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***Research Paper***

## Spatiotemporal analysis of meteorological drought in El Niño years over Oromia region, Ethiopia


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### ABSTRACT

Drought is one of the most common natural disasters globally; having major impacts on environmental, economic, and social conditions and Ethiopia is no exception particularly the Oromia region. In order to evaluate and characterize the meteorological droughts associated with El Niño years over the Oromia region, the satellite data CHIRPS was used. The monthly time series data for the period from 1991 to 2020 was used for temporal and spatial analysis of meteorological drought using standardized precipitation index (SPI) across SPI3, SPI6, SPI9 and SPI12 indices using GeoCLIM, GIS, and Python tools. The results of this study show that meteorological droughts during the El Niño years indicated an increment across weak, moderate, and strong El Niño events over the Oromia region. The dryness was visualized with frequency and duration in time-scale across short-term drought indices in time steps. The time-scale temporal meteorological drought indices in three to twelve months show that the drought indices varied in magnitude, duration, and frequency in meteorological droughts. In general, the meteorological drought severity of correlation for the remaining zones analysis between SPI3 and SPI6, SPI6 and SPI12, and SPI9 and SPI12 indices was dominated by an increment of the correlation values over short to long timescales over the study area.



***Keywords:*** Meteorological drought; El Niño; SPI; impact


Ethiopia experiences meteorological dryness and exhibits spatiotemporal climate variability (Kourouma *et al*., 2022). The consequences of recent meteorological droughts that have occurred in various sections of Ethiopia and the spatiotemporal assessment of drought linked to changes in atmospheric and ocean circulation (Liou & Mulualem, 2019). Despite the fact that several studies have investigated how climate change is related to Ethiopia's recurrent droughts impact (Degefu *et al*., 2017).The amount and distribution of Ethiopia's seasonal rainfall are significantly impacted by the El Niño Southern Oscillation (ENSO) phenomenon. Due to the El Niño phenomenon, which occurs approximately every 3 to 5 years, the intensity and frequency of droughts have substantially increased across the nation in recent decades. The spread of the drought severity has an impact on Ethiopia (Wossenyeleh *et al.*, 2022). Because a significant portion of Ethiopia's agriculture relies on rain-fed farming, droughts can have a significant influence on the country's crops.

According to several studies utilizing standardized precipitation evapotranspiration indexes (SPEI) and standardized precipitation index (SPI) drought indices with the severity of the drought in Ethiopia's Rift Valley is analyzed (Kebede *et al*., 2019). Lee *et al*., (2018) studied spatio-temporal variability of meteorological droughts in the Mekong delta area of Vietnam to detect drought events using the standardized precipitation index (SPI) at different time scales based on 32-year (1984-2015) monthly rainfall data. They also studied the degree and intensity of drought in the years of El Nino phenomenon during and reported that the frequency of drought scales decreased while their spatial distribution tends to increase with main scales including moderate and severe droughts. Sridhara *et al.,* (2021) used five indices such as deciles index (DI), percent normal (PN), China-Z index (CZI), Z-Score index (ZSI) and standardized precipitation index (SPI) to assess and monitor the drought in Karnataka, India. Other researchers used the standardized groundwater index (SGWI)


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and the standardized precipitation index (SPI) in the Bilate River catchment in the Rift Valley basin of Ethiopia to study the spread of drought in a semi-arid environment using the standardized hydrological cycle (Wossenyeleh *et al*., 2022). The Oromia region is extremely susceptible to the effects of drought due to topography, geographical factors and anthropogenic (Dufera *et al.*, 2023).

Therefore, this study was undertaken to evaluate and analyze the spatial and temporal meteorological drought and evaluate the spatiotemporal meteorological drought in Oromia region and its association with weak, moderate and strong El Niño years over study area.

## MATERIALS AND METHOD

### *Study area*

Oromia region extends from 3.51° to 10.38° N latitude and 34.13° to 42.98° E longitude. In addition to high, rocky mountain ranges, undulating plateaus, gorges, deeply incised river valleys, and rolling plains, it exhibits a significant amount of physiographic variation (FDRE 2008). The height above sea level varies from 343 meters to 4238 meters. The majority of the population in the region relies on small-scale farming as a source of income. The main crops grown in the area include maize, teff, wheat, barley, etc, and various kinds of oil seeds. The region is covered with important river systems and lakes that provide irrigation needs of the important crops (Dufera *et al.*, 2023).

### *Data sources*

The observation data gathered from Ethiopian Meteorology Institute (EMI). 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◦ × 0.05◦) or (~5km) spatial resolution, a time series from 1981 to 2021. Source of data: https://data.chc.ucsb.edu/products/CHIRPS-2.0/ for spatial rainfall climatology and SPI spatial analysis. In this study; the SPI monthly time series chirps-month data at a spatial resolution of 0.1 degree resolution similarly 10 km × 10 km considered for the period from 1991 to 2020 for temporal meteorological drought (SPI3, SPI6, SPI9 and SPI12 indices) analysis; the source: https://earlywarning.usgs.gov/fews/ewx_lite/index.html over study area.

### *Analysis*

We used the data analysis techniques of GeoCLIM, and Python tools for spatial and temporal analysis over the study area. The GeoCLIM program is part of a set of agro climate analysis products developed by the FEWS NET and the United States Geological Survey (USGS). In 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.

## RESULTS AND DISCUSSION

The result of this research was a spatiotemporal analysis of drought weather patterns in El Niño years with time-scale linkage and the progression of the drought across SPI3, SPI6, SPI9 and SPI12 indices over the study area. The spatiotemporal distribution of meteorological drought in El Niño years in time series revealed that the means of drought indices varied from mild, moderate, severe, and extreme droughts between the years of 1981 and 2021(Fig. 1). Generally, the spatiotemporal analysis of meteorological droughts varied according to the severity of the drought, with the association between the time scales being particularly strong on both short and long-time scales.

### *Rainfall climatology over Oromia region*

Rainfall in Ethiopia is distributed unevenly and varies greatly over time and space. There are variations in the seasonal and annual rainfall patterns through Ethiopia including regions, zones, and districts. The magnitudes of seasonal Bega (October-January) is dry, Belg (February-May) has short rainfall, and Kiremt (June-September) has main rainfall and annual (January-December) rainfall distribution throughout Oromia region were compared with ten-year intervals of 1981–1990, 1991–2000, 2001–2010, and 2011–2021 (Fig. 1). Fig. 1(c) and (d) show the development of rainfall climatology for the Kiremt season over the research area from 1981 to 1990, 1991 to 2000, 2001 to 2010, and 2011 to 2021. The climatology of rainfall shows that a ten-year (decadal mean rainfall) comparison shows variations in quantity and distribution from seasons to annuals in spatial coverage. The seasonal and annual rainfall distributions were varied due to Inter Tropical Convergence Zone (ITCZ) movement from North to South Pole. In Fig. 1, the distribution of spatial rainfall over the research area is indicated.

### *Meteorological droughts for El Niño years*

Spatial analysis of meteorological droughts for El Niño years demonstrated weak El Niño in 2004, 2006, 2014, and 2018, moderate El Niño in 1986, 1994, 2002, and 2009, and strong El Niño events in 1982, 1987, 1991, 1997, and 2015 (Sources: https://ggweather.com/enso/oni.htm) with SPI3, SPI6, SPI9 and SPI12 indices over the study area (Fig. (2), (3), and (4)). The results show that meteorological droughts are indicated in spatial and area coverage with different magnitudes of drought severity on time scales. In this study, meteorological drought analysis shows a variation of drought severity in spatial and area coverage on a time scale over the zones. Meteorological droughts towards the El Niño years show an increment across weak, moderate, and strong El Niño events over the Oromia Region during the period of 1981–2021.

### *Weak El Niño years*

The result of the spatial meteorological drought of weak El Niño years like 2004, 2006, 2014, and 2018 indicated mild, moderate, severe, and extreme drought in different zones during the mentioned years. Standardized precipitation index (SPI3) shows that the drought severity indicated severe drought in Guji zone, mild to moderate drought in a few parts of Arsi, a few parts of west Harerghe and East Harerghe zones, and severe to extreme drought in Borena zone and south-east Bale zones during 2004. SPI-6 drought indices show that in Bale, most parts of Arsi, west and east Harerghe, Guji, and some parts of Borena zones indicated moderate to severe droughts (Fig. 2 (a)). In long-term meteorological drought across

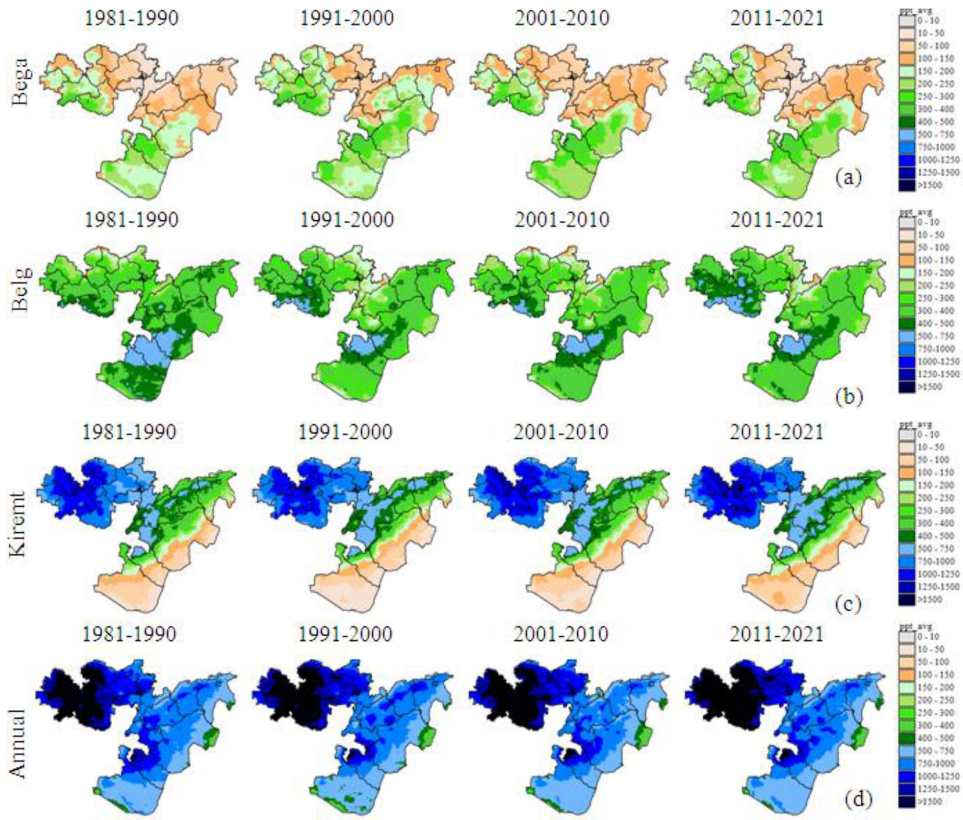


**Fig. 1:** Seasonal (a) Bega, (b) Belg, (c) Kiremt, and (d) annual rainfall climatology of ten-year intervals over Oromia region

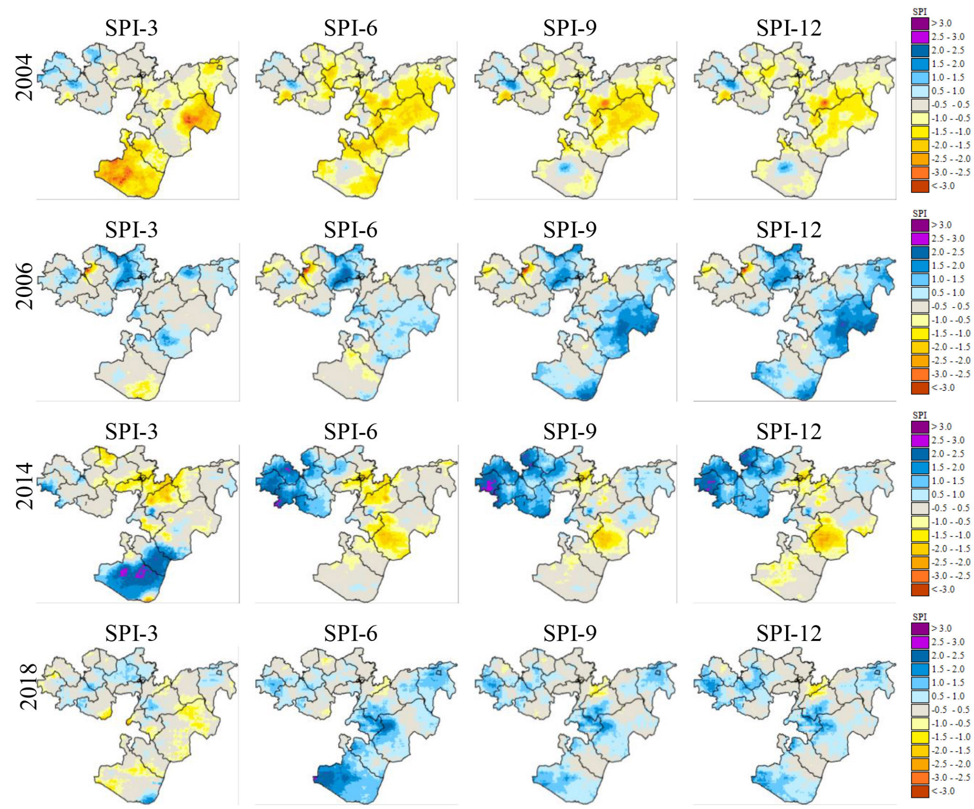


**Fig. 2:** Weak El Niño years across SPI3, SPI6, SPI9 and SPI12indices during 1981-2021.

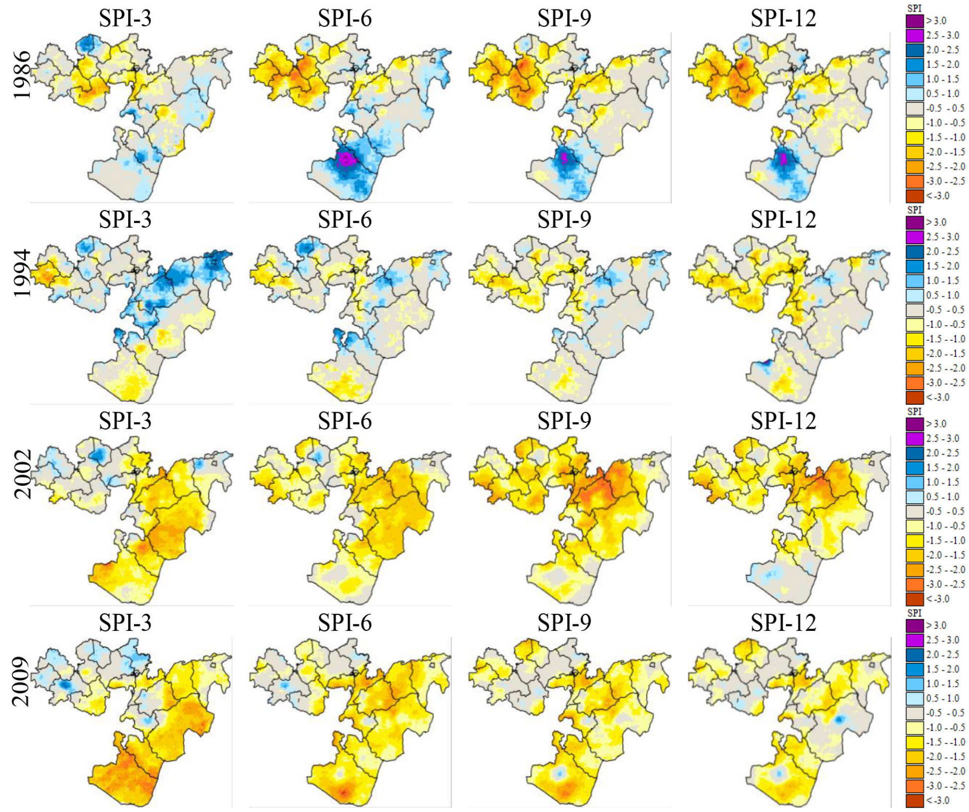


**Fig. 3:** Moderate El Niño years across SPI3, SPI6, SPI9 and SPI12 indices during 1981-2021.

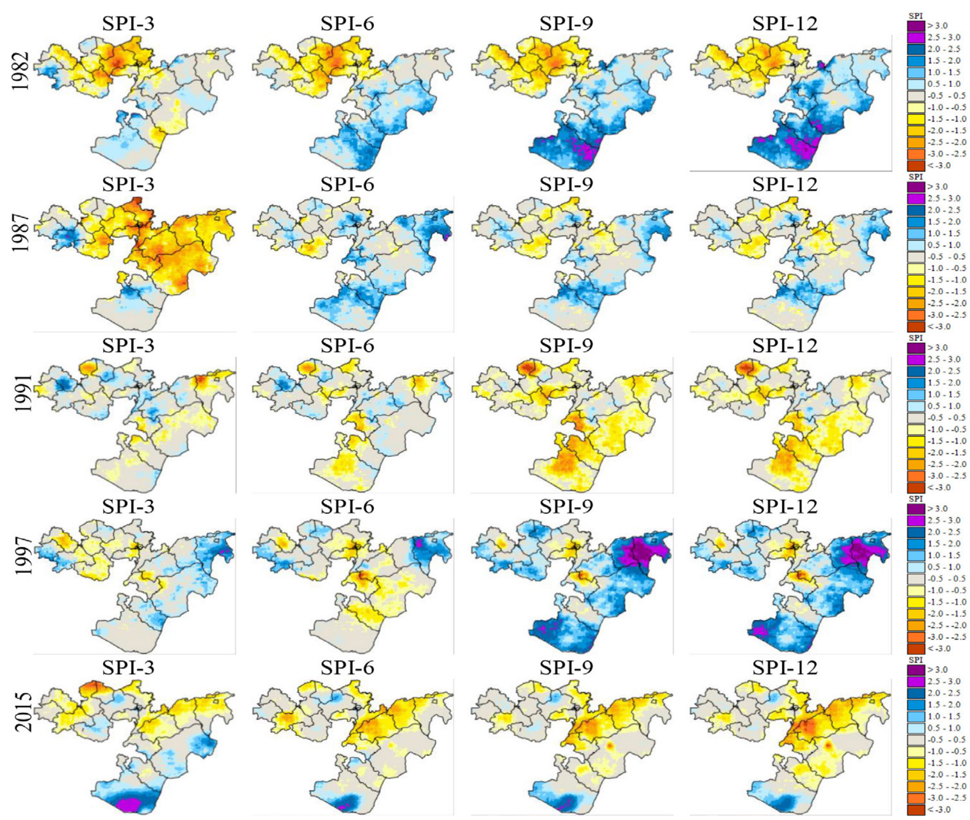


**Fig. 4:** Strong El Niño years across SPI3, SPI6, SPI9 and SPI12 indices during 1981-2021.

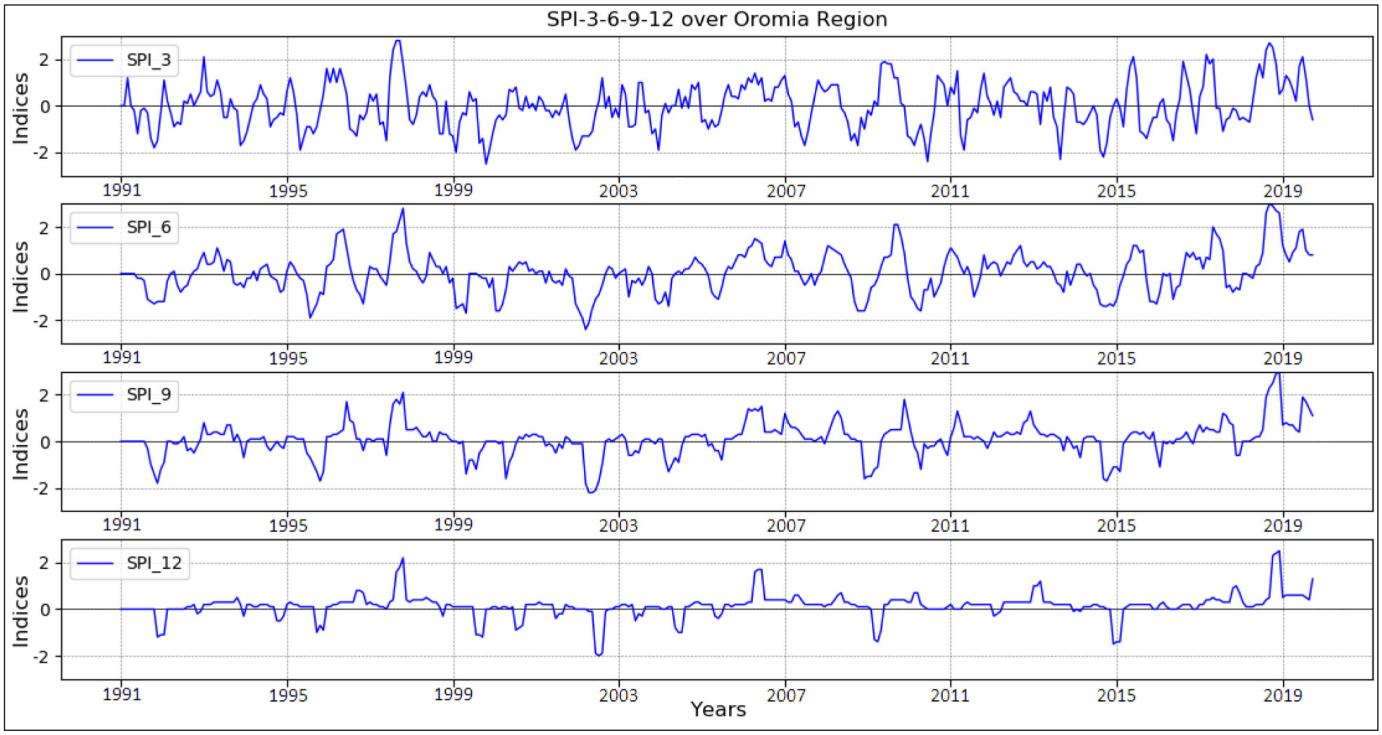


**Fig.5:** Temporal analysis of meteorological drought across SPI3, SPI6, SPI9, SPI12indices over Oromia Region during the period of 1991-2020.

SPI9 and SPI12, moderate to severe conditions were indicated over Bale, Arsi (extreme in the pocket area), a few parts of east and west Hareghe, a few parts of east Showa, south-west Showa, and a few parts of the Ilubabor zone during 2004 on time scales.

Meteorological drought analysis shows that in short- to long-term indices (SPI3, SPI6, SPI9, SPI12), drought severity was indicated as moderate to severe over Horo Guduru, west Showa, east Showa, Arsi, a few parts of west Arsi, a pocket area of south Borena, and a few parts of west Hareghe across SPI3 during 2014. Drought severity over east Showa, a few parts of west Arsi, Arsi and south Bale, and a few parts of Borena have had mild to moderate drought conditions across SPI6, SPI9, SPI12 indices in time scale during 2014. In general, weak El Niño years demonstrated the meteorological drought frequency, duration, and intensity during 2004 and 2014 (slightly extended over the zones) in spatial and area coverage (Fig. 2). In 2006 and 2018, the meteorological drought severity indicated mild to wet drought conditions over the study area.

### Moderate El Niño years

Meteorological droughts in El Niño years 1986, 1994, 2002, and 2009 show mild, moderate, severe, and extreme droughts over the region during the period 1991–2020. The drought severity in spatial and area coverage extended in drought duration and intensity from short-term to long-term drought events over the west parts of the Oromia region during 1986 (Fig. 4). Spatial meteorological drought analysis during 2002 and 2009 shows that severe to extreme droughts, except in a few parts of the zones, indicated less drought conditions across the SPI3, SPI6, SPI9 and SPI12 indices. Especially extreme drought occurred over east Showa and Arsi (2002 long-term meteorological drought indices) and Borena (2009 short-term meteorological drought indices) over the study area (Fig. 3).

### Strong El Niño years

Meteorological drought spatial analysis towards strong El Niño years shows that severe to extreme drought was observed over the west part of Oromia Region across north Showa, southwest Showa, Horo Guduru, west Wellega, and a few parts of Jimma, Ilubabor, and Kelem Wellega in 1986 (Fig. 4). Drought severity in short-term drought at SPI3 shows that it was severe to extreme over central Oromia, Bale, east Oromia, and some parts of west Oromia during 1987 over the study area. In 1991, meteorological droughts slightly increased from mild to moderate and severe droughts across SPI3, SPI6, SPI9, SPI12 indices in time scales over Oromia Region. Meteorological drought spatial analysis towards 1997 and 2015 indicated extreme drought at pocket areas of central Oromia, west and east of Oromia Region, during strong El Niño years.

### Temporal analysis of meteorological droughts

The result of the analysis shows that the time scale of meteorological drought trends from short-term to long-term of the SPI3, SPI6 to SPI9, SPI12 indices, respectively, varied in frequency, duration, and intensity of drought severity. In Fig. 5, below, the meteorological drought severity is seen in the short term of SPI3 to SPI6 indices and in the long term of SPI9 to SPI12 indices in time scales over the study area. Temporal meteorological droughts in time series show that over the study area, the means of drought intensity values of each year for different durations were from mild, moderate, severe, and extreme drought frequency during the period of 1991–2020. Temporal analysis shows that in Fig. 5, for the initial three-month timescale of meteorological drought on SPI-3 indices, the mean SPI3 was observed to have high frequency and drought intensity during the period of 1991–2020. Standard precipitation index (SPI6) analysis shows that (Fig. 5) there is slight decrease in the frequency of meteorological drought over the study area. SPI9 and SPI12 trend analysis indicates less frequency and drought intensity in time scale over the study area. The time-scale temporal meteorological drought indicated in the short term with the association of drought severity depends on the rainfall deficit over the region. Drought severity extended in duration and frequency on SPI3, SPI6 indices compared to SPI9, SPI12 indices across time scales.

Based on a three-month period (SPI3), the data indicates that the research area experienced extreme drought in 1999, 2000, 2011, 2014, and 2015, and severe drought conditions in 1991, 1994, 1995, 2002, 2004, 2008, 2009, and 2017. A time-series examination of the meteorological drought spanning the SPI6 to SPI9 and SPI12 indices revealed a marginal reduction in the region's level of drought severity. Using frequency and duration on a time scale across short-term drought indicators in time steps, the dryness was displayed. The mean SPI3, SPI6, SPI9, and SPI12 temporal meteorological drought indices during a period of three to twelve months demonstrate the variability of the drought indices with respect to the intensity, length, and frequency of meteorological (rainfall deficit) droughts over the research area from 1991 to 2020. From meteorological droughts, frequency was high with extended duration compared to the initial to last months of drought indices: mild, moderate, severe, and extreme drought variables, which were considered in this study area. However, as the time scale increases, the shorter duration of meteorological droughts related to severity during 1991–2020 over the Oromia region increases. In general, the temporal meteorological drought analysis showed a slight decrease from short-term to long-term drought indices during 1991–2020 over the study area.

## CONCLUSION

In this study, the meteorological droughts occurrence in frequency, duration, and intensity indicated a variation over the central, west, south, and east Oromia regions. Meteorological droughts from short-term to long-term drought indices severity strength and the correlation between them demonstrated high in time scales over the study area. In general, this finding will useful for further studies on drought of the meteorological drought severity of correlation for the remaining zones analysis between SPI3 and SPI6, SPI6 and SPI12, and SPI9 and SPI12 indices was dominated by an increment of the correlation values over short to long timescales over the study area. The time-scale temporal meteorological drought indicated in the short term with the association of drought indices depends on the deficiency of rainfall over the region. Drought severity extended in duration and frequency on SPI3, SPI6 indices compared to SPI9, SPI12 indices across time scales. In general, the temporal meteorological drought analysis showed a slight decrease from short-term to long-term drought indices during 1991–2020 over the study area.

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***Author's contribution***: Author conceived of the presented idea, developed the theory, and performed the computations.

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