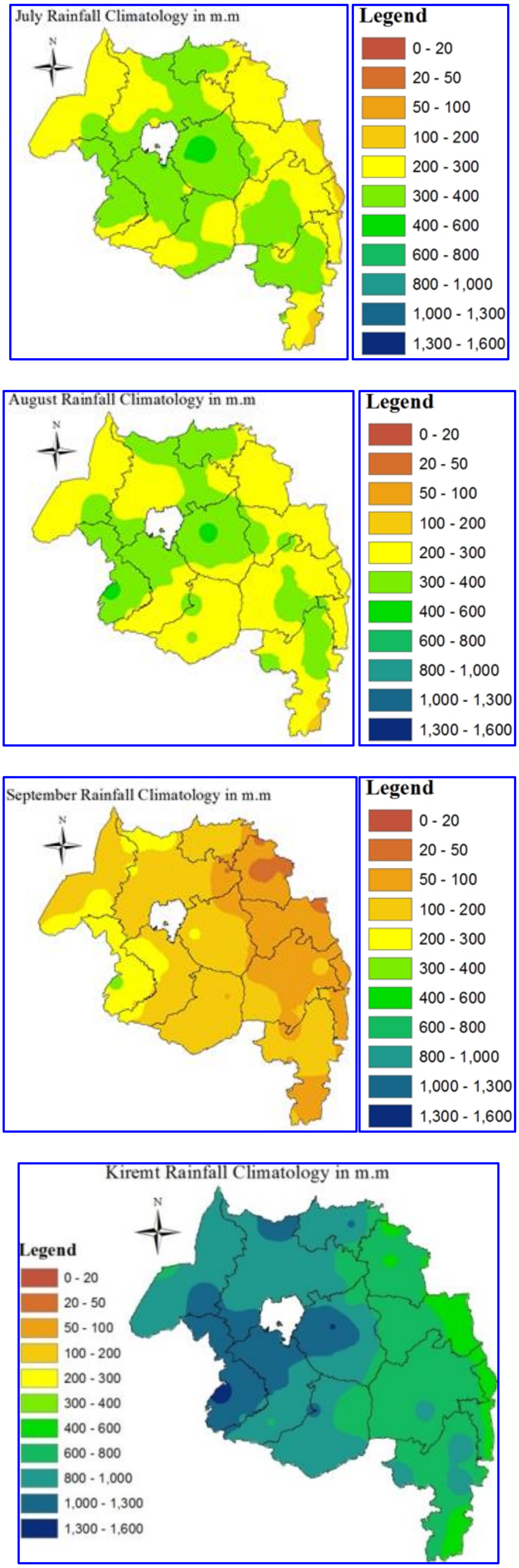
Figure 3. *Rainfall climatology for Belg Season.*

Belg is the small rainy period for most parts of Ethiopia except for south and southeastern low-land areas [17, 32]. This season has a great deal of regional and temporal variability in rainfall as well as a high frequency of maximum temperatures in certain places [34, 35]. March, April, and May are the warmest months during the *Belg* season. Global governing systems affecting *Belg* season: mid-latitude frontal systems from the Mediterranean Sea, moisture inflow from the northern Indian Ocean and the adjacent Arabian Sea, seasonal oscillation of the ITCZ, ENSO phenomena, IOD phenomena, and the formation and propagation of tropical cyclones across the southern Indian Ocean. From February to May, the Arabian High moves toward the northern Arabian Sea and pushes over the water body, causing a moist, southeasterly air current to flow toward Ethiopia [17]. Occasionally, there are also frontal lows that either originate from the Mediterranean area or originate within the Atlantic Ocean and are swept through from west to east; this produces excess rainfall over the east, central, and south parts of Ethiopia [34]. Therefore, moist, easterly, and southeasterly winds produce *Belg* rainfall, which is the short rainy season for many parts of the country but the main rainy season for the southern and southeastern parts of Ethiopia [32].

3.1.3. Rainfall Climatology During *Kiremt* Season and Annually

During the *Kiremt* season, most parts of central, northern, and western showed high rainfall amounts (800 mm-1000 mm), whereas the smallest rainfall distribution was recorded in some parts of northern and northeastern areas of Amhara (400 mm-800 mm) (Figure 4). This result also in line those of [14] who reported that spatial distribution of annual rainfall was varied from 850 to 1485 mm over Amhara region. However, in this study south western area of Amhara region received up to 1600 mm. The formation of a subtropical high-pressure system over St. Helena, Mascarene, and the Azores affects Ethiopia's moisture flux and rainfall due to the systems' strength and position [36].





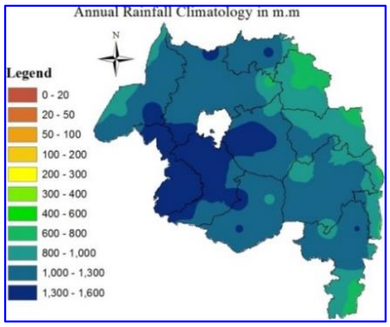


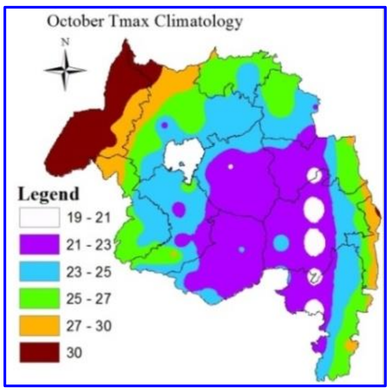
Figure 4*. Rainfall climatology during Kiremt season and annually.*

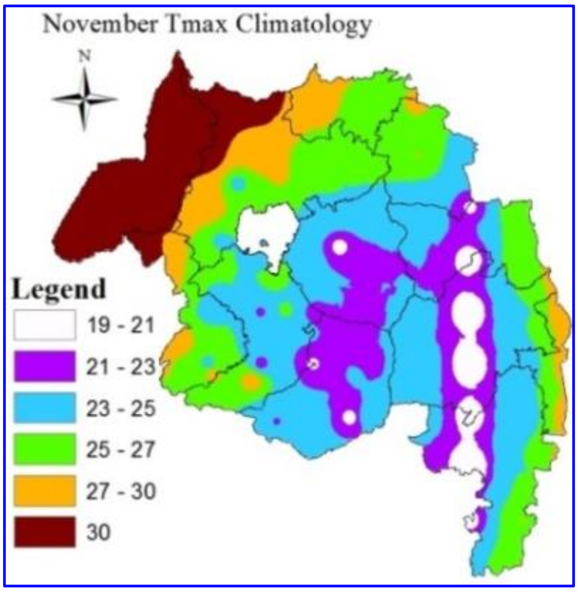
Similarly, the regional distribution of annual rainfall from 1991 to 2020 is shown in Figure 4. Long-term mean annual rainfall in the Amhara region is distributed geographically between 800 mm and 1600 mm. The Figure shows that western and northeastern parts of the Amhara region are received the most and least rainfall, respectively. Wagihmera, north Wollo, and Oromiya special zones are the areas receiving a small amount of annual rainfall, while Awi and west Gojjam zone is the area receiving a high amount of rainfall. Most parts of Amhara region have received 1000 mm-1300 mm of annual rainfall (Figure 4). This results are also in line those of Alemu and Mesfin [31, 37] who reported that spatial distribution of annual rainfall was varied from 1000 to 1300 mm over most of Amhara region. However, in this study south western area of Amhara region especially Awi zone received up to 1600 mm.

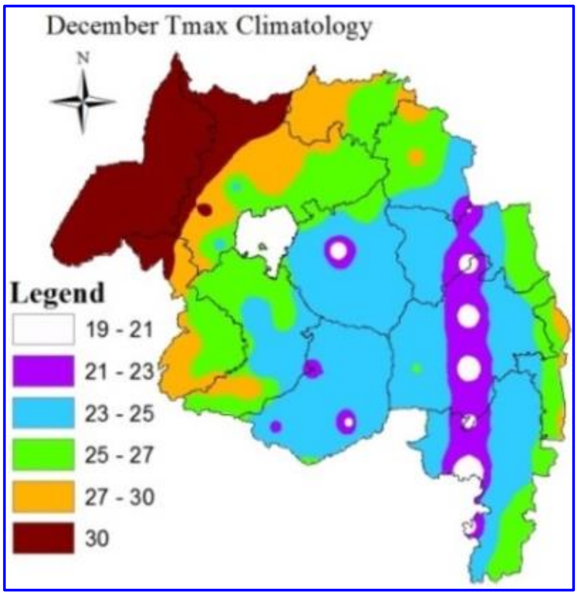
3.2. Climatology of Maximum Temperature

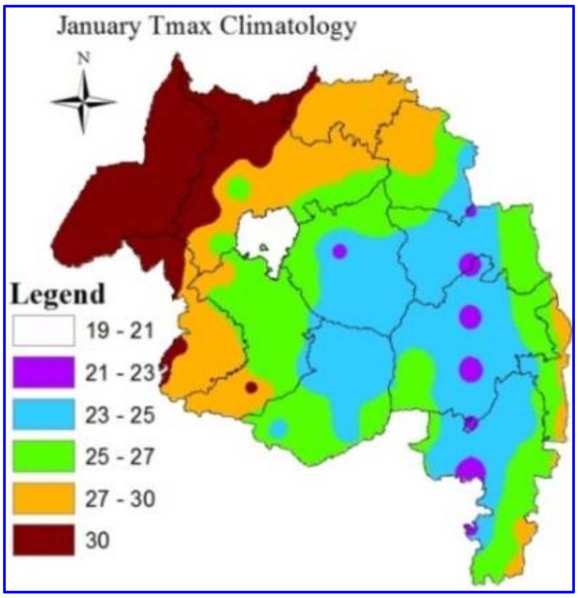
3.2.1. Climatology of Maximum Temperature During *Bega* Season

Some highland areas of Amhara region like Deber Tabor, Dingayber, Gidan, Wadela, Teneta, Woreielu, Jama and Ensaro have been recorded 19-23°C during *Bega* season (Figure 5). Most parts of Amhara region have been recorded 23-27°C maximum temperature during *Bega* season. Some parts of central Gondar and north Gondar have been recorded 27-30°C. Whereas, western parts of west Gondar has been recorded more than 30°C maximum temperature.









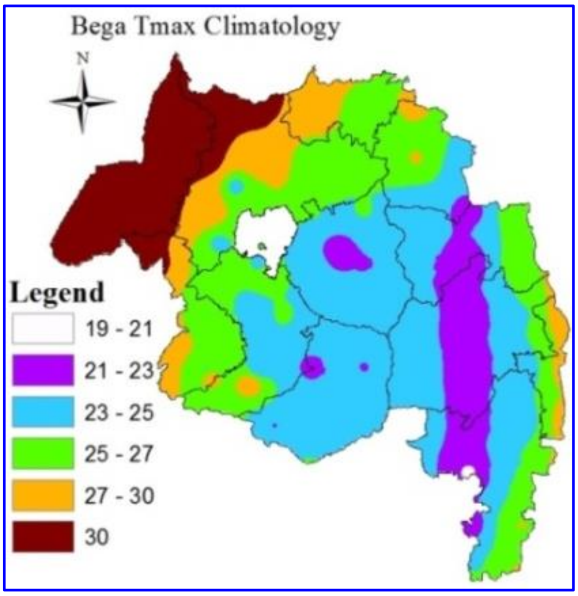
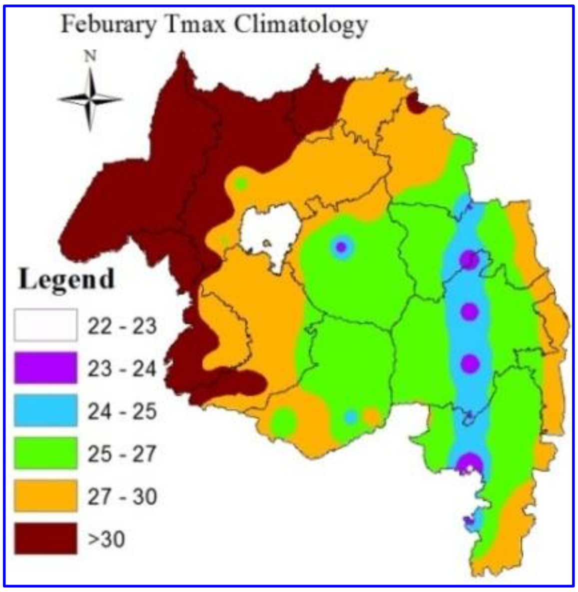
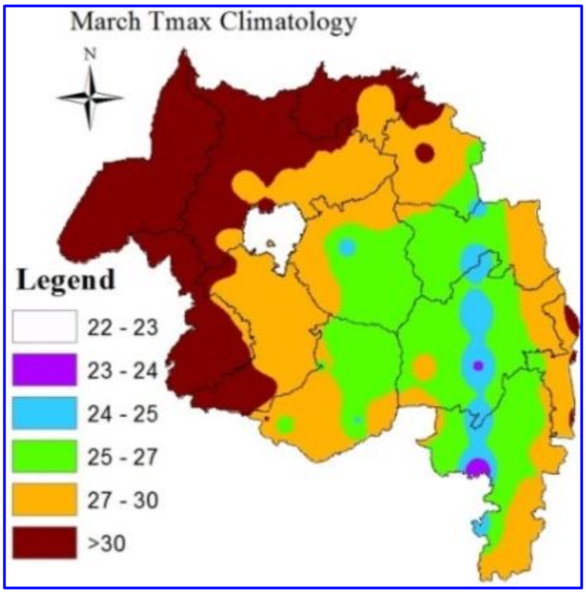


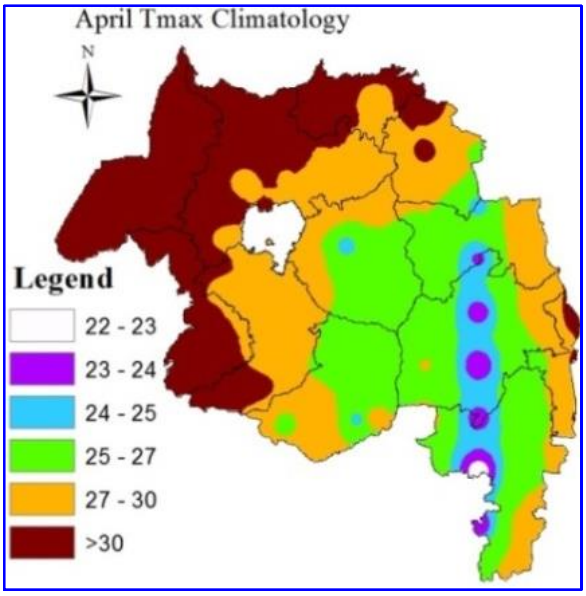
Figure 5. *Climatology of maximum temperature over Amhara region during Bega season.*

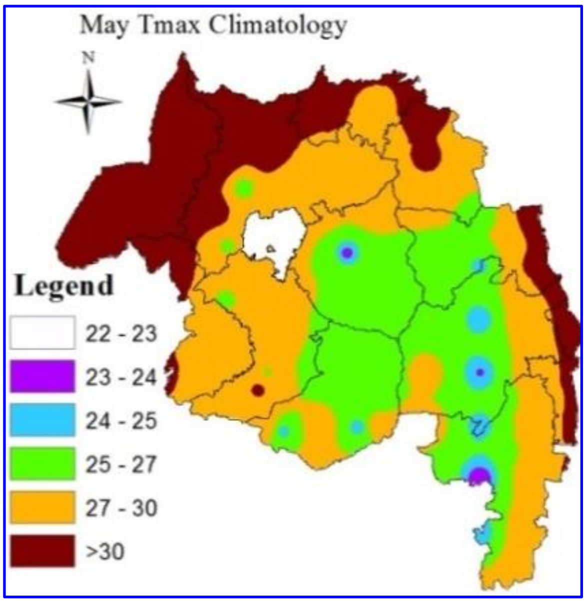
3.2.2. Climatology of Maximum Temperature During *Belg* Season

Similarly, during *Belg* season maximum temperatures in most parts of Amhara region have been reported to range from 25 to 30°C, with the exception of a few pocket regions. During the *Belg* season, the maximum temperature ranged from 27°C to 38°C in the northwestern Amhara region, as well as in certain areas of Awi zone (Figure 6). These results, in line with those of Gashaw [38], conclude that maximum temperature ranged from 19.3°C to 21.1°C in the cool and moist AEZ during the *Bega* and *Belg* seasons, respectively. Similarly, in the warm semi-arid agroecology zone, the highest maximum temperature was observed in the *Belg* season (31.7°C).









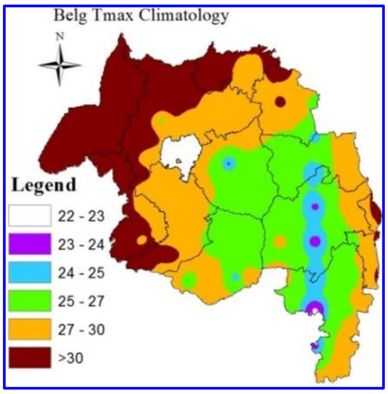
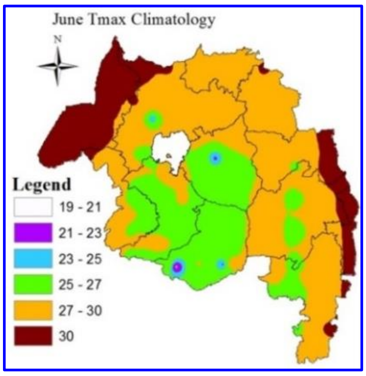
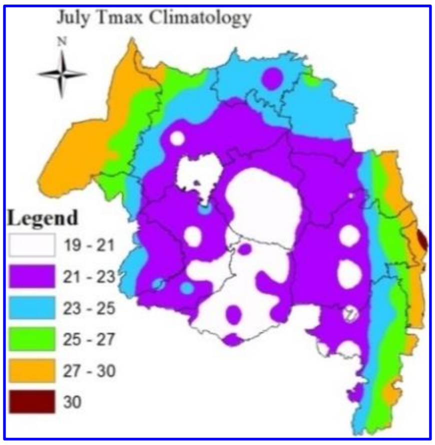


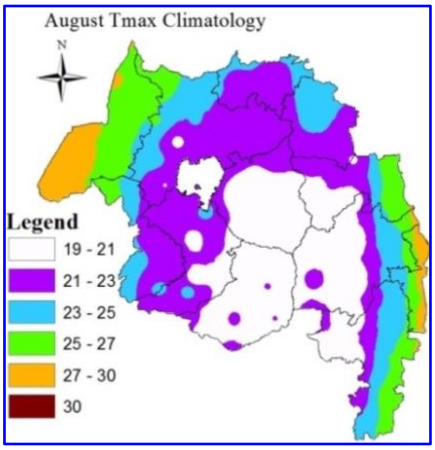
Figure 6. *Climatology of maximum temperature over Amhara region during Belg season.*

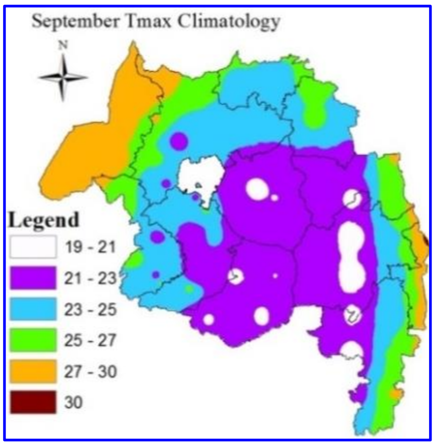
3.2.3. Climatology of Maximum Temperature During *Kiremt* Season and Annual Time Scale

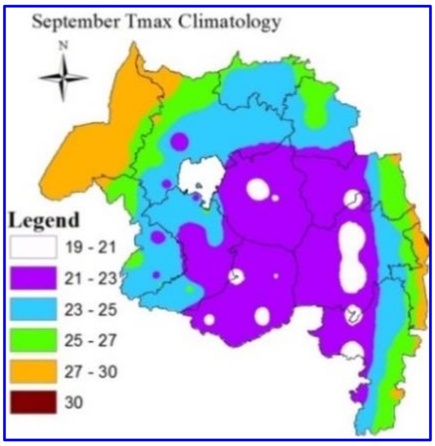
Similarly, during *Kiremt* season maximum temperatures in most parts of Amhara region have been reported to range from 21 to 27°C, with the exception of a few pocket regions. While the during the *Kiremt* season, maximum temperature have been ranged from 27°C to 32°C in the western portion of west Gondar, as well as in certain areas of Awi zone (Figure 7). Overall, the maximum temperature during *Kiremt* season is gradually decreased from July up to September. Similarly, the maximum temperature for most of Amhara region is measured between 23°C and 27°C annually. There have also been reports of annual maximum temperatures of less than 23°C in a few areas, particularly in the eastern part of Amhara region. In addition, temperatures between 27°C and 30°C have been recorded in a few places in the eastern, northern, northwestern portion of the Amhara region (Figure 7). Therefore, the maximum temperature reaches its highest level during *Belg* season (Feb- May) but, decrease again to lowest temperature level in *Kiremt* season (June-September). The findings, aligning with those from Gashaw [38] indicate that regions of lower elevation (hot arid and warm semi-arid agroecology zones) had the highest maximum temperatures. Conversely, higher elevation areas, like cool and moist AEZ, experienced lower temperatures. This elevation-related temperature variation is further explored by Osima [39] who determined that elevation plays a significant role in temperature distribution in Ethiopia.











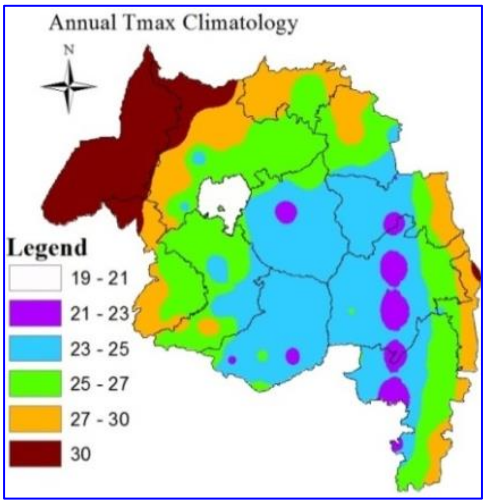
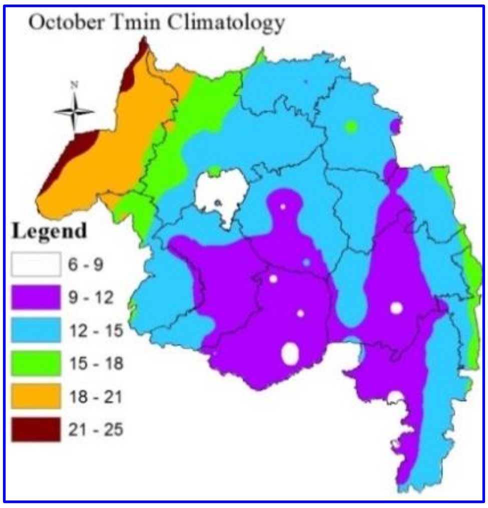


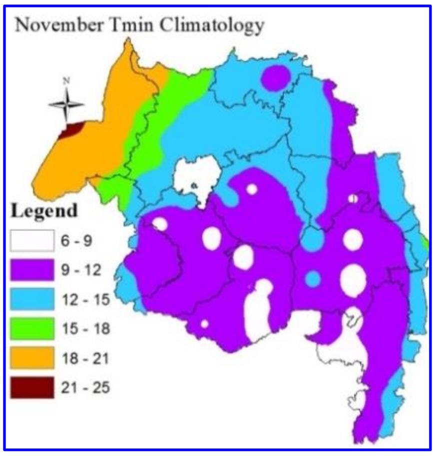
Figure 7. *Climatology of maximum temperature during Kiremt season and annually.*

3.3. Climatology of Minimum Temperature

3.3.1. Climatology of Minimum Temperature During *Bega* and *Belg* Season

Most parts of Amhara region have recorded between 9°C and 15°C minimum temperature during the *Bega* season. However, on some specific areas (highland areas) have less than 9°C. While on the northwestern part of Amhara region have been recorded more than 15°C during *Bega* season. Hence, the minimum temperature during *Bega* season is gradually decreased (colder) from November up to January. The rise in temperature within the highland areas, where crop cultivation is presently carried out, could render certain regions unsuitable for agriculture. Additionally, the temperature increase in many high-altitude areas may foster conditions that facilitate the spread of malaria, making malaria intervention necessary [40].

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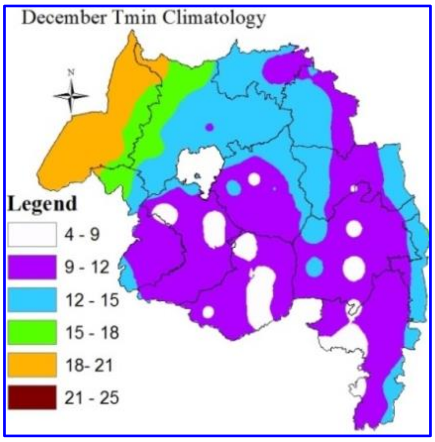
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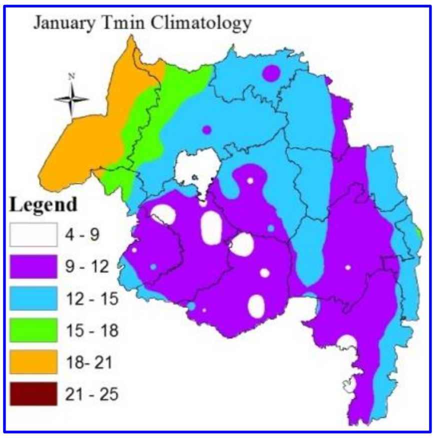
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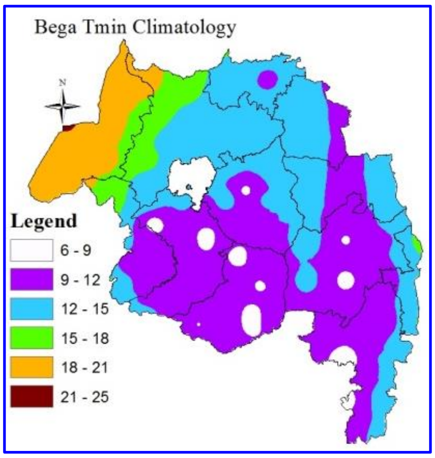
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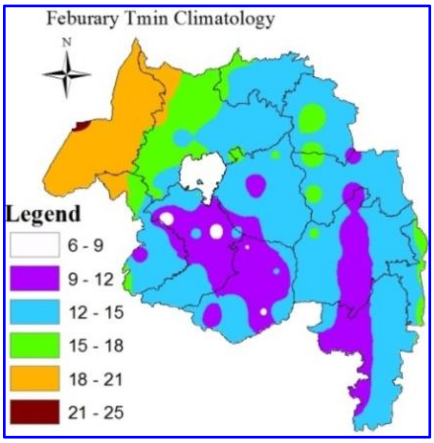
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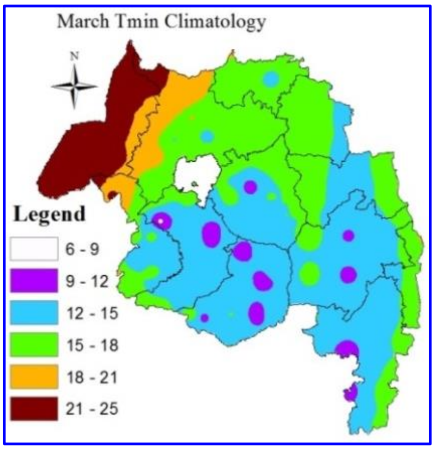
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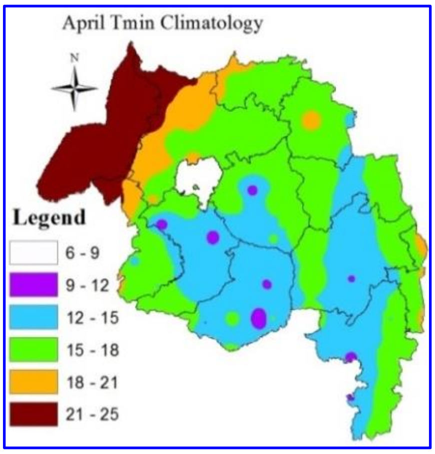
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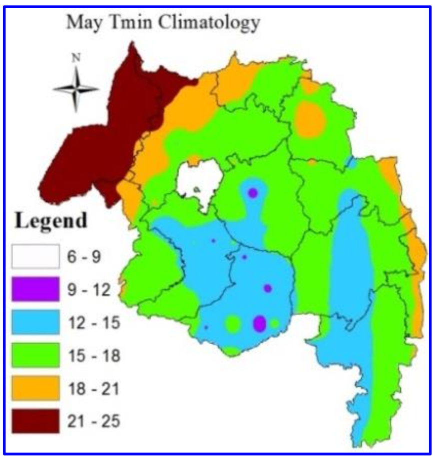
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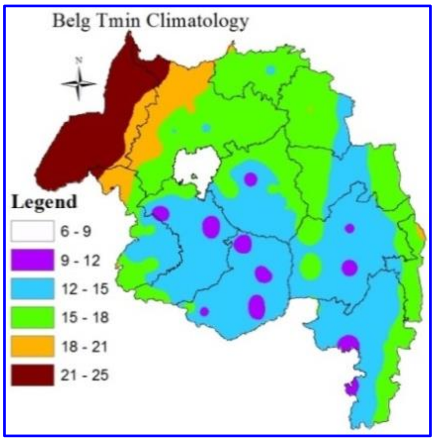


Figure 8. *Climatology of minimum temperature over Amhara region during Bega and Belg season.*

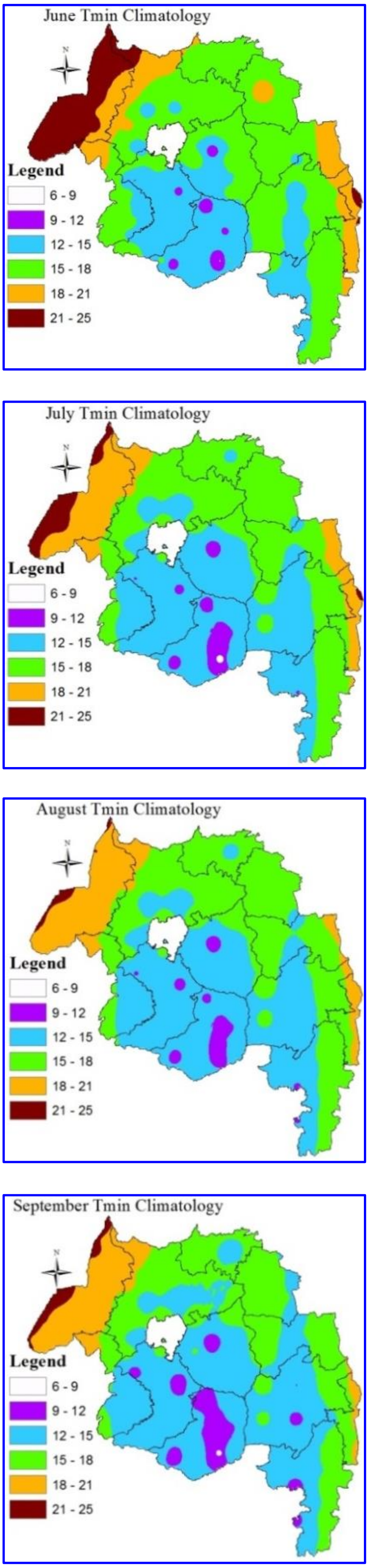
Most parts of Amhara region have recorded between 12°C and 18°C minimum temperature during the *Belg* season. However, on some specific areas (highland areas) have less than 12°C. While on the northwestern part of Amhara region have been recorded more than 20°C during *Belg* season. Hence, the minimum temperature during *Belg* season is gradually increased (warmer) from February up to May. Rising temperatures can greatly influence various aspects, including mental health and physical health, as well as create thermal instability in different systems such as dwarf nova disks [41].

3.3.2. Climatology of Minimum Temperature During *Kiremt* Season and Annual

Most parts of Amhara region have recorded between 12°C and 18°C minimum temperature during the *Kiremt* season. However, on some specific areas (highland areas) have less than 12°C. While on the northwestern part of Amhara region have been recorded more than 20°C during *Kiremt* season.

The minimum temperature for most of Amhara region is measured between 12°C and 18°C annually. There have also been reports of annual minimum temperatures of less than 12°C in a few areas, particularly in the central part of Amhara region. In addition, temperatures between 18°C and 25°C have been recorded in a few places in the northern, northwestern portion of the Amhara region (Figure 9). Therefore, the minimum temperature reaches its lowest level during *Bega* season (October- January) but, increase again to highest temperature level in *Belg* season (Feburary-May).

In comparison to the *Kiremt* and *Belg* seasons, the *Bega* season experiences the lowest minimum temperatures, ranging from 9 to 15°C, as illustrated in Figure 8. This phenomenon may be attributed to the strengthening of dry and cold high-pressure systems over the northern and central highlands of Ethiopia during the *Bega* season [42, 43]. This result can be beneficial for farmers and practitioners to adjust their annual and seasonal weather-related strategies, such as irrigation planning and crop selection, in response to shifting temperature trends.



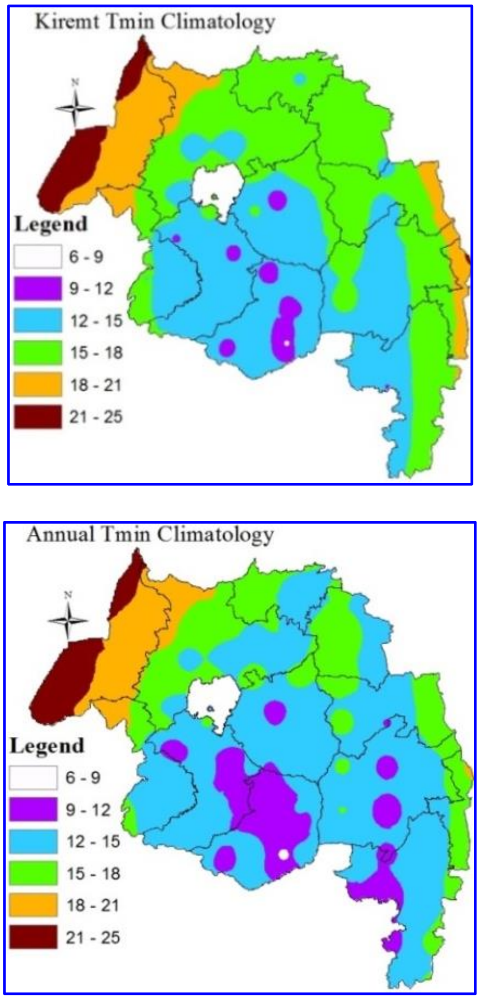


Figure 9. *Climatology of minimum temperature during Kiremt season and annually.*

4. Conclusions

This study investigated the spatial distribution of monthly, seasonal and annual rainfall as well as its spatial distribution of maximum and minimum temperature in different time scales. In the Amhara region, there was heterogeneity in the spatial distribution of seasonal and annual rainfall and its temperature. Hence, most parts of Amhara region have received 1000 mm-1300 mm of annual rainfall. Similarly, the maximum temperature for most of Amhara region is measured between 23 °C and 27°C annually. Additionally, the majority of Amhara's areas have reported minimum temperatures between 12 and 18 degrees Celsius on an annual basis.

Generally, the rainfall distribution and amount have increased from *Bega* to *Kiremt* over Amhara region. Similarly, the temperature pattern shows increased intensity from *Bega* to *Belg*, and slight decrease in *Kiremt*, and an increase again at the end of the *Kiremt* season. Based on these findings, we recommend that the Forecast and Early Warning and Development Meteorology team use this recent climatology to easily give a seasonal climate forecast for different sectors like agriculture, health, and investment. Furthermore, the paper is provides actionable insights and recommendations for decision-makers in water resources and agricultural sectors, supporting the development of climate-resilient agricultural practices and water resource management strategies. However, they do not examine how these changes influence crop yield. Consequently, scholars will pursue additional studies related to the effects of climate change in by utilizing official yield statistics and the perceptions of rural households regarding crop yield changes over the years.

Abbreviations

CDT	Climate Data Tool
CHIRPSv2.0	Climate Hazard Group Infrared Precipitation with Stations Version 2.0
EMI	Ethiopian Meteorological Institute
ENSO	EL-Nino Southern Oscillation
ERA5	The European Center for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5
IOD	Indian Ocean Dipole
IMERG v6.0	Integrated Multi-Satellite Retrievals Version 6.0
IPCC	Intergovernmental Panel on Climate Change
NetCDF	Network Common Data Form
NMA	National Meteorology Agency
NMSA	National Meteorology Services Agency

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Author Contributions

Tilahun Sewagegn: Conceptualization, data collection, statistical analysis, and writing original draft preparation

Endeg Aniley: Supervision, Writing-review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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