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Impact of Climate Change on Meteorological Droughts at Dawa Sub watershed, Genale Dawa River Basin, Southern Ethiopia

Ayana Bulti Olana*

Oromia Agricultural Research Institute, Mechara Agricultural Research Center, Department of Irrigation and Drainage Engineering, Mechara, Ethiopia
Haramaya University, School of Water Resources and Environmental Engineering, Department of Irrigation Engineering, Haramaya, Ethiopia

*Corresponding author

Abstract

Climate change refers to long-term shifts in the statistical patterns of the climate system, including changes in global temperature and rainfall, driven by both human activities and natural processes. Meteorological drought refers to a prolonged period of significantly below-average precipitation, compared to the typical climate norms of a region. Drought has been a significant event with far-reaching effects across agriculture, society, the economy, and the environment. Gaining insight into how climate change influences the frequency, duration, and intensity of meteorological droughts remains a critical challenge. This study conducted a coordinated regional climate downscaling experiment for Africa using CMIP5-based GCM-RCM ensembles to statistically refine climate change scenarios. It assessed the impact of climate change on meteorological drought under RCP4.5 and RCP8.5, aiming to support early warning systems and guide adaptation strategies. Daily temperature and precipitation data over a 30-year overlap were bias-corrected using CMhyd, while DrinC tools characterized drought conditions. The HBV Light model was calibrated (1991–2010) and validated (2011–2020), showing strong performance (calibration: R^2 = 0.88, NSE = 0.77; validation: R^2 = 0.86, NSE = 0.83). Simulations revealed a significant decline in mean annual discharge under both scenarios, with total flow reductions of 1.6–3.5% and 4.6–4.9%. Notably, Belg season flows increased by ~39–40% in the 2020s and ~38–39% in the 2050s. These changes align with shifts in precipitation patterns. To address these impacts, communities should adopt soil and water conservation measures, plant drought-tolerant crops and trees, and implement water harvesting systems. Future research should incorporate wet day frequency to enhance drought prediction accuracy under changing climate conditions.

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Keywords

Climate change, CMhyd, CORDEX, DrinC, Meteorological Drought, Ethiopia, HBV

Introduction

Extreme rainfall events that occur when there is a lack of precipitation cause drought. According to the IPCC's Fourth Assessment Report (AR4), drought is defined as a long-term absence or significant deficiency of precipitation (Trenberth et al., 2013). Depending on how much anthropogenic greenhouse gases (GHG) are released into the atmosphere over the next few decades, the IPCC predicts that global surface temperatures could rise by 1-2°C by 2050 and by 2-5°C by the end of the twenty-first century. The IPCC has stated that human-induced changes are most likely to be the cause of the observed changes (IPCC, 2007a; 2014). Ethiopia is primarily described as a country with considerable precipitation variability that is arid and semi-arid (Negash *et al*., 2020; Kourouma *et al*. 2021; Eze *et al*. 2022). Ethiopia has seen several types of droughts over the last 57 years, varying in length and intensity. The years 1965, 1969, 1973, 1983, 1987, 1989, 1997, 1998, 1999, 2003, 2005, 2008, 2009, 2012, and 2015 were designated as drought-stricken years by (Degefu 1987; Quinn *et al*. 1987; Nicholls 1993; Webb and von Braun 1994; Ayalew 1996; Gebrehiwot *et al.* 2011; Tagel *et al*. 2011; Masih *et al.* 2014; Manpreet 2018; Bisrat and Berhanu 2019). Thirteen of the 30 historical drought occurrences that have affected the country in the last century were severe enough to affect the entire country. (McCann 1995; Gebrehiwot *et al*. 2011). Ethiopia has experienced drought at least once every ten years since 1970. Due to the El Nino phenomenon, drought has become more severe and frequent nationwide in recent decades, occurring about every three to five years. (Margaret 2003; Qu *et al.* 2019)

Some research studies have mentioned the impact of global warming on changes in drought (Trenberth *et al.,* 2013; Dai, 2012). Drought is frequently divided into different categories: agricultural, hydrological, and meteorological. A period of months to years with precipitation below normal or a prolonged period of no precipitation in a region is known as a meteorological drought. It is usually accompanied by high temperatures, strong winds, and low humidity, all of which can raise potential evapotranspiration and is known as a meteorological drought (Raghavan and Liong, 2015, Muse *et al.,* 2023). To evaluate the meteorological drought, we utilize the Standardized Precipitation Index (SPI), one of the primary drought indices. The benefit of employing SPI (Vu, Raghavan, and Liong, 2015) is that it just requires precipitation data as input, which makes it perfect for places like the research region of this paper where data collection of other meteorological parameters may not be possible. Due to its ease of adaptation to local climate, low data needs, and flexibility to be calculated at nearly any period, the SPI is regarded as the most suitable indicator for tracking drought variations (Ntale and Gan, 2003). SPI is suggested to be used as a universal meteorological drought index for more effective drought monitoring and climate risk management (WMO, 2009). Global Climate Models (GCMs) at very small or large scales have been used in earlier research evaluating the effects of climate change on Ethiopia. Particularly for areas lacking a meteorological station, these GCMs offer decision-makers very little useful information regarding the specific impacts and spatial extent of meteorological drought, climatic variability, and change. (Prudhomme *et al.* 2014; Georeactors *et al*. 2019; 2020; Haile *et al.* 2020; Hirko *et al*. 2021). One of the issues impeding efforts to accurately and confidently forecast or predict catastrophic climatic phenomena in many parts of Africa, including Ethiopia, is the paucity of data resulting from the uneven deployment of meteorological stations around the nation.

Materials and Methods

Description of the Study Area

The Dawa River watershed lies between 38^0 2' 48' and 41^0 2' 34"E and between 4^0 5'8" and 6^0 27' 18"N (Fig.1). It is situated 567 kilometers southwest of Addis Ababa and comprises part of Ethiopia's southeast highlands.

Climate and Topographic Data

The National Meteorological Institute states that the climate of the Dawa River Basin is primarily sub-tropical and tropical agro-climatic, with temperatures between 150 and 28.80 degrees Celsius and rainfall between 600 and 1250 millimeters. The DEM was utilized to offer a range of data that aided in creating a map of the landforms, soil types, and hydrologic information to study the catchment-drainage networks. The research areas' terrain is usually shown by a 12.5 m by 12.5 m digital elevation model

Methodology for Gathering and Preparing Data

The simulation of the HBV model is validated and calibrated using the streamflow data. Melka Guba station supplied daily streamflow data for the Dawa sub-basin from the Ministry of Water and Energy (MoWE). The FAO 2016 provided the land use and land cover photos used in this study, while the Harmonized World Soil Database (HWSD) provided the soil data. According to LULC data, ArcGIS Version 10 covers and classifies areas with trees, bushes, grassland, crops, aquatic vegetation or flooded areas, lichen mosses or sparse vegetation, bare areas, built-up areas, and water bodies.

Standardized Precipitation Index Methods

McKee (1993) initially presented the SPI through an analysis of past monthly precipitation. A time scale of period 'i' months (i = 3, 6, 12, 24, 48) is determined by selecting a set of average periods based on a moving window. The normal-SPI, log-SPI, and gamma-SPI Standardized Precipitation Index methods are widely used to assess the severity of meteorological drought. Long-term precipitation patterns Mishra and Singh, 2010 can be utilized to compute the Mckee *et al,* 1993. Each index has the same classification, as shown in Table 2, where dry times are indicated by negative SPI values and wet periods are indicated by positive SPI values Cacciamani *et al.,* 2007.

Meteorological Drought Indicators Selection

Meteorological drought indicators are typically based on precipitation**,** temperature**,** and evapotranspiration data. Their selection depends on:

Data availability and quality
Climatic characteristics of the region
Temporal scale (monthly, seasonal, annual)
Sensitivity to drought onset and recovery

Ease of interpretation for stakeholders and decision-makers

The Palmer Drought Severity Index (PDSI), Palmer Z-Index, Standardized Precipitation Index (SPI), Standardized Precipitation and Evapotranspiration Index (SPEI), Effective Drought Index, and deciles are a few examples of meteorological drought indexes. In our study, we employed the Standardized Precipitation Index (SPI) due to its reliance on readily available precipitation data and its straightforward computational approach, making it one of the most practical and widely used methods for drought assessment.

Results and Discussion

Meteorological Drought Characterizations Using Standard Precipitation Index

A meteorological drought analysis was conducted in the Dawa River watershed at Malka Guba, which was found in the Genale Dawa River basin using SPI from Yabello meteorological stations from 1991 to 2 020. Most often, a short time range is taken into consider ation for meteorological drought study via SPI-6, SPI-9 and SPI-12 (Tareke, 2022a). However, for areas lacking hydrological data (streamflow), SPI-12 and above are used for hydrological drought analysis. However, in this study, SPI-6, SPI-9 and SPI-12 for monitoring meteorological droughts, and the results showed that the severity of the drought rose as the time scale increased from SPI-6, SPI-9 to SPI-12, and the frequency of occurrence increased over a long-time scale analysis.

Figure.1 Location Map of the Study area (Source: Ethiopian Geospatial Map, 2016)

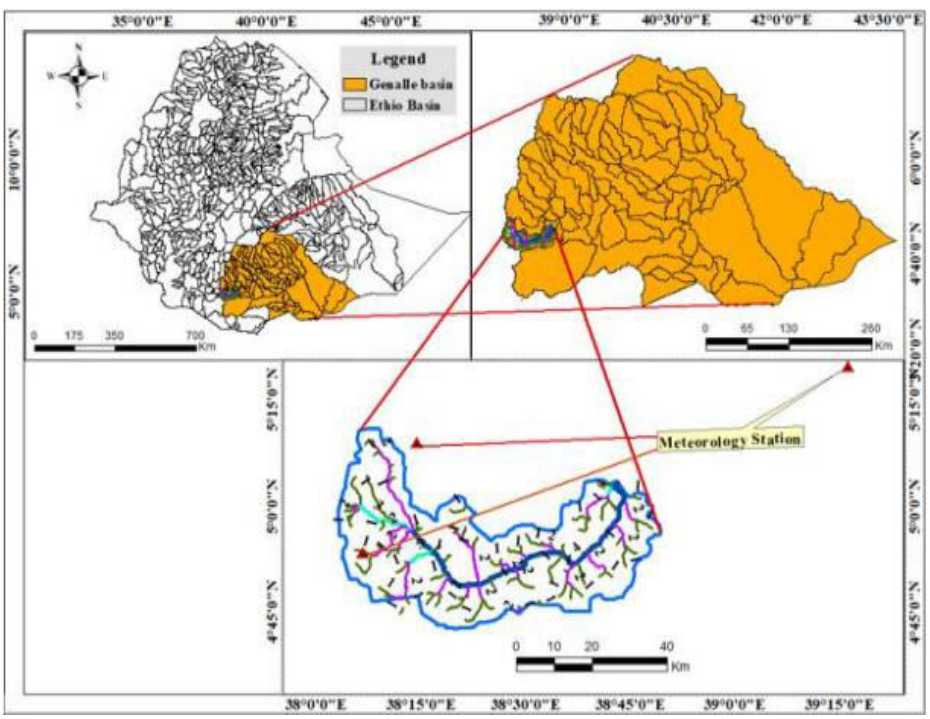

Figure.2 Digital elevation model of Dawa Sub-watershed

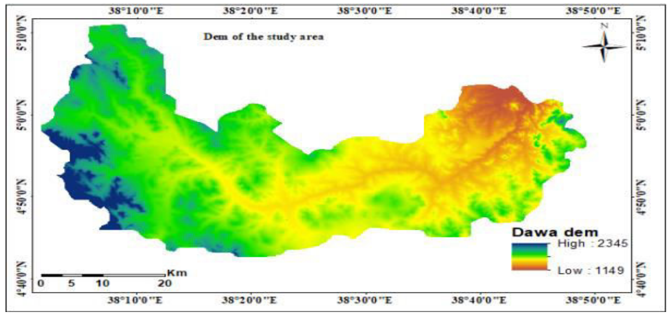

Figure.3 A. Land use land cover (2016) B. Soil type

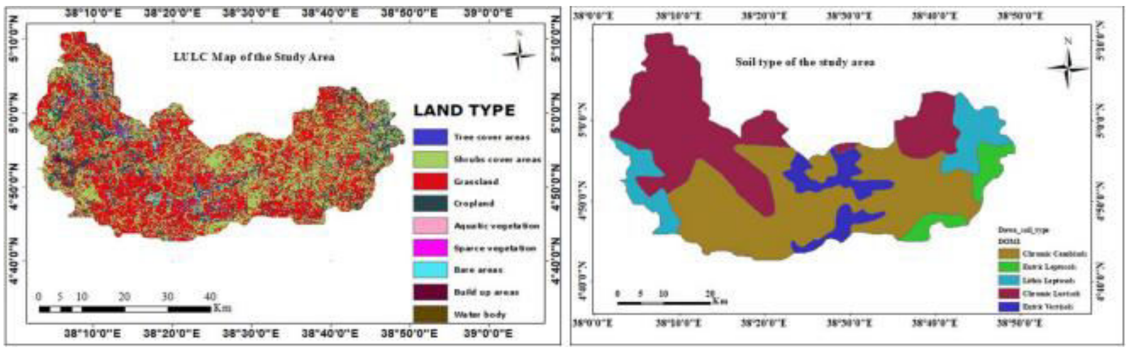

Figure.4 Meteorological drought time series in the Dawa watershed using SPI

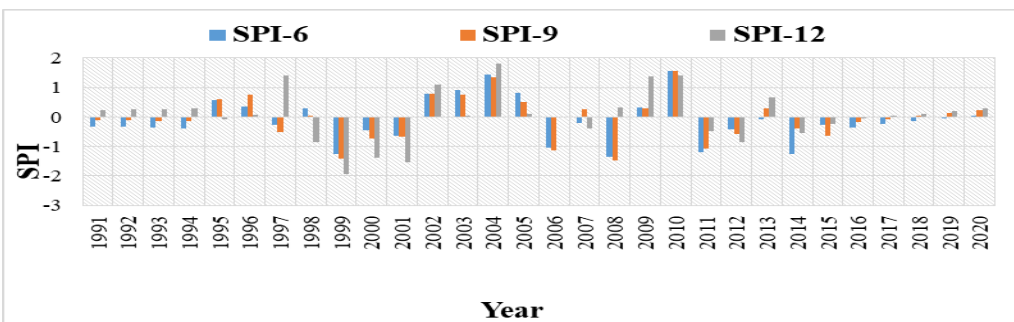

Table.1 The distribution of LULC and soil types in terms of area

LULC			Soil		
LULC type	Area (ha)	Area (%)	Soil type	Area (ha)	Area (%)
Tree cover areas	10112	4.3	Chromic Cambisols	98032	41.5
Shrubs cover areas	86543	36.7	Chromic Luvisols	85854	36.3
Grassland	110428	46.9	Lithic Leptosols	24630	10.4
Cropland	24863	10.6	Eutric Vertisols	17408	7.4
Aquatic vegetation/ flooded	4.6	0.00	Eutric Leptosols	10506	4.4
Lichen mosses/sparse vegetation	63	0.03			
Bare areas	3518	1.5			
Build up areas	204	0.1			
Waterbody	30	0.01			

Table.2 Category of Drought according to SPI Values (McKee *et al.,* 1993, Raghavan *et al.,* 2015)

SPI Values	Drought Category
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ -2	Extreme drought

Table.3 Characterization of drought type and its monthly SPI -6 Months

Drought	Year	Month	SDI
Extreme	1991 1993 1994 1999	4-7 11-12 1-2 9	-2.43, -2.06, -2.16, -2.2, -2.09, -2.19 -2.21, -2.13 -3.07
Severe	1991	8	-1.85
	1992	3, 9	-1.56, -1.7
	1994	3	-1.73
	1999	10	-1.76
	2000	4,7, 8	-1.53, -1.57, -1.59
	2001	9, 10	-1.59, -1.73
	2008	9	-1.54
	2011	4	-1.5
	2016	10	-1.58
	2017	5-8	-1.59, -1.83, -1.7, -1.63
	2019	4	-1.58
Moderate	1991	4	-1
	1992	3, 4	-1.44, -1
	1993	3, 9, 12	-1.42, -1.14, -1.34
	1994	1, 2	-1.34, -1.26
	1995	8, 10-12	-1.2, -1.01, -1.23, -1.22
	1996	1, 10	-1.07, -1.21
	1998	11-12	-1.21, -1.22
	1999	1, 2, 5-8, 11	-1.34, -1.46, -1.06, -1.28, -1.27, 1.26, -1.08
	2000	1-3, 5, 6, 9, 10	-1.01, -1.01, -1.29, -1.31, -1.48, -1, -1.05
	2001	7,8, 11	-1.18, -1.11, -1.01, -1.01
	2003	11	-1.17
	2006	6-9	-1.09, -1.11, -1.37, -1.39,
	2008	5-8	-1.4, -1.36, -1.3, -1.2
	2010	11, 12	-1.28, -1.14
	2011	1-3, 5-8	-1.24, -.1.2, -1.46, -1.18, -1.22, -1.06, -1.13
	2014	5-7	-1.11, -1.27, -1.3
	2016	12	-1.24
	2017	1, 2, 4	-1.24, -1.03, -1.35
	2018	10-12	-1.14, -1.4, -1.27
	2019	1-3, 5	-1.24, -1.2, -1.3, -1.44
Normal	All the rest months		

Table.4 Characterization of drought type and its monthly SPI -9 Months

Drought	**Year**	**Month**	**SPI**
Extreme	1991	8, 10	-2.05, -2.02,
	1994	2, 3	-2.25, -2.16
	1999	12	-2.54
	1991	4-7, 9, 11	-1.58, -1.69, -1.87, -1.93, -1.93, -1.77
Severe	1992	3	-1.55
	1994	11, 12	-1.64, -1.91
	1999	9	-1.5
	2000	1, 7-10	-1.93, -1.81, -1.66, -1.73, -1.58
	2001	12	-1.7
	2002	1	-1.68
	2008	9	-1.55
	2011	4-6	-1.53, -1.55, -1.55
	2017	4-6, 8	-1.87, -1.57, -1.68, -1.67
	2019	2-5	-1.51, -1.63, -1.7, -1.51
	1991	3, 12	-1.06, -1.32
	1992	2, 5, 6	-1.08, -1.08, -1.15
	1993	10	-1.26
Moderate	1994	1, 4, 10	-1.14, -1.36, -1.06
	1998	10-12	-1.11, -1.46, -1.07
	1999	1, 2, 5-7	-1.21, -1.44, -1.36, -1.39, -1.48
	2000	2-6, 11	-1.24, -1.37, -1.42, -1.31, -1.39, -1.38
	2001	10, 11	-1.32, -1.42
	2006	7-9	-1.07, -1.08, -1.27
	2008	5-8	-1.03, -1.15, -1.17, -1.34
	2011	2, 3, 7-10	-1.15, -1.24, -1.36, -1.08, -1.2, --1.14, -
	2017	1, 3, 7, 9	1.4,-1.27
	2018	10-12	-1.24, -1.2, -1.3, -1.44
	2019	1-3, 5	
Normal	All the rest months		

Table.5 Characterization of drought type and its monthly SPI -12 Months

Drought	Year	Month	SDI
Extreme	1991 1993 1994 1999	4-7 11-12 1-2 9	-2.43, -2.06, -2.16, -2.2, -2.09, -2.19 -2.21, -2.13 -3.07
Severe	1991	8	-1.85
	1992	3, 9	-1.56, -1.7
	1994	3	-1.73
	1999	10	-1.76
	2000	4,7, 8	-1.53, -1.57, -1.59
	2001	9, 10	-1.59, -1.73
	2008	9	-1.54
	2011	4	-1.5
	2016	10	-1.58
	2017	5-8	-1.59, -1.83, -1.7, -1.63
	2019	4	-1.58
Moderate	1991	4	-1
	1992	3, 4	-1.44, -1
	1993	3, 9, 12	-1.42, -1.14, -1.34
	1994	1, 2	-1.34, -1.26
	1995	8, 10-12	-1.2, -1.01, -1.23, -1.22
	1996	1, 10	-1.07, -1.21
	1998	11-12	-1.21, -1.22
	1999	1, 2, 5-8, 11	-1.34, -1.46, -1.06, -1.28, -1.27, 1.26, -1.08
	2000	1-3, 5, 6, 9, 10	-1.01, -1.01, -1.29, -1.31, -1.48, -1, -1.05
	2001	7,8, 11	-1.18, -1.11, -1.01, -1.01
	2003	11	-1.17
	2006	6-9	-1.09, -1.11, -1.37, -1.39,
	2008	5-8	-1.4, -1.36, -1.3, -1.2
	2010	11, 12	-1.28, -1.14
	2011	1-3, 5-8	-1.24, -.1.2, -1.46, -1.18, -1.22, -1.06, -1.13
	2014	5-7	-1.11, -1.27, -1.3
	2016	12	-1.24
	2017	1, 2, 4	-1.24, -1.03, -1.35
	2018	10-12	-1.14, -1.4, -1.27
	2019	1-3, 5	-1.24, -1.2, -1.3, -1.44
Normal	All the rest months		

The estimated SPI values were grouped according to the types of drought, as shown in Appendix Table 16. The number of total drought occurrences computed at 6, 9, and 12-month timescales (Feb to May) in the main rainfall season (*Belg*) with weak, moderate, severe, and extreme drought accounted for more than 50% in Figure 31. However, as can be seen from the SPI data, they were of different magnitude classes. Extreme droughts ranged from -2.06 to -3.07 for 6 months, -2.02 to -2.54 for 9 months, and -2.4 to -2.78 for 12 months for various months, respectively, in 1991, 1993, 1994, and 1999 at Yabello station. In the years 1991, 1994, 1999, 2000, 2001, 2008, 2011, 2016, 2017 and 2019, severe drought was noted for 6-month periods with SPI values between -1.5 and -1.83, 9-month periods with SPI values between -1.5 and -1.93, and 12-month periods with SPI values between -1.49 and -1.97 for each of those years. This is consistent with a recent discovery made by Habtamu (2019). Because it is a reliable indication for such climatic zones, ongoing and persistent drought monitoring is therefore necessary to establish when droughts start and end (WMO, 2012).

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