Journal of Agriculture and Natural Resources (2023) 6(1): 115-133
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v6i1.71943

Effects of meteorological and agricultural droughts on crop production in Arsi Zone Ethiopia

Gezahegn Mergia Tullu[1*] and Mekuanint Tariku Guta[2]

[1]Ethiopian Meteorology Institute
[1]Arba Minch University Water Technology Institute
[2]Ethiopian Meteorology Institute

[*]Correspondence: gezahe17@yahoo.com
[*]ORCID: https://orcid.org/0009-0007-9460-0750

Received: June 22, 2023; Revised: September 28, 2023;
Accepted: November11, 2023; Published: November 25, 2023

ABSTRACT

Natural disasters, known as droughts, are mostly brought on by a prolonged decrease in precipitation levels. In the Arsi zone, there is an undiscovered study gap regarding the transmission of drought impacts and factors. The primary goal is to assess how crop output is affected by weather patterns and agricultural droughts while also offering direction for the research area. The Ethiopian Meteorology Institute provided meteorological data, and CHG-UCSB provided CHIRPS data for the years 1991 through 2020. Data on runoff and soil moisture were sourced from USGS FEWS NET between 1991 and 2020, while information on cereal crops was sourced from the Ethiopian Statistical Service between 1995 and 2020. The analysis tools that were employed were ANN, Python, and DrinC. The study's findings demonstrated the spatiotemporal droughts that stretched across time scales from SPI3 and RDI3 to SPI12 and RDI12. Drought indices showed a range of drought events over short to long time scales, including meteorological, agricultural, and hydrological droughts that were mild, moderate, severe, and intense. The Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) showed a significant and increasing propensity to correlate throughout both short and long time periods, but the severity of the droughts differed. With magnitudes of 0.83 across time scales, the maize and barley yield drought correlation was found to be highly correlated. In terms of time scales, the barley and wheat yield drought correlation value was 0.95, while the maize and wheat yield drought correlation was 0.77. Meteorological droughts lead to agricultural droughts, which significantly reduce crop yields in the study area. The degree of the spatiotemporal drought has an impact on the output of wheat, barley, and maize crops throughout time. The results of this work can help improve monitoring and mitigation of droughts, especially for future drought data, and can improve our understanding of the mechanisms causing zonal droughts. This allows us to plan and manage our water resources, soil conservation, and drought-tolerant crop choices in the research region in a more sustainable manner.

Keywords: Drought, SPI, RDI, Effect, Crop production

Correct citation: Tullu, G.M., & Guta, M.T. (2023). Effects of meteorological and agricultural droughts on crop production in Arsi Zone Ethiopia. *Journal of Agriculture and Natural Resources*, 6(1), 115-133. DOI: https://doi.org/10.3126/janr.v6i1.71943

INTRODUCTION

Drought is one of the most prevalent natural disasters in the world and has an effect on the surface of the earth (Schwalm *et al.*, 2017). Wherever in the world, there is a chance of a drought (both in dry and in wet areas). Due to the fact that drought conditions affect the meteorological subsystem, agricultural, hydrological, health and socio-economic as well as the whole environment, they are known as a multi-scalar phenomenon related to ocean-atmosphere coupling. The oceanic or atmospheric circulation systems contribute to drought conditions (McKee, 1995), research on how droughts are spreading as a result of global warming (Zhuang *et al.*, 2022).

Meteorological drought refers to a prolonged period of below-average precipitation, leading to a significant moisture deficit in the atmosphere. It is measured by the amount of rainfall over a specific period compared to historical averages.Agricultural drought occurs when there is insufficient moisture in the soil to support crop growth. It typically follows meteorological drought and is characterized by reduced soil moisture levels that affect agricultural productivity.

Meteorological Drought Effects: Reduced Soil Moisture: Leads to lower water availability for crops. Increased Temperature: Higher temperatures can exacerbate moisture loss through evaporation. Delayed Planting: Farmers may postpone planting due to unfavorable conditions, affecting the growing season.

Agricultural Drought Effects: Crop Stress: Insufficient soil moisture causes stress, leading to wilting and reduced growth. Lower Yields: Drought conditions can significantly reduce crop yields and quality. Pest and Disease Pressure: Stressed plants are more susceptible to pests and diseases, compounding losses. Economic Impact: Reduced agricultural output can lead to economic losses for farmers and higher food prices.

Rationale:Understanding the distinctions and impacts of meteorological and agricultural droughts is crucial for effective agricultural management and policy-making. As climate variability increases, the frequency and severity of droughts are expected to rise, making it essential to study their effects on food security and agricultural sustainability.

The primary objective of this study is to: Assess the impacts of meteorological and agricultural droughts on crop production. Identify adaptive measures that can be implemented to mitigate the adverse effects of drought on agriculture. Provide data-driven insights for policymakers and farmers to enhance resilience against drought conditions.

East Africa is one of the regions in the globe most vulnerable to drought (Muller, 2014; Tadesse, 2016). Recent droughts in East Africa have produced significant crop failures, livestock losses, and human mortality (Haile *et al.*, 2019; Zhao, & Dai, 2015). Soil moisture and hydrological drought are believed to have detrimental consequences on ecosystems, society, and agriculture in the Horn of Africa (Shukla & Wood, 2008; Van Loon, 2015).

Ethiopia displays spatiotemporal climate variability and is characterized by meteorological drought (Eze *et al.*, 2022; Kourouma *et al.*, 2022). Changes in atmospheric and ocean circulation are frequently linked to the effects of recent droughts that have occurred in various parts of Ethiopia and the spatio-temporal evaluation of drought studied (Liou & Mulualem, 2019). Despite the fact that various studies have examined how climate change is related to Ethiopia's ongoing droughts (Degefu *et al.*, 2017; Funk *et al.*, 2012; Zeleke *et al.*, 2017). Researchers found that a severe drought only happens once every three to ten years, with a longer dry cycle in between (Mohammed *et al.*, 2018). Due to climate change, Ethiopia's drought has gotten worse (Zeleke *et al.*, 2022). Ethiopia is also affected by the propagation of drought (Huang *et al.*, 2021; Wossenyeleh *et al.*, 2022). Droughts can have a big impact on crops in Ethiopia, because a lot of the country's agriculture is done with rain-fed farming.

Several studies have examined the distribution of meteorological drought severity in the Rift Valley of Ethiopia using standardized precipitation evapotranspiration index (SPEI) and standardized precipitation index (SPI) drought indexes (Kebede *et al.*, 2019; Moloro, 2018; Nasir *et al.,* 2021). This study examines the spatio-temporal spread of drought propagation and its effects on crop production using the standardized precipitation index (SPI), and reconnaissance drought index (RDI).

This study is essential for the topic since it will raise awareness of the problems and establish a priority list for their drought impact strategies. Spatio-temporal droughts analyzed and evaluate extreme spatiotemporal propagation of drought from SPI3, and RDI3 to SPI12, and RDI12 and its impact crops yields over Arsi zone. Therefore, the goal of this study is to advance scientific understanding of drought by shedding light on the specific meteorological, agricultural, and hydrological drought indicators that have an impact on crop production and productivity in the Arsi zone.

MATERIALS AND METHODS

Study site

Arsi zone located in southern eastern Ethiopia; the Arsi zone is bounded on the south by Bale, on the southwest by the West Arsi zone, on the northwest by East Shewa, on the north by the Afar Region, and on the east by West Harerghe. It has an area of 20,737.24 km^2 and is situated between 7.176° and 8.716° N latitude and 38.773° and 40.734° E longitudes. The zone's population is currently expected to be 2,850,493 based on the 2007 Population and Housing Census Report by ESS, with 88% of the people living in rural regions.

The zone has four agro-ecological zones, the first one is the humid agro-climatic zone with altitude of above 3500 meter above mean sea level, which covers the highest altitudes areas of the zone and constitutes about 2.74% of the total area of the zone. The second one is the sub-humid agro-climatic zone that includes the mountain ranges, massifs and high plateaus of Arsi (2500 to 3500 m) that lies in the central part of the zone. It covers about 22.74% of the total area of the zone. The third is the semi-arid agro-climatic zone (1500 to 2500 m), which comprises low plateaus of the zone and covers about the 49.60% of zonal land surface. Whiles the fourth are arid agro-climatic zone (less than 1500 m) constituting about 24.92% of the total area of the zone; from Arsi zone (Gebiso, 2018).

Data sources

Meteorological data was gathered from the Ethiopian Meteorology Institute (EMI) for rainfall, temperature and relative humidity in the years from 1991- 2020. The satellite data products of Climate Hazards Group Infra-Red Precipitation with Stations (CHIRPS), a gridded rainfall estimate produced in near-real time with a spatial resolution of 0.05 degrees ($0.05^0 \times 0.05^0$) or (~5km) from data source of https://data.chc.ucsb.edu/products/CHIRPS-2.0/ during 1991 to 2020. Soil moisture data for analyzes used to account for the readily available water at the surface and plant root zone level. The soil moisture was used in this study; the monthly time series data at a spatial resolution of 0.1 degree resolution similarly 10 km × 10 km considered for the period from 1991 to 2020; the source: https://earlywarning.usgs.gov/fews/ewx_lite/index.html; and used standardize the soil moisture. Finally data for cereal crops obtained from the Ethiopian Statistical Service (ESS) crops data of Maize, Barley and Wheat (1995-2020) over study area.

METHODOLOGY

The data analysis techniques by DrinC (Drought Indices Calculator), Artificial Neuron Network (ANN) for crop prediction and Python tools for spatial and temporal analysis over study area. In the Simple inverse distance weighting, the background grid also contributes a weight to the interpolation routine, and the relative weight of the background grid increases with increasing distance to surrounding stations. For this study, tools like DrinC (Drought Indices Calculator), Python tools used for temporal analysis and GIS Software used for spatial drought analysis over study area.

RESULTS AND DISCUSSION

The result of this study was the effects of meteorological and agricultural droughts analysis with time-scale linkage and comparison between SPI3 and RDI3 up to SPI12 and RDI12 indices. This study looked at droughts and how they spread over time and space. It was compared different measurements of drought and found that the severity of droughts varied from mild to extreme from 1991 to 2020. It was also analyzed at how often droughts occurred, how long they lasted, and how intense they were. It was found that the severity of the drought affected how it spread, and there were strong connections between different measurements of drought on both short and long time scales. This had an impact on crop production of maize, barley, and wheat in the study area.

Temporal Comparison of Time Series Meteorological and Agricultural Drought Indices

The result of the analysis shows that the time-scale of drought trends from meteorological to agricultural droughts in the indices mean values from SPI3 and RDI3 up to SPI12 and RDI12 were variations in the frequency and severity of drought. The analysis looked at different types of droughts and how they changed over time. The results showed that the frequency and severity of droughts varied. In a graph, it was seen how the severity of droughts changed from mild to extreme over a period of 30 years.

The severity of drought analyzed across meteorological and agricultural drought indices over a three-month period. The severity of drought across mild, moderate, severe, and extreme droughts were happen, and it was also seen at how many years in the past have had similar levels of drought severity. Based on how droughts happen over time, it was seen that in the propagation of droughts, there were different levels of drought severity. Some years have mild droughts, some have moderate droughts, some have severe droughts, and some have really extreme droughts. In a nine-month period, it was seen that the most severe droughts are more common than the milder ones.

The extent, length, and frequency of the drought indices varied from meteorological to agricultural droughts depicted in the accumulation periods, according to the temporal effects of drought indices over the course of three to twelve months. From meteorological to agricultural droughts-which were taken into consideration in this study-frequency, was high and length was prolonged when compared to the first to final months of drought indices: mild, moderate, severe, and extreme drought variables. The prolonged duration of meteorological, and agricultural droughts connected to drought strength has, nonetheless, prevailed as the time scale grows. The investigation of the historical spread of droughts generally revealed that periods of drought accumulation included both severe and exceptional droughts.

In general the first three months, there were mild, moderate, severe, and extreme droughts. The severity of the droughts varied each year. The same pattern was seen for the next three months but with different numbers of drought years. The same pattern was also seen for the next nine months but with different numbers of drought years. In the twelve-month period, there were mild, moderate, and severe droughts. The severity of the droughts varied each year. The analysis looked at different types of droughts and how they changed over time. It found that there were variations in the frequency and severity of droughts. The results are shown in a graph that shows how severe the droughts were from 1991 to 2020. The graph shows that there were mild, moderate, severe, and extreme droughts during this time period.

The time series analysis at how drought spreads from the meteorological to affecting agriculture activities. In the Arata area, there have been different levels of drought in different years. Some years had just a little bit of drought, some had a small more and some had a lot. Some years had just a little bit of moderate drought, some had a spot more severe and some had extreme drought.

Sometimes the meteorological can be really vary and dry, this consequence of severity of drought events. The time series analysis, which means analyzing at patterns over time, shows that in certain years there were different levels of drought. These measurements help scientists understand how severe the drought is in different areas. Overall, all these measurements show that there were different levels of drought in different years. In general, the data shows that Arata experienced droughts of varying severity over the years.

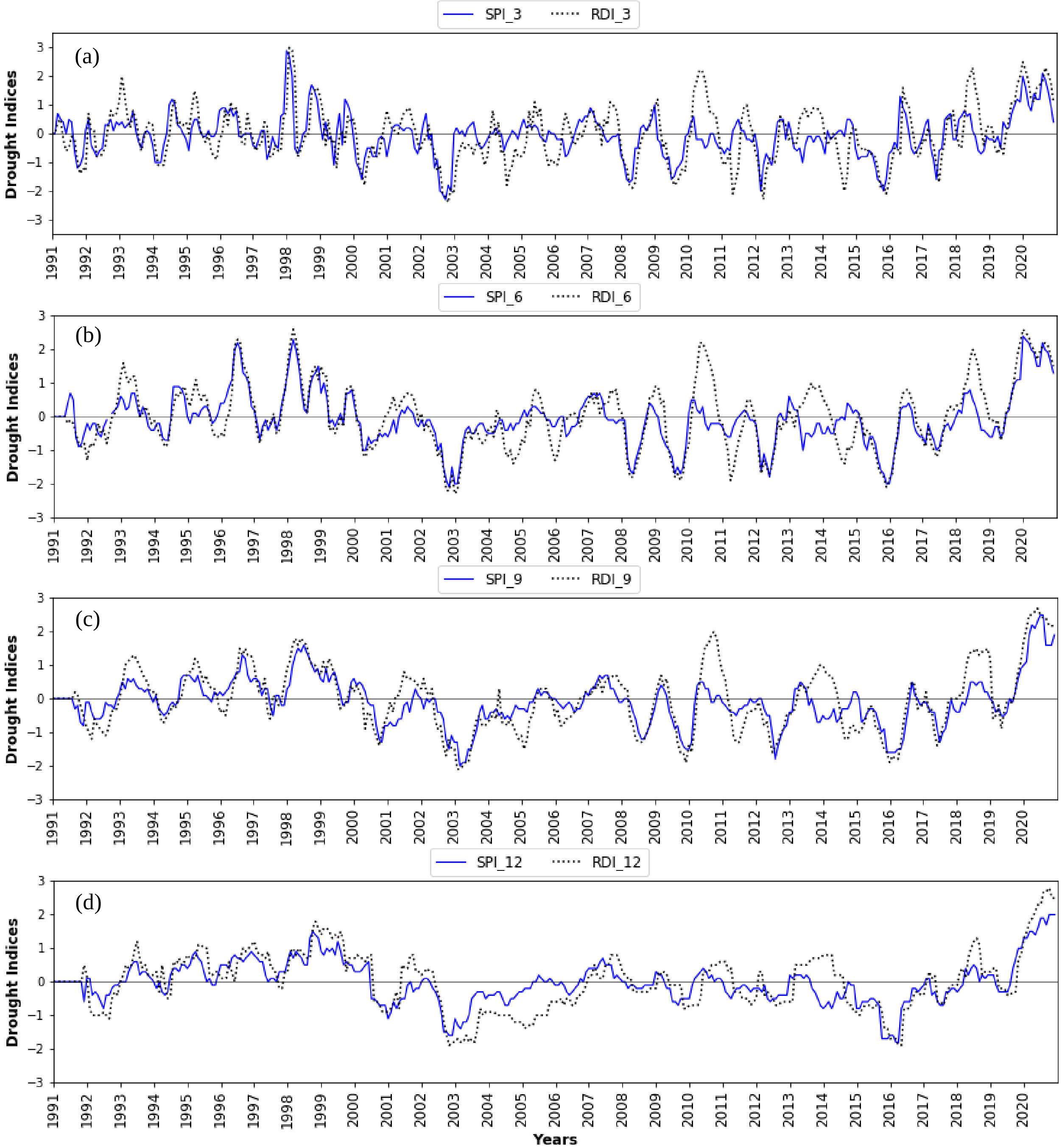


Figure 4.1: Time series comparison drought indices for the time scales of 3, 6, 9 and 12 months over Arsi zone.

Spatial Drought Analysis of Meteorological and Agricultural Droughts

In this study, I analyzed at how droughts extends from one place to another in spatial and area coverage. The effect of drought indicates that the variation of drought severity is covered in frequency and duration across the SPI and RDI indices in time scales. It was found that droughts can range from mild to extreme, and occurs in different areas at different periods from 1991-2020 to investigate in spatial propagation of drought events.

According to the result, June-July-August (JJA), July-August-September (JAS), and August-September-October (ASO) of three months showed severe, extreme, and exceptional drought over El Niño years 2002, 2009, and 2015 in short-term drought indices. Seasonal variability is particularly important for the propagation of meteorological and agricultural droughts, especially in the west, northeast, south, and southeast of Arsi, where the response of soil moisture and runoff is dependent on rainfall amount. Drought in the short-term SPI3 indices of JJA demonstrated severe to extreme drought over the north, northwest, east, south, southeast, and west of Arsi. The severity and intensity of the drought influenced Kiremt rainfall distribution and insufficient crop production. Drought extended from short-term meteorological and agricultural drought accumulation in time scales over the study area. In the figure 4.2, JAS shows that severe and extreme drought is indicated over northeast, east, central, south, and west Arsi with different levels of magnitude; however, drought severity propagates from SPI3, RDI3, and SDI3, except for the central, pocket area, and a few parts of east Arsi. Similarly, figures demonstrated extreme and exceptional droughts over most parts of the Arsi zone in the three months of August, September, and October (ASO). It was demonstrated the propagation of drought on a short-term scale in rainy months (JJA, JAS, and ASO) and was also influenced by rainfall variability over the study area. In general, El Niño years enhance drought severity and influence rainfall distribution, soil moisture and runoff during the Kiremt season, as well as impact crop production and water availability. It was found the intensity of drought propagation from meteorological to agricultural droughts to also be influenced by a deficiency of rainfall, a soil moisture deficit, and the deficiency of runoff on short- to long-term scales.

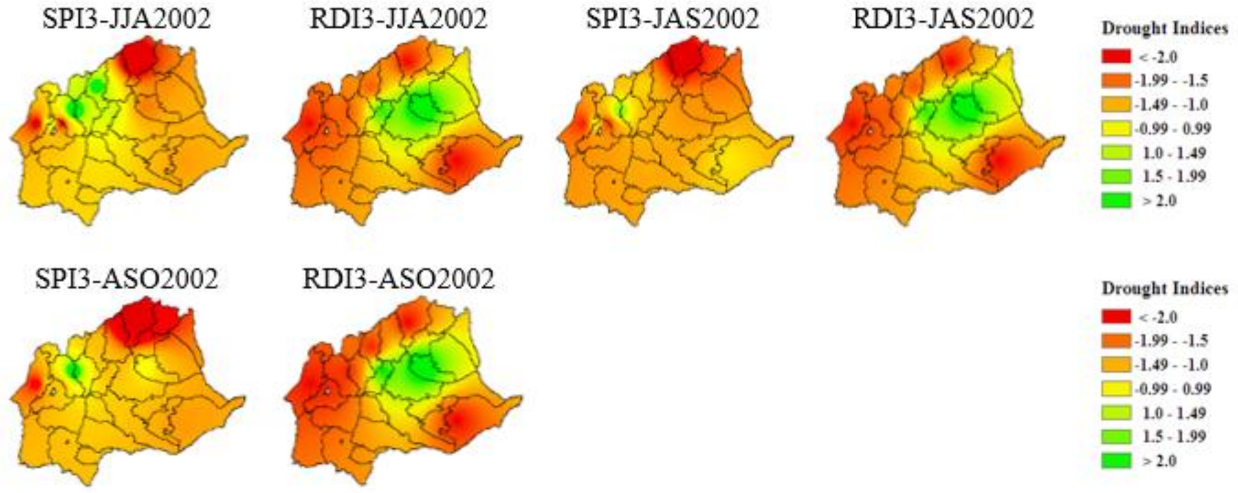


Figure 4.2: Spatial drought analyzes of SPI3 and RDI3 for JJA-June-July-August, JAS-July-August-September, and ASO-August-September-October on three months in 2002.

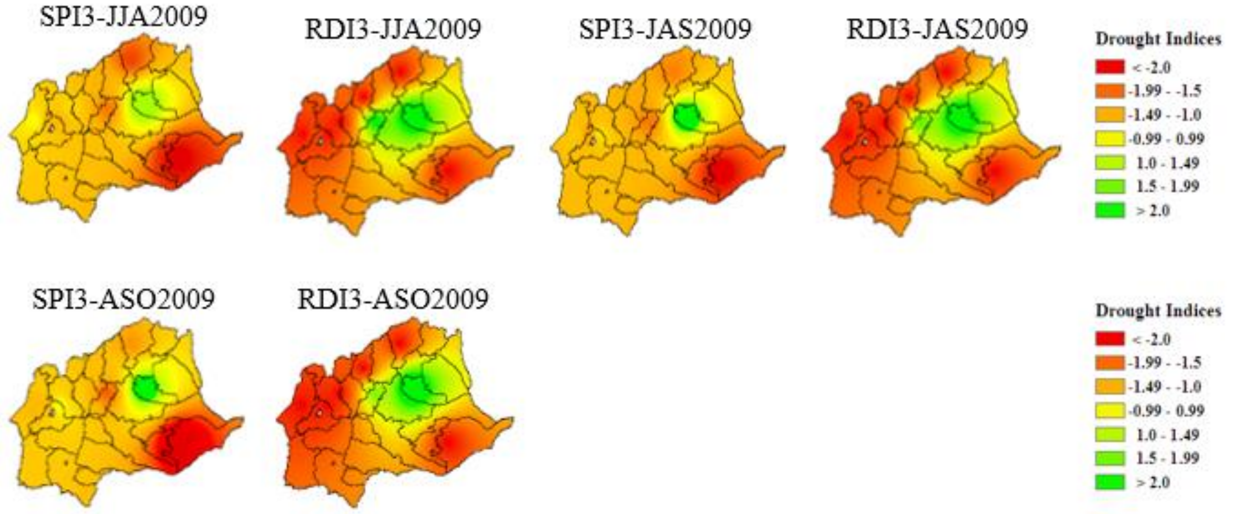


Figure 4.3: Spatial drought analyzes of SPI3 and RDI3 for JJA- June-July-August, JAS-July-August-September, and ASO-August-September-October on three months in 2009.

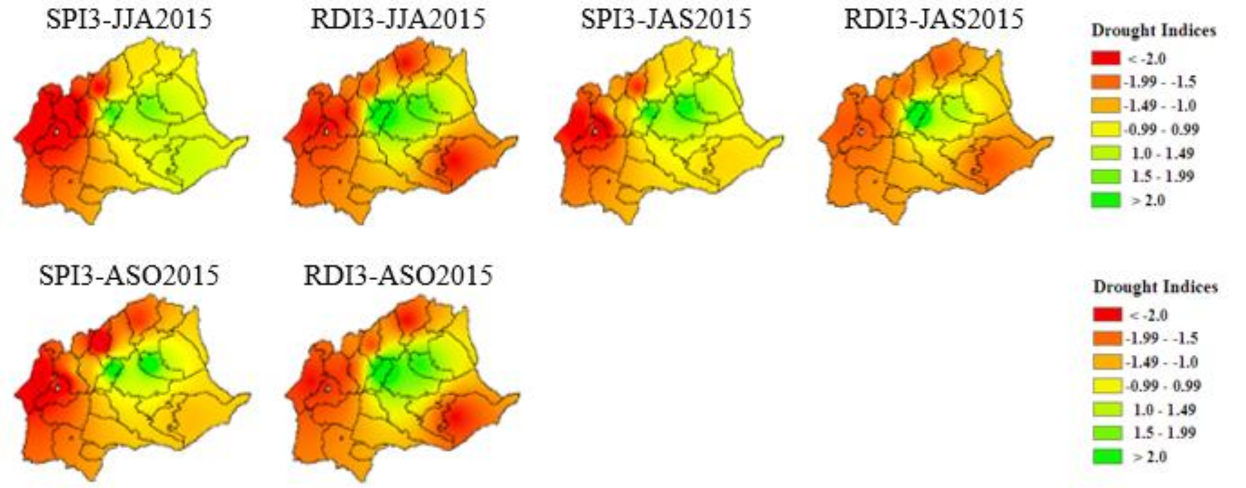


Figure 4.4: Spatial drought analyzes of SPI3 and RDI3 for JJA- June-July-August, JAS-July-August-September, and ASO-August-September-October on three months in 2015.

In general the above figures represent the spatial distribution of one of the strongest droughts presented in JJA, JAS, and ASO of 2002, 2009, and 2015 (figure 4.2, 4.3, 4.4), linked to the El Niño phenomenon that started in JJA of 2002, 2009, and 2015, reaching its peak drought intensity in ASO. Based on this, the map shows in short time scales SPI3 and RDI3 values at different time scales, which clearly indicate the presence of an extreme drought across accumulation periods over the study area. Kiremt season impacted by El Niño phenomena, considered a deficit of rainfall, soil moisture deficit, and runoff deficit to be prevailed drought propagation in time scales over the study area.

Severe to extreme drought was shown over the study area for the months of June, July, August, and September in the El Niño years 2002 in time scales across SPI3, RDI3, SPI6, RDI6, SPI12, and RDI12.

Drought that extends from short- to long-term scales of SPI and RDI indices showed a month-to-month increase in severity. In a short amount of time, the drought in the northeast, south, southwest, central, and west parts of Arsi has gotten severe. The investigation in the area showed that the severity of drought increased from meteorological to agricultural and hydrological droughts in terms of both geographical and area coverage. Particularly, the Kiremt season (June, July, August, and September) saw the highest level of drought intensity during the period of 2002. The global drought signal linked with the ENSO (El Niño events) consequences on Kiremt season which is from June to September prevailed in time scales.

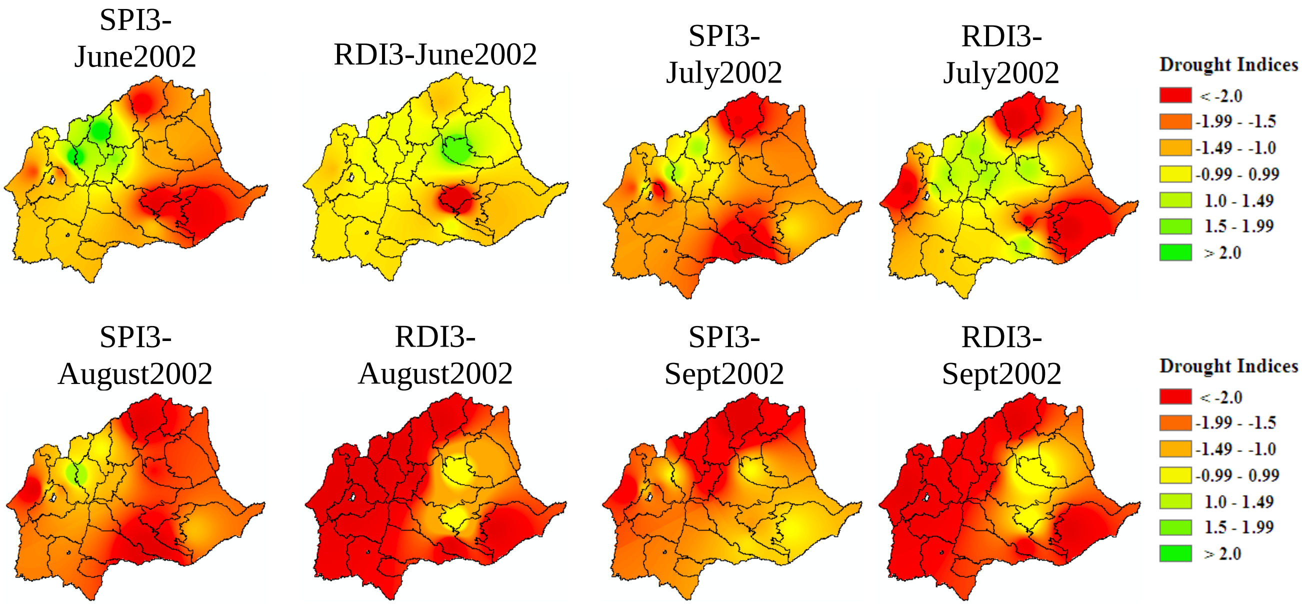


Figure 4.5: Spatial drought analyses of SPI3 and RDI3 for monthly June, July, August, and September in 2002.

The effects of drought that extends from short- to long-term scales of SPI, and RDI indices showed a month-to-month increase in severity. In a short amount of time, the drought in the northeast, south, southwest, central, and west parts of Arsi has gotten severe. The investigation in the area showed that the severity of drought increased from meteorological to agricultural and hydrological droughts in terms of both geographical and area coverage. Particularly, the Kiremt season (June, July, August, and September) saw the highest level of drought intensity during the period of 2002. The global drought signal linked with the ENSO (El Niño events) consequences on Kiremt season which is from June to September prevailed in time scales.

Frequency of Meteorological and Agricultural Droughts

In meteorological and agricultural droughts, the frequency of moderate, severe and extreme droughts were shown to be more frequent across SPI3, SPI6, SPI9, and SPI12 indices, with different levels of the magnitudes. The frequency of drought severity across moderate, severe and extreme droughts in short to long time scales prevailed. According to the result shown in the figure 4.6, the effects of drought were described for the frequency of drought severity influenced in time periods. In general sometimes, when there is a rainfall deficit for a long period of time influenced on soil moisture and runoff with the consequence of drought frequency across severe to extreme droughts in time scales. The severity of the drought varied in time scales. This study demonstrated at different levels of drought frequency and magnitude measures how often drought severity occurred in time periods.

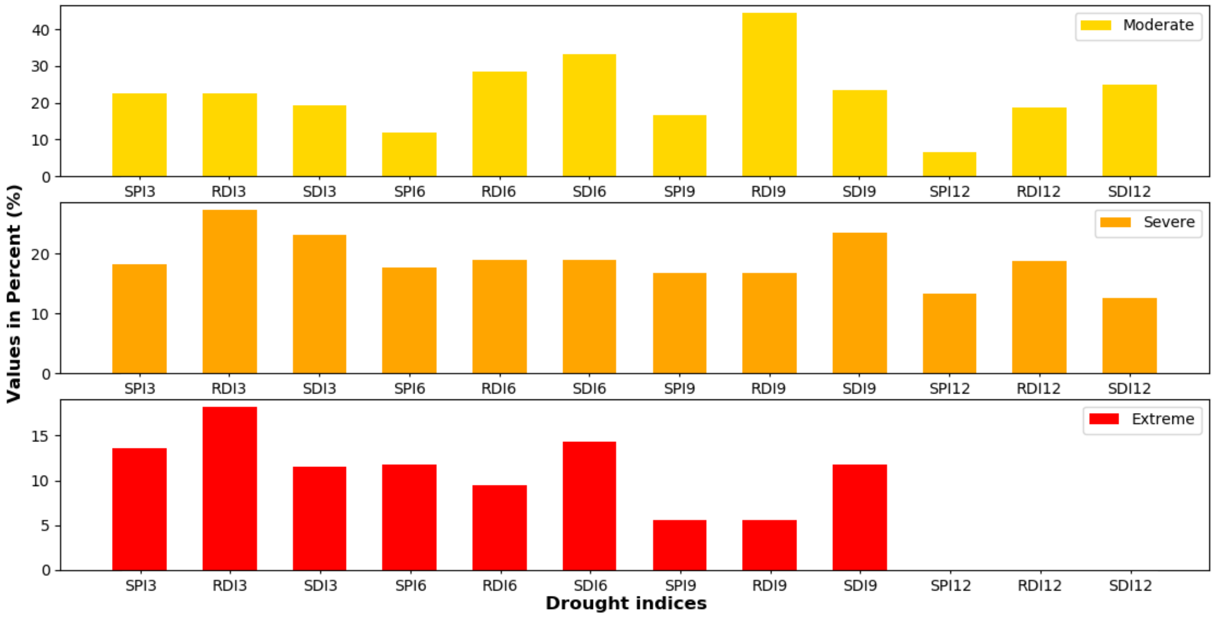
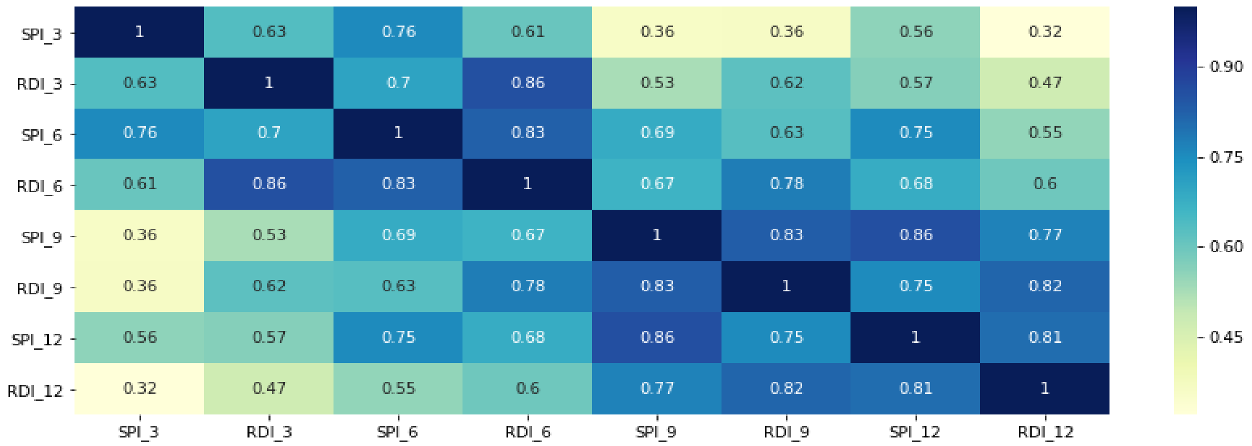


Figure 4.6: Propagation of droughts in percent for moderate, severe, and extreme drought indices for the time scales 3, 6, 9 and 12-months.

According to the result, the correlation values show that there is a strong association between short to long time scales with different level of the magnitudes (figure 4.7). In the 3, 6, 9 and 12-months an increment in correlation values was the dominant factor in the propagation of drought in significantly positive correlation between the SPI and RDI indices. This information supports the result obtained in the correlation values between drought indices with high drought indication in time periods.



	SPI_3	RDI_3	SPI_6	RDI_6	SPI_9	RDI_9	SPI_12	RDI_12
SPI_3	1	0.63	0.76	0.61	0.36	0.36	0.56	0.32
RDI_3	0.63	1	0.7	0.86	0.53	0.62	0.57	0.47
SPI_6	0.76	0.7	1	0.83	0.69	0.63	0.75	0.55
RDI_6	0.61	0.86	0.83	1	0.67	0.78	0.68	0.6
SPI_9	0.36	0.53	0.69	0.67	1	0.83	0.86	0.77
RDI_9	0.36	0.62	0.63	0.78	0.83	1	0.75	0.82
SPI_12	0.56	0.57	0.75	0.68	0.86	0.75	1	0.81
RDI_12	0.32	0.47	0.55	0.6	0.77	0.82	0.81	1

Figure 4.7: Correlation between standard precipitation index (SPI) and reconnaissance drought index (RDI) on heat map.

Effects of Meteorological and Agricultural Drought on Crops Production

In this study, it was analyzed the time series, and how droughts affect crops such as maize, barley, and wheat production. It was found that droughts can have both positive and negative effects on crop yield in time period. Some years were extreme and exceptional drought for crops because of drought propagation from meteorological to agricultural and hydrological. The different measurements are better for detecting droughts depending on drought tolerant crops if it was seen at short-term or long-term impacts (Bonaccorso *et al.*, 2003; Edwards, 1997).

Based on the research how drought affected the amount of crop yield in different areas. The result show that in certain years, like 1992, 1997, and 2002, there was a rainfall deficit and it had an impact on crops like maize, barley, and wheat yield. In 2002, there was a severe drought and it made it even harder for crops production (Piguet, 2003). This happened again in 2009, and it had an impact on the amount of crop yield. Overall, these years were considered as significantly severe to extreme drought phenomena. It was found that in 2011, 2012, and 2015, when there was a rainfall deficit, it actually supported crops maize, barley, and wheat was better performance. The same conditions occurred from 2014 to 2017. This might be because the farmers used drought tolerant types of crops that survived in dry spell conditions and irrigation systems. As input information, farmers were used weather forecasts and agro-meteorology advice to help them deal with dry spell and drought severity.

El Niño is a climate pattern that happens every few years. It happened in 1991, 1994, 1997, 2002 and other years (Gidey *et al.*, 2018; Haile *et al.*, 2021a, 2021b; Kalisa *et al.*, 2020; Mera, 2018; Mohammed *et al.*, 2018). When ENSO (El Niño) events happens, it can cause a drought, which means there is the deficit of rainfall influence on crops to have grown well performance. This can make it severe and exceptional drought for crop yield. In the years 1997, 2002, and 2009, the drought caused as high impact on crop production. The trend lines show that in the El Niño year of 2015 rainfall declined, in contrast there was better crop yield in this year, further investigation and more research is needed to understand why and to find ways to develop crops that can survive droughts.

The severity of droughts in short time scales (SPI3 and RDI3) show that there have been extreme and exceptional droughts in expected years that have affected the crop yields. This is shown in figure 4.8 (a) and (b). The severity of the droughts has been extreme in the time periods of three months, and it has affected how much rainfall available (meteorological), and how much moisture is available in the soil (agricultural). This has had an impact on the crops performance and how well they have production. Even short time scale droughts can have a significant impact on crops, particularly when they occur during phenological stages of crop development, such as after planting or during flowering. Drought severity can develop on time scales, resulting in a decline in the quantity and quality of crops production. As soil moisture decreases, crops dehydrate and become more vulnerable to pests and diseases. The Arsi zone, which was known for having loss more than enough resources, experienced a severe deficit of rainfall in 2002 which was drought year. This led to a long-lasting decline in the crop production, availability of food, making it harder for people to have enough to get (Piguet, 2003).

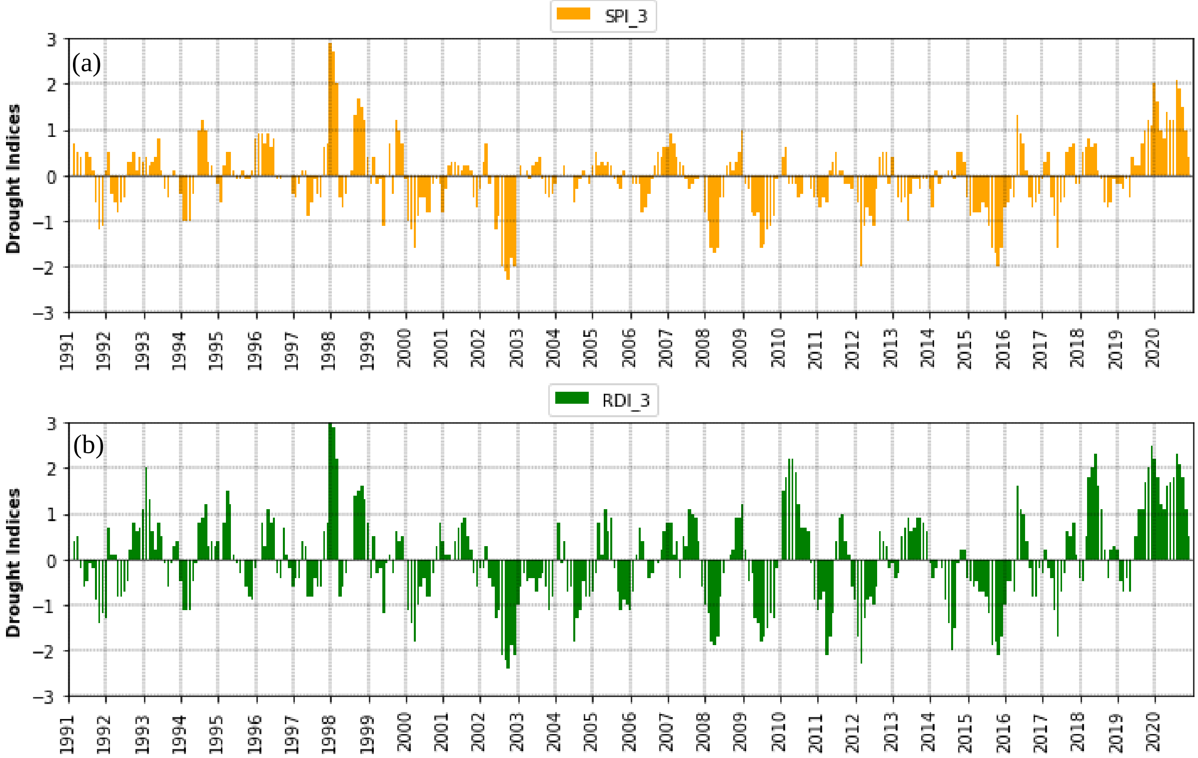


Figure 4.8: Time series analysis of 3-month time scale with bar plot for SPI3 and RDI3 during 1991–2020.

Time series analysis show that on standardized yield across maize, barley and wheat with drought indices of short time scales SPI3 and RDI3 during 1995–2020 (figure 4.9). In this study, It was seen at how droughts affect crops across maize, barley, and wheat production as shown on trend line figure. I also found specific years where droughts had a big impact on crop production.

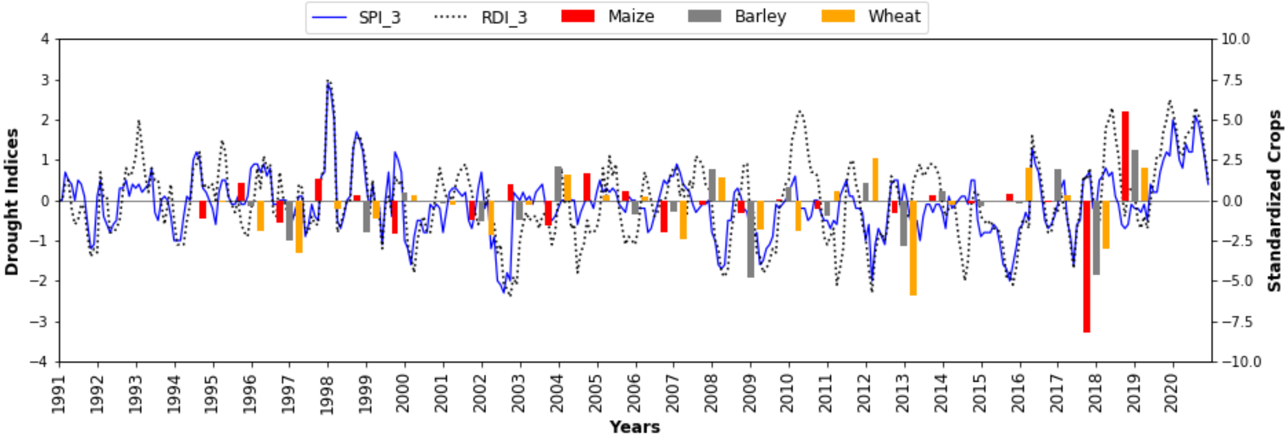


Figure 4.9: Time series analysis of standardized yield across maize, barley and wheat, and short time scales SPI3 and RDI3 during 1995–2020.

Artificial neuron network analysis result shows that for crop prediction on maize, barley and wheat; however, the performance of crop prediction was better in time scales except drought years. From the figure 4.10 of the result demonstrated through comparison between crop yield and crop prediction of maize, barley and wheat have better crop prediction performance. The extent El Niño events reliably predict crop yields as crop varieties influence on artificial neuron network prediction. The rainfall parameter stand as the factor including temperature, soil moisture and relative humidity affected crop yields during ENSO (El Niño) events. Artificial neural networks can accurately predict crop yield based on climate and crop data, leading to more efficient and profitable farming.

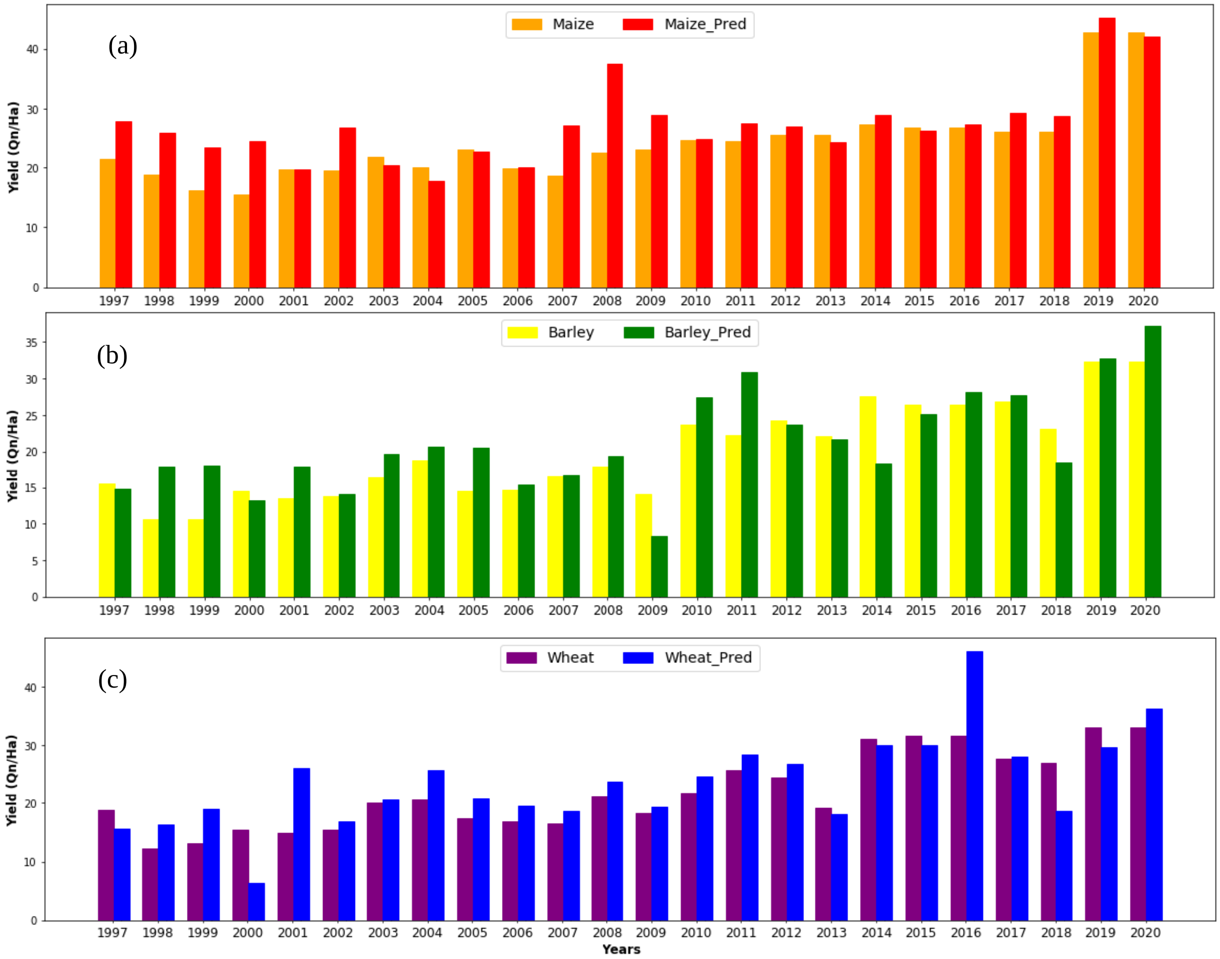


Figure 4.10 Time series analysis of crop prediction for (a) maize, (b) barley and (c) wheat.

DISCUSSION

Based on analysis, it was determined that crop yields for maize, barley, and wheat have experienced significantly unfavorable effects due to drought propagation over the study area's time periods. The variability study of the drought indicated significant spatiotemporal changes in the relationship between the expansion of the drought and the production of maize, barley, and wheat. The strength of the correlation between SPI3 and RDI3 to SPI12 and RDI12 showed significantly high and across maize, barley, and wheat yield, the districts that were more vulnerable to drought were determined. The results showed a large spatiotemporal diversity in the transmission of drought sensitivity and its impacts on the output of wheat, barley, and maize. It was hypothesized that district-level variability in drought sensitivity and impacts could be influenced by local physical characteristics like the availability of groundwater or soil water retention capacity because the SPI does not account for soil moisture or groundwater storage (Tong *et al.*, 2018). However, each crop's sensitivity to the drought varied, as shown by differences in the strength of the correlations with the drought indices 0.831, 0.946, and 0.767, with barley yields showing stronger correlations than maize and wheat yields (figure 4.7 respective). The effects of the drought were propagated similarly in space and time for maize, barley, and wheat yields over study area.

In previous research, the main focus was on monitoring drought over upper Blue Nile, river basins and water bodies, as well as meteorological and hydrological drought (Kebede *et al.*, 2018; Tareke & Awoke, 2022; Wubneh *et al.*, 2023). This research centered on the spatiotemporal spread of drought and how it affected yield in terms of drought severity through time steps. The majority of developing countries are especially vulnerable to severe droughts and climate change because their economies are mostly focused on agriculture (Waseem *et al.*, 2022). Severe occurrences, including heat waves, hot extremes, and droughts, are predicted to get worse and more common in the near future (Khan *et al.*, 2020). Drought indices were used to show the spread of the drought state over the time period (between planting and harvesting) in order to quantify the impact of the drought on agricultural yield. Future studies may consider variance in addition to the average when establishing relationships between drought and agricultural yield. Understanding how extreme weather events, such as droughts, affect the agricultural sector is essential for enhancing its capacity to adapt to climate change (Long *et al.*, 2014). Previous research has indicated that evapotranspiration, soil moisture, runoff, and rainfall may all be strongly associated with drought (Fang *et al.*, 2020; Han *et al.*, 2019).

A meteorological phenomenon or drought progresses through the hydrological cycle into a hydrological phenomenon or drought that eventually affects crops or terrestrial ecosystems (Tallaksen & Van Lanen, 2004; Wilhite, 2000). It is not possible to directly extract hydrological or agricultural drought indicators from meteorological drought indicators (Peters *et al.*, 2003; Wada *et al.*, 2013), which is why this analysis supports the theory that meteorological droughts are the cause of both hydrological and agricultural droughts. Higher evaporation rates and a deficit of rainfall cause this to happen. The hydrological community has become more interested in the study of drought propagation during the past ten years (Peters *et al.*, 2003, 2006; Stahl *et al.*, 2015; Tallaksen *et al.*, 2009; Tallaksen & Stahl, 2014). Hydrological drought and meteorological drought have been found to be significantly correlated, with the exception of catchments where groundwater storage and snow processes are significant (Haslinger *et al.*, 2014). According to Van Loon *et al.* (2012), a number of characteristics of drought propagation have been identified. (a) Meteorological drought is attenuated when storage is high at the beginning of an event (pooling); (b) Meteorological drought is attenuated (attenuation); (c) a lag between a meteorological, soil moisture and hydrological drought occurs; and (d) a drought lengthens as it progresses from a meteorological, agricultural, and hydrological drought.

To further understand the consequences of the extreme propagation of droughts on each crop in the research area, future attempts should also take into account the variety of each crop yield in the Arsi zone, as well as the water balance, irrigation efficiency, and water productivity. Additionally, stakeholders can plan for zonal shifts in actual and realized crop output under the stress of future climate change by understanding the spatial pattern of drought sensitivity for crops and fluctuations in their patterns over time (Zipper *et al.*, 2016). Future research should look at new phenotypes capable of surviving harsh meteorological, agricultural, and hydrological droughts and providing higher yields in Arsi zone under various agro-ecological circumstances, given the vulnerability of agricultural systems to drought propagation. This study was a first step in examining how drought spread and the potential effects of extreme meteorological, agricultural, and hydrological droughts on crop production in the study area; however, more research into the socio-economic and long-term effects of drought impacts should be investigated.

CONCLUSION

This study indicated that propagation of droughts can cause significant losses in crop yield and quality, leading to food insecurity and economic losses, particularly in vulnerable woredas of the Arsi zone. The impact of droughts on crop production was found to be significant, with a reduction in crop yield and quality. The extent of the damage varied across crop types, with some crops being more sensitive to drought than others. For instance, maize, barley and wheat were found to be more vulnerable to drought from 1995 to 2009 in time series. Also it was found that the severity of the drought had a proportional impact on the crop production loss.

To mitigate the impact of droughts on crop production, the adoption of various strategies is needed. Firstly, there is a need for improved water management practices to ensure efficient use of available water resources, especially in woredas of the Arsi zone that are prone to droughts. This can include the use of efficient irrigation systems like drip irrigation, which reduces water wastage and minimizes soil erosion. It was also important to increase the adoption of rainwater harvesting and storage facilities to ensure water availability during dry seasons.

Secondly, there is a need for crop diversification and the promotion of drought-resistant crop varieties. The cultivation of diverse crop types can help minimize the impact of drought on food production as different crop types have varied levels of drought resistance. Therefore, there should be incentives provided to farmers to cultivate drought-resistant crops and to increase awareness on diversified farming.

Thirdly, the development of early warning systems and the promotion of climate-smart agriculture practices are essential in enhancing agricultural resilience and ensuring food security. Farmers should be provided with adequate information on the onset of droughts and the expected severity to enable them to make informed decisions and take necessary precautions to minimize crop losses.

In conclusion, mitigating the impact of droughts on agriculture requires a multi-sectoral approach that involves governments, farmers, researchers, and other stakeholders. The policymakers should be encouraged to prioritize the implementation of the recommended strategies to enhance agricultural resilience and ensure food security in drought-prone woredas of the Arsi zone.

ACKNOWLEDGMENTS

The authors would like to thank the EMI and ESS for availability data.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Authors' contributions

Author conceived of the presented idea, developed the theory, and performed the computations.

Conflicts of Interest

The Authors declare no conflicts of interest.

REFERENCES

Bonaccorso, B., Bordi, I., Cancelliere, A., Rossi, G., & Sutera, A. (2003). Spatial variability of drought: an analysis of the SPI in Sicily. *Water Resources Management*, *17*, 273–296.

Degefu, M. A., Rowell, D. P., & Bewket, W. (2017). Teleconnections between Ethiopian rainfall variability and global SSTs: observations and methods for model evaluation. *Meteorology and Atmospheric Physics*, *129*, 173–186.

Edwards, D. C. (1997). *Characteristics of 20th Century drought in the United States at multiple time scales.* Air Force Inst of Tech Wright-Patterson Afb Oh.

Eze, E., Girma, A., Zenebe, A., Okolo, C. C., Kourouma, J. M., & Negash, E. (2022). Predictors of drought-induced crop yield/losses in two agroecologies of southern Tigray, Northern Ethiopia. *Scientific Reports*, *12*(1), 1–14.

Fang, W., Huang, S., Huang, Q., Huang, G., Wang, H., Leng, G., & Wang, L. (2020). Identifying drought propagation by simultaneously considering linear and nonlinear dependence in the Wei River basin of the Loess Plateau, China. *Journal of Hydrology*, *591*, 125287.

Funk, C., Michaelsen, J., & Marshall, M. T. (2012). Mapping recent decadal climate variations in precipitation and temperature across eastern Africa. *Remote Sensing of Drought: Innovative Monitoring Approaches*, *331*(7), 331–355.

Gebiso, T. (2018). Livestock production system characterization in Arsi Zone, Ethiopia. *International Journal of Livestock Production*, *9*(9), 238–245.

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A. (2018). Modeling the spatio-temporal meteorological drought characteristics using the standardized precipitation index (SPI) in raya and its environs, northern Ethiopia. *Earth Systems and Environment*, *2*, 281–292.

Haile, B. T., Zeleke, T. T., Beketie, K. T., Ayal, D. Y., & Feyisa, G. L. (2021a). Analysis of El Niño Southern Oscillation and its impact on rainfall distribution and productivity of selected cereal crops in Kembata Alaba Tembaro zone. *Climate Services*, *23*, 100254.

Haile, B. T., Zeleke, T. T., Beketie, K. T., Ayal, D. Y., & Feyisa, G. L. (2021b). Analysis of El Niño Southern Oscillation and its impact on rainfall distribution and productivity of selected cereal crops in Kembata Alaba Tembaro zone. In *Climate Services* (Vol. 23). https://doi.org/10.1016/j.cliser.2021.100254

Haile, G. G., Tang, Q., Sun, S., Huang, Z., Zhang, X., & Liu, X. (2019). Droughts in East Africa: Causes, impacts and resilience. *Earth-Science Reviews*, *193*, 146–161.

Han, Z., Huang, S., Huang, Q., Leng, G., Wang, H., Bai, Q., Zhao, J., Ma, L., Wang, L., & Du, M. (2019). Propagation dynamics from meteorological to groundwater drought and their possible influence factors. *Journal of Hydrology*, *578*, 124102.

Haslinger, K., Koffler, D., Schöner, W., & Laaha, G. (2014). Exploring the link between meteorological drought and streamflow: Effects of climate-catchment interaction. *Water Resources Research*, *50*(3), 2468–2487.

Huang, S., Zhang, X., Chen, N., Li, B., Ma, H., Xu, L., Li, R., & Niyogi, D. (2021). Drought propagation modification after the construction of the Three Gorges Dam in the Yangtze River Basin. *Journal of Hydrology*, *603*, 127138.

Kalisa, W., Zhang, J., Igbawua, T., Ujoh, F., Ebohon, O. J., Namugize, J. N., & Yao, F. (2020). Spatio-temporal analysis of drought and return periods over the East African region using Standardized Precipitation Index from 1920 to 2016. *Agricultural Water Management*, *237*, 106195.

Kebede, A., Kang, M. S., & Bekele, E. (2019). Advances in mechanisms of drought tolerance in crops, with emphasis on barley. *Advances in Agronomy*, *156*, 265–314.

Kebede, A., Raju, U., Koricha, D., & Nigussie, M. (2018). Characterizing and monitoring drought over Upper Blue Nile of Ethiopia with the aid of copula analysis. *International Journal of Environment and Climate Change*, *8*(4), 283–294.

Khan, M. I., Zhu, X., Arshad, M., Zaman, M., Niaz, Y., Ullah, I., Anjum, M. N., & Uzair, M. (2020). Assessment of spatiotemporal characteristics of agro-meteorological drought events based on comparing Standardized Soil Moisture Index, Standardized Precipitation Index and Multivariate Standardized Drought Index. *Journal of Water and Climate Change*, *11*(S1), 1–17.

Kourouma, J. M., Eze, E., Kelem, G., Negash, E., Phiri, D., Vinya, R., Girma, A., & Zenebe, A. (2022). Spatiotemporal climate variability and meteorological drought characterization in Ethiopia. *Geomatics, Natural Hazards and Risk*, *13*(1), 2049–2085.

Liou, Y.-A., & Mulualem, G. M. (2019). Spatio–temporal assessment of drought in Ethiopia and the impact of recent intense droughts. *Remote Sensing*, *11*(15), 1828.

Long, D., Shen, Y., Sun, A., Hong, Y., Longuevergne, L., Yang, Y., Li, B., & Chen, L. (2014). Drought and flood monitoring for a large karst plateau in Southwest China using extended GRACE data. *Remote Sensing of Environment*, *155*, 145–160.

McKee, T. B. (1995). Drought monitoring with multiple time scales. *Proceedings of 9th Conference on Applied Climatology, Boston, 1995*.

Mera, G. A. (2018). Drought and its impacts in Ethiopia. *Weather and Climate Extremes*, *22*(June), 24–35.

Mohammed, Y., Yimer, F., Tadesse, M., & Tesfaye, K. (2018). Meteorological drought assessment in north east highlands of Ethiopia. *International Journal of Climate Change Strategies and Management*, *10*(1), 142–160.

Moloro, T. L. (2018). Spatio-temporal analysis of rainfall variability and meteorological drought: a case study in Bilate River Basin, Southern Rift Valley, Ethiopia. *International Journal of Environmental Sciences & Natural Resources*, *14*(4), 76–89.

Muller, J. C.-Y. (2014). Adapting to climate change and addressing drought–learning from the Red Cross Red Crescent experiences in the Horn of Africa. *Weather and Climate Extremes*, *3*, 31–36.

Nasir, J., Assefa, E., Zeleke, T., & Gidey, E. (2021). Meteorological Drought in Northwestern Escarpment of Ethiopian Rift Valley: detection seasonal and spatial trends. *Environmental Systems Research*, *10*, 1–20.

Peters, E., Bier, G., Van Lanen, H. A. J., & Torfs, P. (2006). Propagation and spatial distribution of drought in a groundwater catchment. *Journal of Hydrology, 321*(1–4), 257–275.

Peters, E., Torfs, P., Van Lanen, H. A. J., & Bier, G. (2003). Propagation of drought through groundwater—a new approach using linear reservoir theory. *Hydrological Processes*, *17*(15), 3023–3040.

Piguet, F. (n.d.). *Promising 2003 harvest in Arsi zone with the exception of some pocket areas*.

Schwalm, C. R., Anderegg, W. R. L., Michalak, A. M., Fisher, J. B., Biondi, F., Koch, G., Litvak, M., Ogle, K., Shaw, J. D., & Wolf, A. (2017). Global patterns of drought recovery. *Nature*, *548*(7666), 202–205.

Shukla, S., & Wood, A. W. (2008). Use of a standardized runoff index for characterizing hydrologic drought. *Geophysical Research Letters*, *35*(2).

Stahl, K., Kohn, I., Blauhut, V., Urquijo, J., De Stefano, L., Acacio, V., Dias, S., Bifulco, C., Stagge, J. H., & Tallaksen, L. M. (2015). Impacts of European drought events: insights from an international database of text-based reports. *Natural Hazards & Earth System Sciences Discussions*, *3*(9).

Tadesse, T. (2016). Strategic framework for drought management and enhancing resilience in Africa. *African Drought Conference*.

Tallaksen, L. M., Hisdal, H., & Van Lanen, H. A. J. (2009). Space–time modelling of catchment scale drought characteristics. *Journal of Hydrology*, *375*(3–4), 363–372.

Tallaksen, L. M., & Stahl, K. (2014). Spatial and temporal patterns of large-scale droughts in Europe: Model dispersion and performance. *Geophysical Research Letters*, *41*(2), 429–434.

Tallaksen, L. M., & Van Lanen, H. A. J. (2004). *Hydrological drought: processes and estimation methods for streamflow and groundwater*.

Tareke, K. A., & Awoke, A. G. (2022). Hydrological drought analysis using streamflow drought index (SDI) in Ethiopia. *Advances in Meteorology*, *2022*, 1–19.

Tong, S., Lai, Q., Zhang, J., Bao, Y., Lusi, A., Ma, Q., Li, X., & Zhang, F. (2018). Spatiotemporal drought variability on the Mongolian Plateau from 1980–2014 based on the SPEI-PM, intensity analysis and Hurst exponent. *Science of the Total Environment*, *615*, 1557–1565.

Van Loon, A. F. (2015). Hydrological drought explained. *Wiley Interdisciplinary Reviews: Water*, *2*(4), 359–392.

Wada, Y., Van Beek, L. P. H., Wanders, N., & Bierkens, M. F. P. (2013). Human water consumption intensifies hydrological drought worldwide. *Environmental Research Letters*, *8*(3), 34036.

Waseem, M., Khurshid, T., Abbas, A., Ahmad, I., & Javed, Z. (2022). Impact of meteorological drought on agriculture production at different scales in Punjab, Pakistan. *Journal of Water and Climate Change*, *13*(1), 113–124.

Wilhite, D. A. (2000). *Drought as a natural hazard: concepts and definitions*.

Wossenyeleh, B. K., Kasa, A. S., Verbeiren, B., & Huysmans, M. (2022). Drought propagation in the hydrological cycle in a semiarid region: a case study in the Bilate catchment, Ethiopia. *Hydrogeology Journal*, *30*(3), 751–766.

Wubneh, M. A., Alemu, M. G., Fekadie, F. T., Worku, T. A., Demamu, M. T., & Aman, T. F. (2023). Meteorological and hydrological drought monitoring and trend analysis for selected gauged watersheds in the Lake Tana basin, Ethiopia: Under future climate change impact scenario. *Scientific African*, *20*, e01738.

Zeleke, E. B., Melesse, A. M., & Kidanewold, B. B. (2022). Assessment of Climate and Catchment Control on Drought Propagation in the Tekeze River Basin, Ethiopia. *Water*, *14*(10), 1564.

Zeleke, T. T., Giorgi, F., Diro, G. T., & Zaitchik, B. F. (2017). Trend and periodicity of drought over Ethiopia. *International Journal of Climatology*, *37*(13), 4733–4748.

Zhao, T., & Dai, A. (2015). The magnitude and causes of global drought changes in the twenty-first century under a low–moderate emissions scenario. *Journal of Climate*, *28*(11), 4490–4512.

Zhuang, X., Hao, Z., Singh, V. P., Zhang, Y., Feng, S., Xu, Y., & Hao, F. (2022). Drought propagation under global warming: Characteristics, approaches, processes, and controlling factors. *Science of The Total Environment*, 156021.

Zipper, S. C., Qiu, J., & Kucharik, C. J. (2016). Drought effects on US maize and soybean production: spatiotemporal patterns and historical changes. *Environmental Research Letters*, *11*(9), 94021.