

## Analysis of Meteorological Drought in Cases of North Wello Zone, Ethiopia

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**Received:** August 16, 2024; **Accepted:** August 24, 2024; **Published:** August 28, 2024**ABSTRACT**

Drought is a commonly used term, but the most complex and least realized of all the natural hazards affecting more people than any other hazards. The main objective of the study was to investigate the spatial-temporal occurrence of Meteorological drought indices analysis in the study areas. The study was undertaken to investigate the magnitude, frequency, and trends of drought incidence in North Wello Zone Ethiopia using monthly rainfall records for the period 1990 to 2020 of North Wello zone stations and CHIRPS satellite data. Drought Index Calculator used to analyse standard precipitation index (SPI). The correlation between station data and CHIRPS data in this study was 0.89 which shows highly correlation between them. the result of meteorological drought indices map analysis on the years 1999, 2000, and 2008 severely dry to extremely dry conditions in the Belg season, similarly in 19990, 199308, 201507, 201508, and 201509 have got meteorological drought indices with extremely dry Kiremt season on the North Wello Zone. The drought magnitude of different time scales varied from slight to extremely severe in the studied stations. The identification of the temporal and spatial characteristics of droughts in the North Wello Zone will be useful for the development of a drought preparedness plan in the Zone. Generally increasing tendencies of drought were observed during the main rainy season and decreasing tendencies of drought during the short rainy season and annual scale were observed in the study area.

**Keywords:** Analysis, Meteorological Drought, SPI, Spatiotemporal**Introduction**

Drought is a commonly used term, but the most complex and least realized of all the natural hazards affecting more people than any other hazards [1]. Drought is generally characterized as a short-term meteorological occurrence that stems from a shortage of rainfall for a long period compared with average and normal conditions [2]. Furthermore, described drought as a normal, recurring phenomenon of climate that practically occurs in all regions of the world [3].

There are four types of droughts namely; meteorological, agricultural, hydrological, and socio-economic droughts [2,4]. A meteorological drought is a deficiency of rainfall that can be observed immediately [5]. Agricultural drought is measured in terms of deficiency in soil moisture, and rainfall; ground water on the other hand is deficient in water availability in surface and subsurface water reservoirs. And reduction in crop yield

[2]. Hydrological drought on the other hand is the deficiency in water availability in surface and subsurface water reservoirs. Socio-economic drought is the final phase of drought that is caused by prolonged shortages in agricultural production and food thus affecting the overall economy [6]

For this study, meteorological drought was adopted where rainfall is commonly used for drought analysis. Meteorological Drought is based on the degree of dryness or rainfall deficit and the length of the dry period [7]. Most often think about drought about precipitation, assessing the degree of dryness (in comparison to a local or regional average) and the duration of the dry period. This is known as a meteorological drought, which is highly specific to a region as average precipitation may vary considerably spatially.

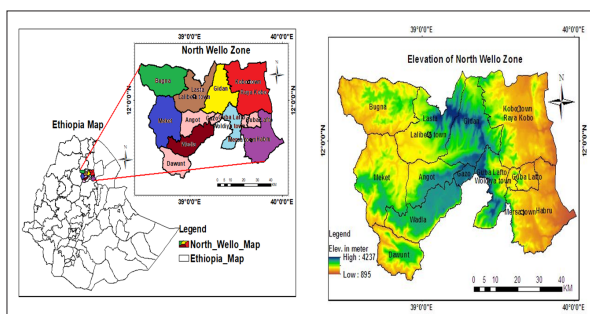
According to Meteorological drought occurs when there is a prolonged time with less than average precipitation. The magnitude and severity of meteorological drought that impacts on social and economic systems of any particular human society

will be dependent on the underlying vulnerability and particular region exposed to the event, as well as climate and weather patterns that determine the frequency and severity of the event [8]. In North Wello, prolonged and recurrent drought is the most typical corrupt event of climate change. Remarkably, the drought cycle has been shortened earlier increasing its risk. As a result, the reproductive performance of livestock was reduced even though livestock mortality is increasing.

In North Wello, drought occurs every 1-2 years, compared to every 6-8 years in the past [4]. This threat livestock production system recurrently erodes the livestock asset before full recovery is achieved [9]. Over the past decades and recently there have been quite a lot of studies about drought which have been carried out in different parts of drought-prone areas and the study areas such as. Most of these studies have been devoted to analyzing the impacts of the droughts. Though studies made so far are important they lack the important ingredients which are the extent of the problem by employing different indices including the Standard Precipitation Index (SPI).

### Study Area

North Wello is a zone in the Amhara Region of Ethiopia. It is bordered on the south by South Wello, on the west by South Gondar, on the north by Wag Hemra, on the northeast by Tigray Region, and the east by Afar Region; part of its southern border is defined by the Mille River. Its highest point is Mount Abuna Yosef. Its towns include Lasta Lalibela (known for its rock-cut churches) and Woldia (also spelled Woldia). North Wello acquired its name from the former province of Wello. North Wello is a zone in the Amhara Region of Ethiopia. located in southern Ethiopia between 11° 20'N-11° 50' N and 38° 40' - 39° 30' E, at a distance of 580 kilometers away from Addis Ababa. The study area experiences a bi-modal monsoon rainfall type, where 40% of the 300-900mm annual rainfall occurs during February to May (Belg) and 60% between June to August (Kiremt). The same source further contends that the average annual temperature of the area is 26.5°C. The principal feature of rainfall in most parts of the North Wello Zone is its seasonal character, poor distribution, and variability from year to year. For the past decades, an erratic distribution of rainfall has been the major climatic factor affecting crop yields in the study area.



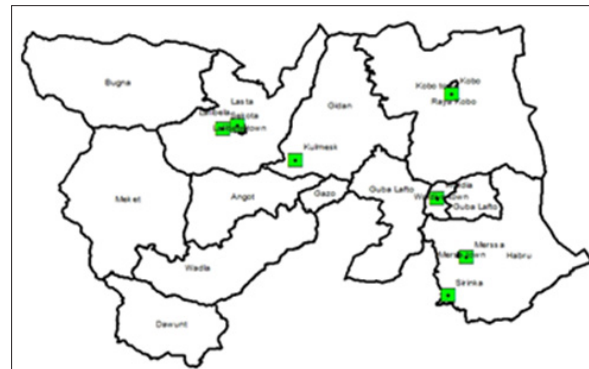
**Figure 1:** Study Area of North Wello and its Elevation

### Materials and Methods

#### Data Sources

Two types of data sets will be used in this study; this data sets are chirps and observed stations data [10]. The reference period selected will be 1990-2020; which was recently recommended by Monthly rainfall data from seven stations for the period (1990-

2020) were obtained from the Ethiopian Meteorological Institute (EMI) and used as an input variable to calculate meteorological drought. To fill in the missing values, grid data was used. The Drought Index Calculator (DrinC) which was developed by the Laboratory of Reclamation Works and Water Resources Management, National Technical University of Athens was used to analyze the standard precipitation index (SPI).



**Figure 2:** Distribution of Stations for Study Area

**Table 1: Stations Used in this Study Area**

| No | Stations Name | Longitude | Latitude | Altitude |
|----|---------------|-----------|----------|----------|
| 1  | Lalibela      | 39.04     | 12.04    | 2487     |
| 2  | Woldia        | 39.59     | 11.83    | 1894     |
| 3  | Kobo          | 39.63     | 12.13    | 1470     |
| 4  | Merssa        | 39.67     | 11.66    | 1878     |
| 5  | Kulmesk       | 39.2      | 11.94    | 2300     |
| 6  | Sirinka       | 39.62     | 11.55    | 1861     |
| 7  | Sekota        | 39        | 12.03    | 2258     |

### Research Design and Methods of Analysis

The study used mixed methods, particularly the concurrent triangulation approach as the research design. The purpose of mixed methods research is to build on the synergy and strength that exists between quantitative and qualitative research methods to understand a phenomenon more fully than is possible using either quantitative or qualitative methods alone. Monthly rainfall data from seven stations for the period (1990-2020) were obtained from the Ethiopian Meteorological Institute (EMI) and used as an input variable to calculate meteorological drought. To fill in the missing values, girded data were used. To analyze the standard precipitation index using satellite and station data by climate data tool (CDT) which is the main tool, GIS Software was used.

### Standard Precipitation Index Computation

The Standard Precipitation Index (SPI) is used to identify the meteorological drought or deficit of precipitation for multiple timescales in the studied stations. The SPI is a z-score and represents the drought event departure from the mean, expressed in standard deviation units. Although SPI can be calculated from 1 month up to 72 months, 1-24 months is the best practical range of application. The SPI values were computed at three timescales, as used 2 months (SPI-2), 3 months (SPI-3), and 12 months or annual (SPI-12). The SPI-2 was used to assess drought during Belg season, SPI-3 was used to assess droughts during the Kiremt seasons, which represent the shorter and main rainy

seasons, respectively, and SPI-12 was used to assess the annual drought [4]. To calculate the SPI, a long-term precipitation record at the desired station is first fitted to a probability distribution (e.g. gamma distribution), which is then transformed into a normal distribution so that the mean SPI is zero. It is expressed mathematically as follows:

$$SPI_{ij} = \frac{X_{ij} - \mu_{ij}}{\sigma_{ij}}$$

Where  $SPI_{ij}$  is the SPI of the  $i^{th}$  month at the  $j^{th}$  timescale,

$X_{ij}$  is the rainfall total for the  $i^{th}$  month at the  $j^{th}$  time scale,

$\mu_{ij}$  and  $\sigma_{ij}$  are the long-term mean and standard deviation associated with the  $i^{th}$  month at the  $j^{th}$  time scale, respectively.

The Drought Index Calculator (DrinC) which was developed by the Laboratory of Reclamation Works and Water Resources Management, National Technical University of Athens used to analyze standard precipitation index (SPI) first defined the index and the criteria for drought classifications by SPI values. In this research, the modified classification of SPI according to as shown in Table 2.

**Table 2: Spi-Based Drought Severity Class**

| Index Value             | Class SPI      | Value         | Drought severity class |
|-------------------------|----------------|---------------|------------------------|
| $SPI \geq 2.0$          | Extremely wet  | -             | -                      |
| $1.5 \leq SPI < 2.0$    | Very wet       | Above 0       | No drought             |
| $1.0 \leq SPI \leq 1.5$ | Moderately wet | -             | -                      |
| $-1.0 < SPI < 1.0$      | Nearly Normal  | 0.0 to -0.99  | Slight drought         |
| $-2.0 < SPI \leq -1.5$  | Severely dry   | -1.5 to -1.99 | Severe drought         |
| $SPI \leq -2.0$         | Extremely dry  | y -2 and less | Extreme drought        |

### The Climate Data Tool

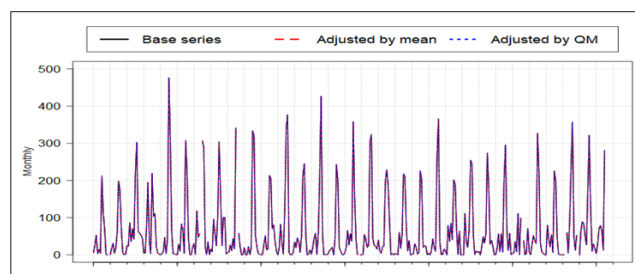
The Climate Data Tool (CDT) is a free, open-source R package created specifically for national meteorological services. CDT allows these agencies to:

- Organize millions of station observations
- Assess data availability and highlight gaps in the observational record
- Assess and correct data-quality issues
- Combine station observations with proxies such as satellite rainfall and climate model reanalysis products to fill temporal and spatial gaps in the observational record
- Evaluate gridded products, including satellite, reanalysis, and combined data products
- Extract data from gridded products, including satellite, reanalysis, and combined data products. Description: Climate Data Tools (CDT) is a set of utility functions for meteorological data quality control, homogenization, validation of precipitation, and merging station data with satellite.

### Results and Discussions

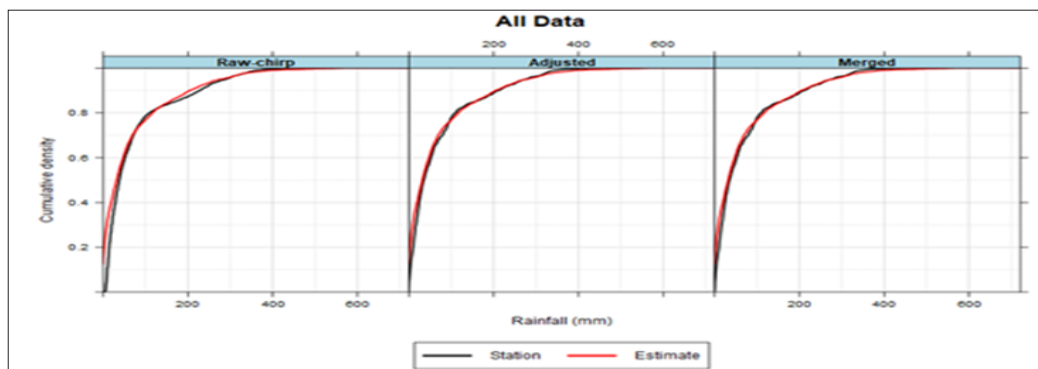
Temporal and Spatial Analysis of Drought in North Wello Zone Before the meteorological drought index of graphs and map analysis we should have to check the data quality control, station coordinates, homogeneity, spatial interpolation, merging climate data for rainfall data, validation, spatial point data, validation, multiple data set CDT station format for precipitation data, analysis climatology and anomaly analysis, spatial analysis, drought indices standardize precipitation index (SPI) and visualization for plot multiple data set for this study CDT tool steps are used.

The graph illustrates three-time series datasets from 1990 to 2020, showing monthly values and their fluctuations. It includes the original data, which reflects variability over time; the mean-adjusted data, which smooths out fluctuations to reveal overall trends; and the Quantile Mapping (QM)-adjusted data, which also reduces variability while accounting for different statistical properties. Overall, the graph demonstrates how these adjustments impact the representation of the original data, clarifying trends and patterns.



**Figure 3: Homogeneity Adjusted for Lalibela Station.**

The graph displays cumulative density functions (CDF) for rainfall data across three categories: Raw-chirp, Adjusted, and Merged. Raw-chirp (Left Panel) This section shows the cumulative distribution of raw chirp rainfall data. The black line represents the observed data from the station, while the red line indicates the estimated values. The close alignment of these lines suggests that the estimates closely match the observed data. Adjusted (Middle Panel). This panel presents the cumulative density for the adjusted rainfall data. Similar to the first panel, the black line shows the station data and the red line represents the estimates. The adjustments made to the raw data appear to maintain a good fit with the observed values. Merged (Right Panel) This final panel illustrates the cumulative density for the merged dataset, which likely combines data from various sources or methods. The black and red lines again indicate the station and estimated values, respectively, showing how the merging process affects the distribution. Overall, the graph highlights the distribution of rainfall data across different processing methods, with the lines indicating the relationship between observed and estimated values in each category. The consistent shape of the curves suggests that the adjustments and merging processes preserve a similar distribution pattern.



**Figure 4:** Cumulative Distribution map of raw, adjusted, and merged data sets versus the observed

The above graph indicates the comparison between the station data and Estimated data related to raw, adjusted, and merged data. The above figure indicates that Adjusted data is better cloth to station station-estimated data.

### Spatial Characteristics of Drought in North Wello

North Wello, a zone in the Amhara Region of Ethiopia, has experienced significant droughts that have impacted its agriculture, water resources, and overall livelihood. Understanding the spatial characteristics of drought in this region is essential for effective planning and mitigation strategies. North Wello is characterized by a rugged landscape with highlands, plateaus, and valleys. Elevation ranges from lowlands in the east to highlands in the west, creating a diverse range of microclimates. The region generally experiences a semi-arid to arid climate, with most of its rainfall concentrated in the summer months (June to September). The variability in elevation and microclimates means that drought can manifest differently across the region. Rainfall in North Wello is highly variable both spatially and temporally. Certain areas, especially the lowlands, receive significantly less rainfall compared to the highlands. This variability makes some areas more vulnerable to drought. The region relies heavily on the kiremt (main rainy season), and any delay or reduction in rainfall during this period can lead to severe drought conditions. North Wello has a range of soil types, from fertile volcanic soils in the highlands to more arid, less fertile soils in the lowlands.

Drought impacts are more severe in areas with poor soils, as these cannot retain moisture well. Vegetation cover is closely linked to soil and rainfall patterns. Drought-prone areas often have sparse vegetation, which further exacerbates the effects of drought by reducing soil moisture retention and increasing erosion. The majority of the agriculture in North Wello is rain-fed, making it highly vulnerable to drought. Area's dependent on a single growing season are particularly at risk. Different crops have varying levels of drought tolerance. In North Wello, the choice of crops (e.g., Teff, sorghum, barley) can influence the spatial impact of drought. Rivers and streams in North Wello are often seasonal and rely on consistent rainfall. During droughts, these water sources dry up, leading to water scarcity. In some parts of North Wello, groundwater is an important source of water. However, the recharge rates for aquifers are low, and drought conditions can severely limit groundwater availability. Higher population density areas experience more pressure on natural resources, which can exacerbate the impacts of drought. The spatial distribution of infrastructure like roads and irrigation

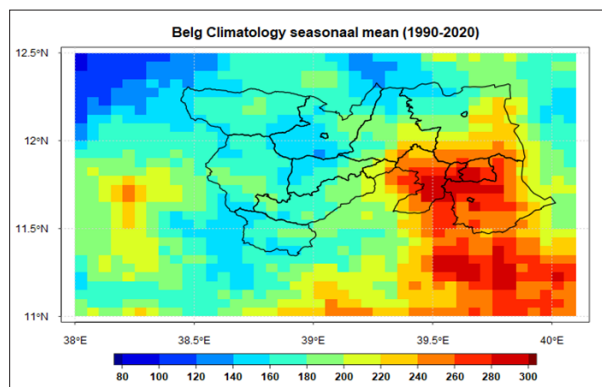
systems is uneven, with some areas being more vulnerable to drought due to a lack of access to water resources or markets.

**Drought Frequency and Severity Spatial Distribution** Some areas within North Wello experience more frequent and severe droughts than others, often linked to their specific climatic, topographic, and land-use characteristics. The lowland areas, particularly those in the eastern part of the zone, are often the most affected by drought due to their arid conditions and reliance on less resilient agricultural practices. Mitigation and Adaptation Efforts to reforest certain areas can help retain soil moisture and reduce the impact of drought. Water Harvesting Techniques like building check dams or rainwater harvesting systems can mitigate the spatial impact of drought by providing water during dry periods. Drought-Resistant Crops Promoting the use of drought-resistant crops in the most vulnerable areas can reduce the overall impact of droughts. Understanding these spatial characteristics is crucial for developing targeted drought mitigation strategies and ensuring the sustainability of agriculture and livelihoods in North Wello.

The temporal and spatial characteristics of droughts in the North Wello Zone were assessed by using satellite data (chirps) and station data analysis of the SPI-3 (three Months) values of each station. The computed SPI-3 Months values of different stations for the period of analysis that ranges from 1990 to 2020. Firstly, the temporal variation of SPI-3 Months calculated from the average monthly precipitation for each Weather station was assessed. The regional drought analysis is useful for determining the spatial distribution and characteristics of drought, and evaluating the most affected areas for a specific drought event.

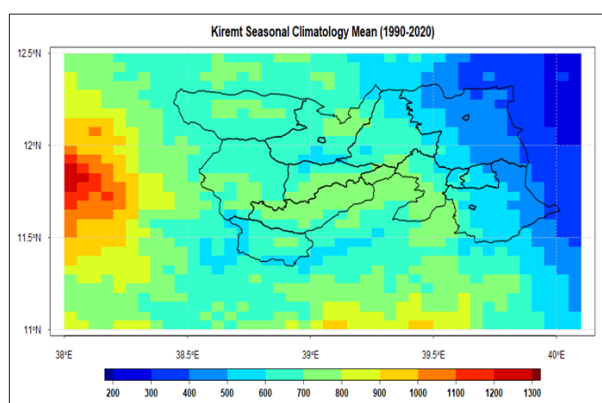
Analysis of the computed SPI-3-month time series revealed the most severe and moderate droughts occurred in the North Wello Zone. SPI-3 Months is used for quantification of precipitation deficit at different time scales since SPI-3 Months indicates drought characteristics like spatial extent. Therefore it can be used as a drought monitoring tool. For the identification of the drought-sensitive Weather stations, SPI data for the Kiremt season was used. The SPI-3 Months values for seven (7) meteorological stations were analyzed to identify meteorological drought indices weather stations. Meteorological drought indices to analyze standard precipitation index (SPI-3) for 30 years. We used a data series of monthly mean precipitation for the calculation of the Standard Precipitation Index (SPI-3 Months). We calculated SPI-3 Months for Kiremt seasons. The temporal evolution of the SPI-3Months' time series showed that the North Wello Zone

experienced extreme to moderate droughts for Kiremt seasons. Meteorological drought graphs and map analysis depend on the results are as follows. In this study, the spatial analysis was performed by plotting using SPI tools.



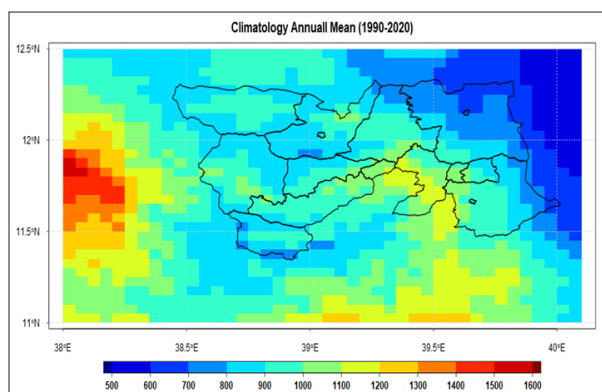
**Figure 5:** Belg climatology seasonal Rainfall (1990-2020)

The above map shows that during Belg season southeastern parts of the North Wello zone received more than 240mm of rainfall amount and northern, central, and western parts received more than 140mm (1990-2020).



**Figure 6:** Kiremt climatology seasonal Rainfall (1990-2020).

This illustrates that the Wello received a high amount of rain during the Kiremt season. This zone received more than 500-800 mm rainfall amount.

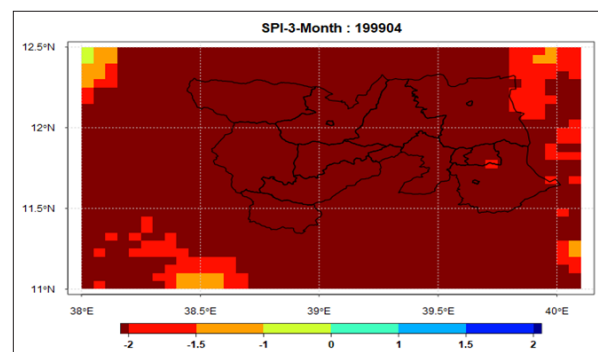


**Figure 7:** Annual climatology seasonal Rainfall (1990-2020).

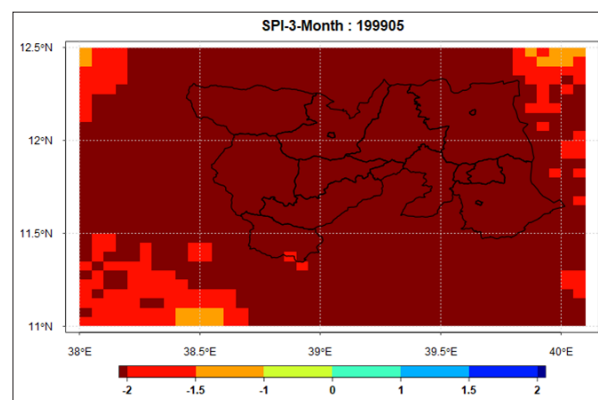
The analysis of the 3-month timescale drought was recorded across the study areas (1990 to 2020) there were varying degrees of severity. This study confirms that the frequency of occurrences of droughts in the main rainy season was the highest at all

stations. Generally, the rainfall pattern in the studied stations exhibits certain characteristics that a drought year is followed by another two or three dry years vis-à-vis the wet years.

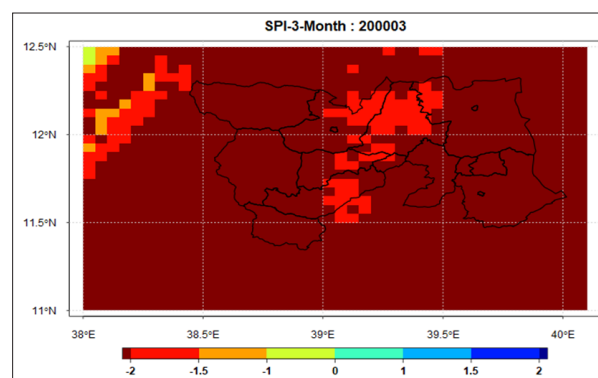
### The spatial characteristics of severe to extreme drought for Belg and Kiremt season



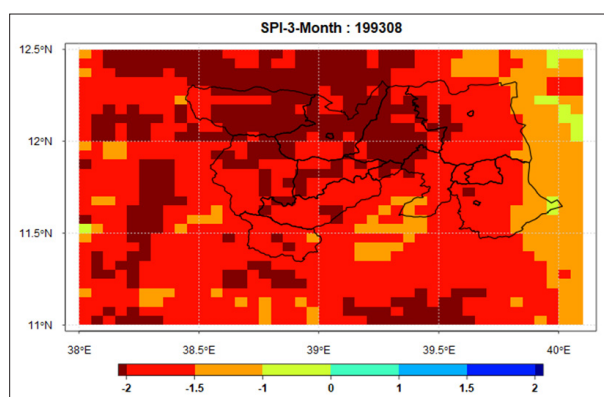
**Figure 8:** Spatial characteristics of severe drought for Belg season (SPI-3: 1999)



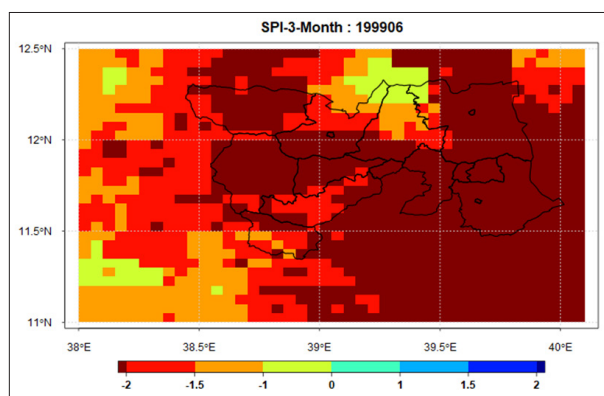
**Figure 9:** Spatial characteristics of severe drought for Belg season (SPI-3: 1999)



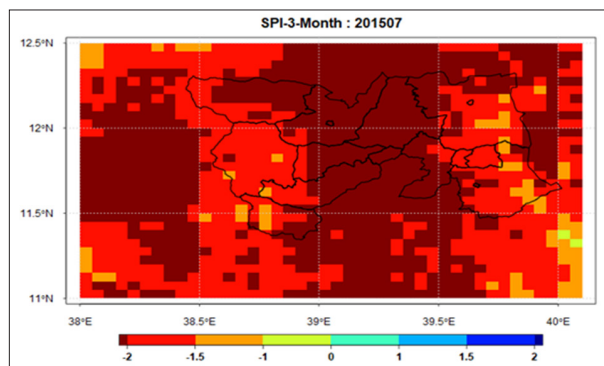
**Figure 10:** Spatial characteristics of severe drought for Belg season (SPI-3: 2008)



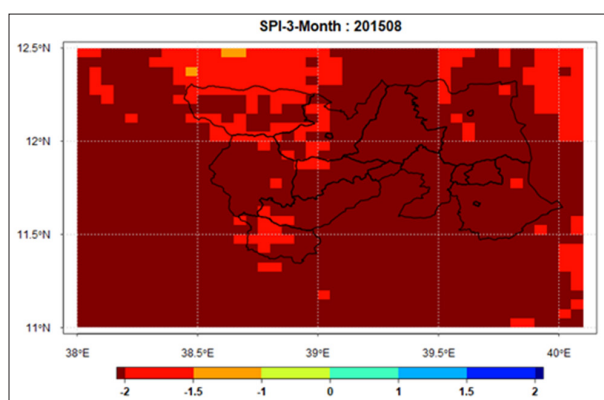
**Figure 11:** Spatial characteristics of severe drought for Kiremt season (SPI-3:1993)



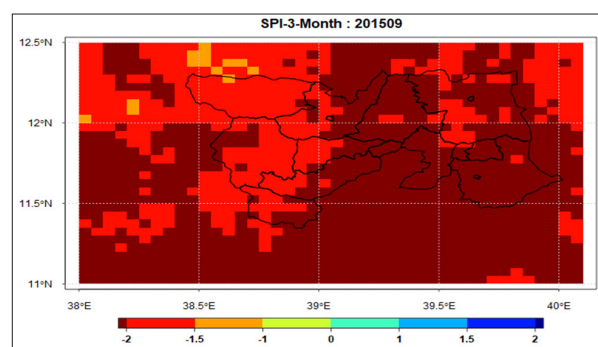
**Figure 12:** Spatial characteristics of severe drought for the Kiremt season (SPI-3:1999)



**Figure 13:** Spatial characteristics of severe drought for Kiremt season (SPI-3: 2015)



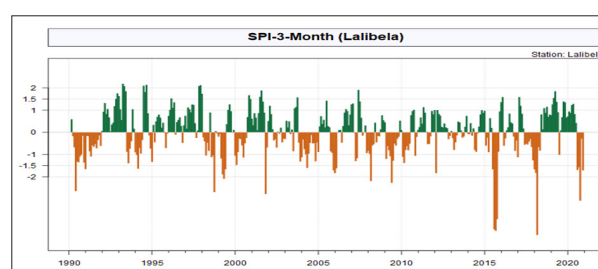
**Figure 14:** Spatial characteristics of severe drought for Kiremt season (SPI-3: 2015)



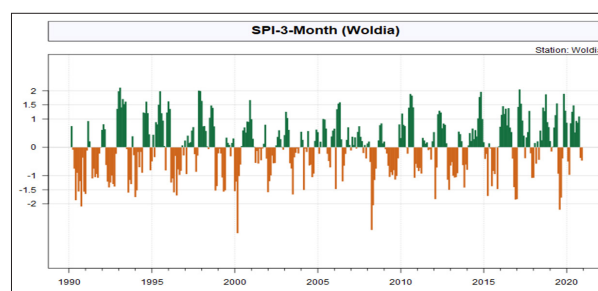
**Figure 15:** Spatial characteristics of severe drought for the Kiremt season (SPI-3: 2015)

From the above meteorological drought indices map analysis (SPI-3) results are shown as follows description. Standard precipitation indices were used for meteorological drought on the developed database and the ability to visualize the distribution values across the area of interest for various time scales. As an example figure shows the variation of SPI across the North Wello Zone from 1990 to 2020 for time scales of SPI- 3 months most of this Zone receives moderate to extreme drought. It should be noted that the result of meteorological drought indices map analysis on the years 199904, 199905, 200003, and 200803 severely dry to extremely dry conditions on belg season, similarly in 199906, 199308, 201507, 201508, and 201509 have got meteorological drought indices with extremely dry of kiremt season on the North Wello Zone.

The spatial distribution of drought for this particular year has small difference when the SPI-3 month was assessed as shown in (Figure 4). Using the SPI-3 month, it seems that some parts of an area were affected by the drought. Figure 4 also shows there is a high probability of drought occurrence in many of the areas in the North Wello Zone as most of the areas in this Zone receive normal to below normal rainfall in many of the years analyzed in this project. However severe and moderate drought has been observed occasionally.



**Figure 16:** SPI-3 month for Lalibela station (1990-2020)



**Figure 17:** SPI-3 month for Woldia station (1990-2020)

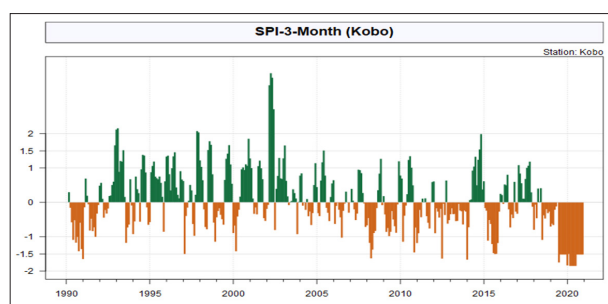


Figure 18: SPI-3 month for Kobo station (1990-2020)

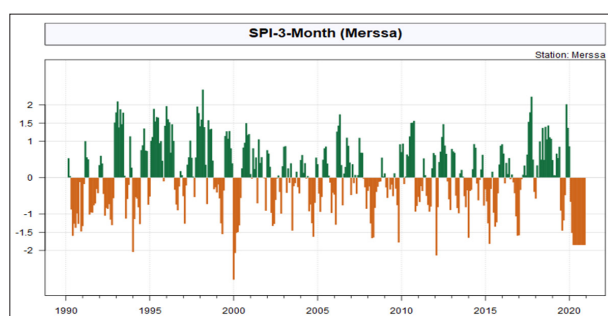


Figure 19: SPI-3 month for Merssa station (1990-2020)

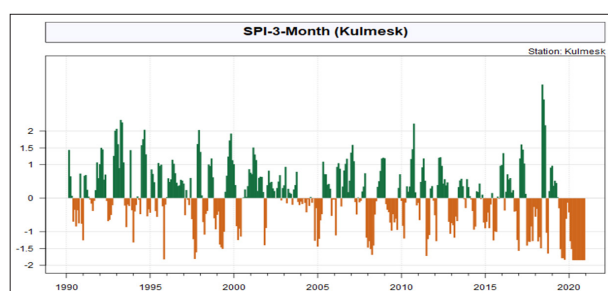


Figure 20: SPI-3 month for Kulmesk station (1990-2020)

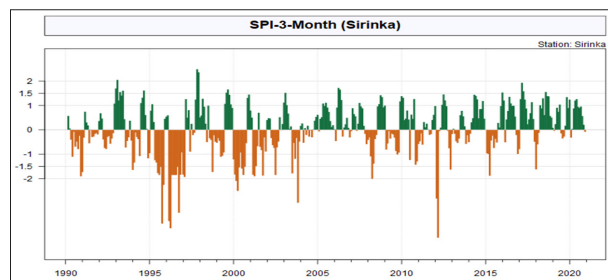


Figure 21: SPI-3 month for Sirinka station (1990-2020)

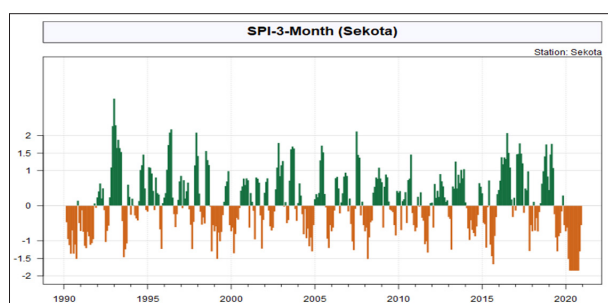


Figure 22: SPI-3 month for Sekota station (1990-2020)

### Trends of Drought Occurrences

Trends of drought occurrences in three (3) months SPI values of March, April, and May were considered to represent the drought conditions from June, July, and August Main rainy season. The

main rainy season (Kiremt): The total number of drought events with slight, moderate, severe, and extreme severe computed at a three-month timescale (June-August) 200-1300 mm rainfall amount climatology season mean in the project area. However, they had varied magnitude classes. Severe drought was recorded in (1991, 1993, 1994, 2004, 2006 and 2012) in Lalibela station which ranged from -0.15 to -2, severe drought was recorded in Woldia station in 1991, 2000, 2008 and 2020 which ranged from -1.59 to -2 Extreme-severe drought, Slight to severe drought was recorded in Merssa stations 1990, 1994, 2005, 2008, 2010, 2014, 2015, 2017 and 2020 with SPI value -2.12. In Sirinka station Severe to Extreme drought was recorded in the years 1996, 1997, 1998, 2004 and 2012 with SPI value -2 to 3 which had a substantial impact on the area whereas in the station extreme severe drought was recorded in the taken years.

Generally, the drought magnitude of three three-month timescales varied from slight to extremely severe in the taken stations. The main source of water for the study areas is rainfall, so any change in rainfall amount and distribution leads to a serious production deficit So, Failure of this season made subsistence farmers vulnerable to the drought impacts. Short rainy season (Belg): The total number of drought events at the 3-month timescale (Mar, Apr, and May) in the entire period of analysis was found in all stations, Figures 9 and 10. Severe drought occurred in 1994, 1999, 2000, and 2008 with values ranging from -1.55 to -1.76. Generally, extreme drought occurred in all of the stations and the drought timescale varied from slight to extremely severe in the studied stations.

### Conclusion and Recommendation

This project investigated the frequency, magnitude, and trends of drought over north Wello during the short and main rainy seasons for the period 1990-2020. The project was able to identify the major drought years within the study period with drought severity. The assessment of meteorological drought showed the occurrence of slight to extreme severe in the historical drought episodes in the projected stations. Generally, this study implies that drought events and their negative effects are highly localized in the study area and there is a need for local-scale planning for drought management and response. Moreover, it may contribute to decision-makers in planning actions for the management of drought and reducing the impact of drought or dryness in the area. There was a highly positive correlation between station data and satellite data with 0.89 which shows that similar data types. Local climate studies, such as the present study, should be strengthened since they are useful for providing scale climate information for drought risk management and adaptation purposes. Moreover, it may contribute to decision-makers in planning actions for the management of drought and reducing the impact of drought/dryness in the area.

### Recommendations

- Meteorological drought severity levels vary spatially, so, for further study, the selection of agricultural technologies and information (drought tolerance crops, the type of crop variety, other weather parameters, and soil moisture conservation practices) should be made to fit into the meteorological drought severity levels. The spatial distribution of seasonal crop moisture deficiency will be different if changes in cropping patterns occur.

- Therefore, if used on an operational basis for drought risk and Vulnerability assessment, the crop climate database will need to be updated periodically as the distribution of crops changes in response to economic factors, climate trends, and government programs.
- In a real sense, a drought is a climatic event that cannot be prevented very easily, but interventions and preparedness for drought can help to cope with drought by developing more resilient ecosystems, improving resilience to recover from drought, and taking various adaptation strategies like water harvesting, making irrigation system more efficient and a geographical shift of modernize the agricultural system.

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