

Research Article

Evolving Climate Classification of East and Central Oromia in a Changing Climate Using the Köppen–Geiger Method

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Abstract

For efficient management of water-related assets, agricultural planning, lowering disaster risks, for educational and urban planning, it is essential to determine climate types. The modified Köppen climate classification of East and Central Oromia was examined in this study, along with shifts in climate type and spatio-temporal variability from 1991 to 2020. This study basis updated rainfall and temperature data from local meteorological stations, in contrast to earlier research that mainly relied on global datasets to characterize climate types at national and global scales. The study area's distinct climatic diversity is a result of its complex topography, which includes highlands, midlands, and natural forest areas. A statistical approach applied to determine Köppen climate types across the study area. The study results determined three major climates groups-tropical, temperate, and arid-and additional the seven sub-climate types identified. The wet, warm summers and dry winter climate dominate the west, central, and east parts of the study area of Shewa, Hararge and Arsi highland areas. The semi-arid steppe (hot) climate type prevails in the Eastern areas. The research finding further observed that the Aw, BSh, Cwb and BWh climate types increased by 2.3%, 1.1%, 0.3% and 0.2% of total land area, respectively. In contrast, Cfb, Cfa and Cwa climate types decreased by 4.1%, 0.3% and 0.1% of the total land area, respectively. This trend indicates long rainy periods have become shorter compared to previous periods. From the study finding, observed changes reveal a shift from cooler and more humid temperate climates toward warmer and drier climate types, suggesting an expansion of long dry and cold-season areas across the study area.

Keywords

Köppen, Climate Types, Classification, Central Oromia

1. Introduction

Historically, Wladimir Köppen formulated the first widely recognized climate classification over a century ago [1, 2]. The tropical region exhibits unique climatic characteristics from north to south and east to west. Historically and in contemporary studies, the Köppen climate classification has been

widely applied in various contexts. Researchers have used it to analyze climate change across different regions and periods, including comparisons between past and present climates, monitoring ongoing changes, and projecting future climate trends [2-4]. Other studies have combined Köppen climate

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classification with research on ecosystems, soil types, dust, and water flow to gain a more comprehensive understanding of how climate change impacts the environment [5, 6]. Additionally, others apply the Köppen climate classification to various models and comparing them with classifications based on existing data to check how well these models work [7, 8]. Even if now over 100 years old, the classification of climate originally formulated by Wladimir Köppen and modified by his collaborators and successors, is still in widespread use.

The African climate typically different like that, Ethiopia endowed the diversified climate resources due to the latitude and altitude difference under different ecology and topography. Ethiopia's landscape varies significantly, affecting its climatic conditions. The East and Central Oromia area has tropical climates with varying average temperatures, while the highlands experience cooler temperatures. Annual precipitation also varies, with lowlands having less than 500mm and highlands having greater than 1800 mm. According to many research findings, some climate zones decrease or disappear completely in some regions, and others appear in some regions of the world [9-11]. The main objective of this study is to classify the climate of Eastern and Central Oromia using a modified Köppen climate classification based on recent observed and gridded temperature and rainfall data from 1991 to 2020. This study also intended to search whether pre-exist of the climate type

currently exist, shift or lost. The result of the current study will put a base for others research and very important for different planners. The study aims to identify current climate types and assess shifts in climate classifications over time in a changing world, thereby providing a more accurate representation of present-day climate categories. In addition, the study seeks to examine transitions among climate categories in the study area.

2. Data and Methods

2.1. Study Area Description

Eastern and Central Oromia are located between 6°–11° N latitude and 36°–43° E longitude, covering the central and eastern parts of the Oromia region. The Somali Region to the east borders the area and southeast, Afar Region to the northeast, Amhara Region to the north and northwest, Jimma and East Wollega zones to the west, and Sidama and the Central Ethiopian Region to the south. The major topographic features of the study area include the Great East African Rift Valley, which extends from northeast to southeast across Ethiopia, the highlands and mountain ranges flanking both sides of the Rift Valley, and the surrounding lowland areas that extend outward from these highlands in all directions.

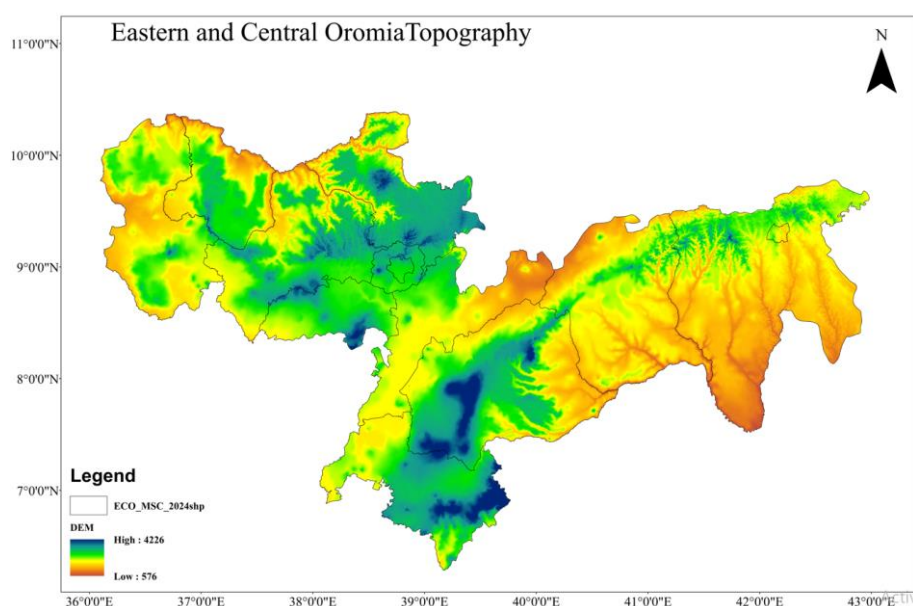


Figure 1. Digital Elevation Model of Eastern and Central Oromia.

2.2. Data Types and Sources

Globally, the primary source of climate data is observation by ground-based weather stations across the continent. However, in many parts of Africa stations are sparse, declining in number, and unevenly distributed [12]. To overcome these challenges the International Research Institute for climate and

society (IRI) initiatives the Enhancing National Climate Service (ENACTS) which was unique, multi-faceted initiative designed to bring climate knowledge into national decision making by improving availability, access, and use of climate information [13, 14]. ENACTS blending station quality-controlled data with satellite data covering over 30 years of rainfall and temperature (minimum and maximum) time series at spatial resolution of 0.0375° and daily time scales [15]. In this

study the ENACTS data of rainfall, maximum and minimum temperature was used for the study period 1991-2020 accessed from Ethiopian Meteorological Institute (EMI).

2.3. Methods

2.4. Koppen Climate Classification Methods

Wladimir Köppen was the first man that introduces the Köppen climate classification to the world and identify five main class and thirty-sub type climate and this classification scheme

letter modified by Rudolf Geiger [1]. Köppen identified a close relationship between the distribution of vegetation and climate. He selected certain values of temperature and precipitation, related them to the distribution of vegetation, and used these values for classifying the climates. The climatic groups are subdividing into types, designated by small letters, and based on seasonality of precipitation and temperature characteristics. Accordingly, there are five main climate zone classification in which the classification was based on temperature and precipitation data and then subdivided based on seasonal characteristics as adopted from [16, 17] and also from (18) as depicted in the following Table 1.

Table 1. Description of Köppen climate classification and defining criteria Rainfall and temperature (°C).

First	Second	Third	Description	Criterion	Definition
A			Tropical	Not (B) & $T_{\text{cold}} \geq 18$	
	f		– Rainforest	$P_{\text{dry}} \geq 60$	
	m		– Monsoon	Not (Af) & $P_{\text{dry}} \geq 100 - \text{MAP}/25$	
	w		– Savannah	Not (Af) & $P_{\text{dry}} < 100 - \text{MAP}/25$	
B			Arid	$\text{MAP} < 10 \times P_{\text{threshold}}$	
	W		– Desert	$\text{MAP} < 5 \times P_{\text{threshold}}$	
	S		– Steppe	$\text{MAP} \geq 5 \times P_{\text{threshold}}$	
		h	– Hot	$\text{MAT} \geq 18$	BSH = Hot semi-arid climate
		k	– Cold	$\text{MAT} < 18$	
C			Temperate	Not (B) & $T_{\text{hot}} > 10$ & $0 < T_{\text{cold}} < 18$	
	w		– Dry winter	$P_{\text{wdry}} < P_{\text{swet}} / 10$	
	s		– Dry summer	Not (w) & $P_{\text{sdry}} < 40$ & $P_{\text{sdry}} < P_{\text{wwet}} / 3$	
	f		– Without dry season	Not (s) or (w)	
		a	– Hot summer	$T_{\text{hot}} \geq 22$	
		b	– Warm summer	Not (a) & $T_{\text{mon10}} \geq 4$	
		c	– Cold summer	Not (a or b) & $1 \leq T_{\text{mon10}} < 4$	
D			Boreal	Not (B) & $T_{\text{hot}} > 10$ & $T_{\text{cold}} \leq 0$	
	w		– Dry winter	$P_{\text{wdry}} < P_{\text{swet}} / 10$	
	s		– Dry summer	Not (w) & $P_{\text{sdry}} < 40$ & $P_{\text{sdry}} < P_{\text{wwet}} / 3$	
	f		– Without dry season	Not (s) or (w)	
		a	– Hot summer	$T_{\text{hot}} \geq 22$	
		b	– Warm summer	Not (a) & $T_{\text{mon10}} \geq 4$	
		c	– Cold summer	Not (a), (b) or (d)	
		d	– Very cold winter	Not (a or b) & $T_{\text{cold}} < -38$	
E			Polar	Not (B) & $T_{\text{hot}} \leq 10$	
	T		– Tundra	$T_{\text{hot}} > 0$	
	F		– Frost	$T_{\text{hot}} \leq 0$	

Where MAP = mean annual precipitation,
 MAT = mean annual temperature,
 T_{cold} = the air temperature of the coldest month,
 T_{hot} = the air temperature of the warmest month,
 T_{mon10} = the number of the months with air temperature greater than 10,

P_{dry} = precipitation in the driest month,
 P_{sdry} = precipitation in the driest month in summer,
 P_{wdry} = precipitation in the driest month in winter,
 P_{swet} = precipitation in the wettest month in summer,
 P_{wwet} = precipitation in the wettest month in winter,
 $P_{\text{threshold}} = 2X\text{MAT}$ if greater than 70% of precipitation falls in winter,

$P_{\text{threshold}} = 2X\text{MAT} + 28$ if greater than 70% of precipitation falls in summer, otherwise,

$P_{\text{threshold}} = 2X\text{MAT} + 14$.

3. Result and Discussion

The average Köppen climate categories of East and central Oromia derived using ENACTS data for a thirty-year period (1991–2020) presented in Figure 2. The findings identify three major climate groups across the study area: Tropical (A), Temperate (C), and Arid (B). The study identified in detailed of seven Köppen sub-climate types, with notable variations observed over time, reflecting shifts in climate types between the initial and final periods of the study.

The Aw climate type (dry winter and wet summer) is the most dominant, occurring in the west, central and northern

pocket, Rift valley and adjoining areas, most eastern, and accounts for approximately 42.0% of the East and central Oromia's total land area. The Cwb climate type, characterized by warm and wet summers, cold and dry winters, is widely distributed across the central parts of west, east, south west and north Shewa province and the high lands of Arsi and Hararge, and represents approximately 36.0% of the total land area. The BSh climate type, representing a tropical semi-arid steppe (hot) climate, distributed in the small pocket lowland areas of rift valley and east marginal parts. It is the third most extensive climate subtype in the study area of east low land, covering approximately 12.6% of the total land area. The Cfb climate type is characterized by adequate precipitation, warm summers, and a less pronounced dry season. It covers the total land areas of 7.8%. The Cwa climate type, featuring hot and wet summers with mild and dry winters, found in rift valley, Arsi lowland and east wellega lowland covering 0.6 %. The BWh climate type, characterized by hot and dry conditions, occurs predominantly in the eastern pocket areas accounts for approximately 0.2% of the central Oromia's land area. The Cfa climate type represents a humid subtropical climate with long, hot summers and short winters. It is limited to small areas in the western lowlands and covers about 0.1% of the total land area (Figures 2-5).

Over all, the land areas classified under the Cfa, Cfb and Cwa climate types declined throughout the study period, whereas the areas covered by the Aw, BSh, BWh and Cwb land area increased. This implies expansion of climate types characterized by longer dry seasons and a decrease in those with extended wet seasons as illustrated in Figures 2-5 and Table 2.

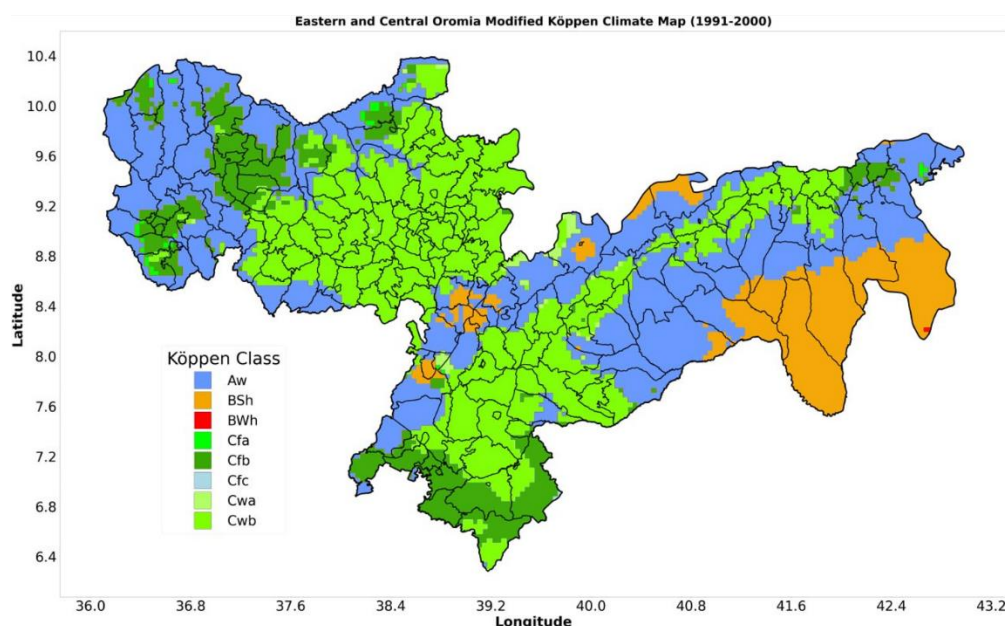


Figure 2. East and Central Oromia Köppen climate classification.

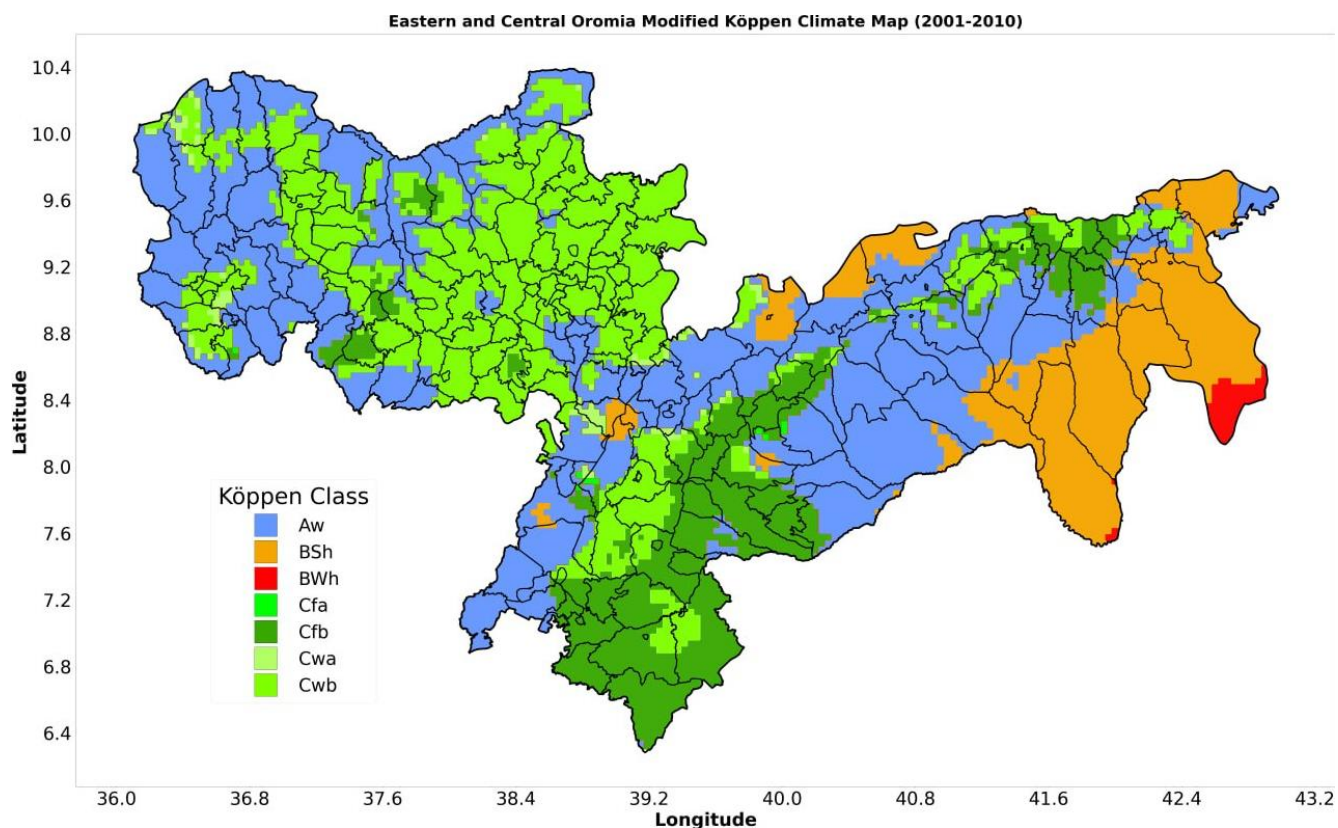


Figure 3. East and Central Oromia Köppen climate classification.

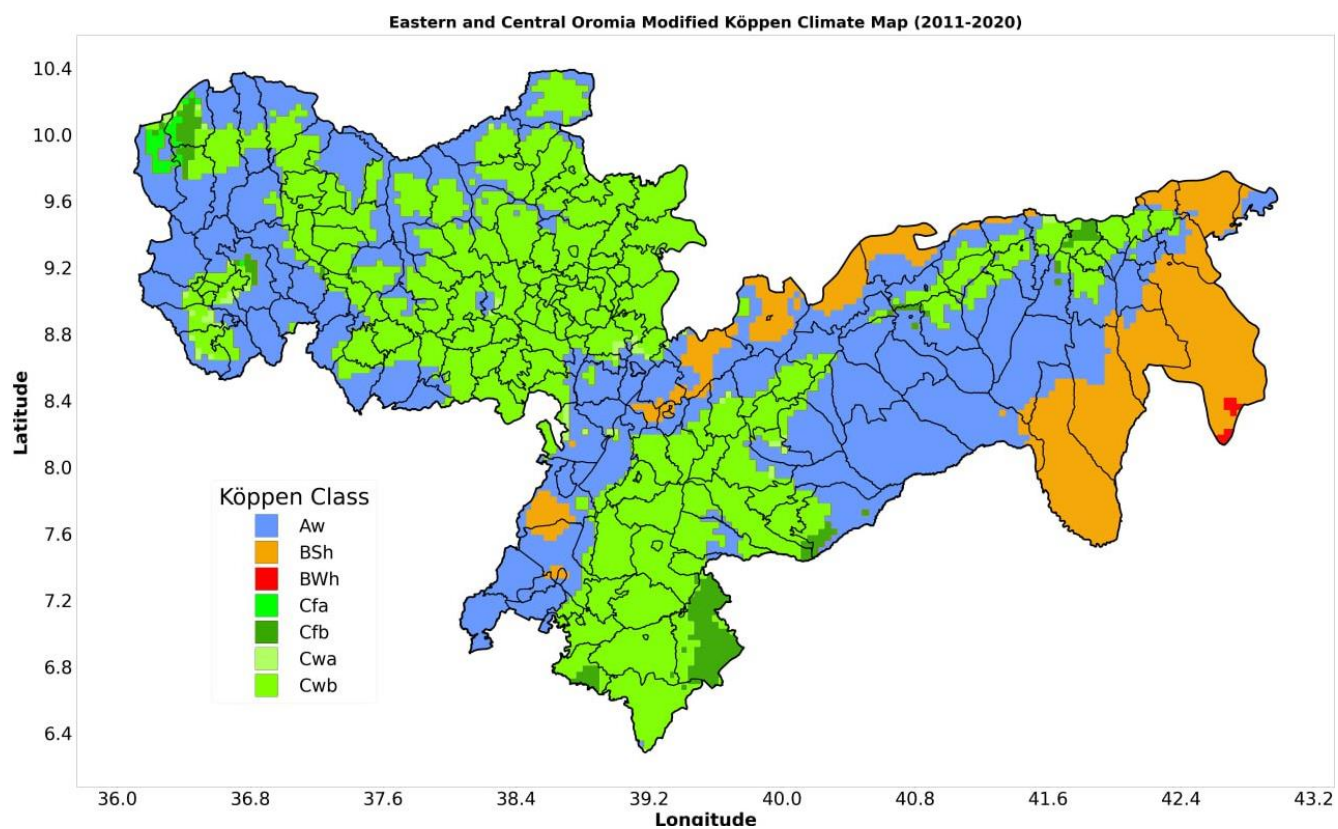


Figure 4. East and Central Oromia Köppen climate classification.

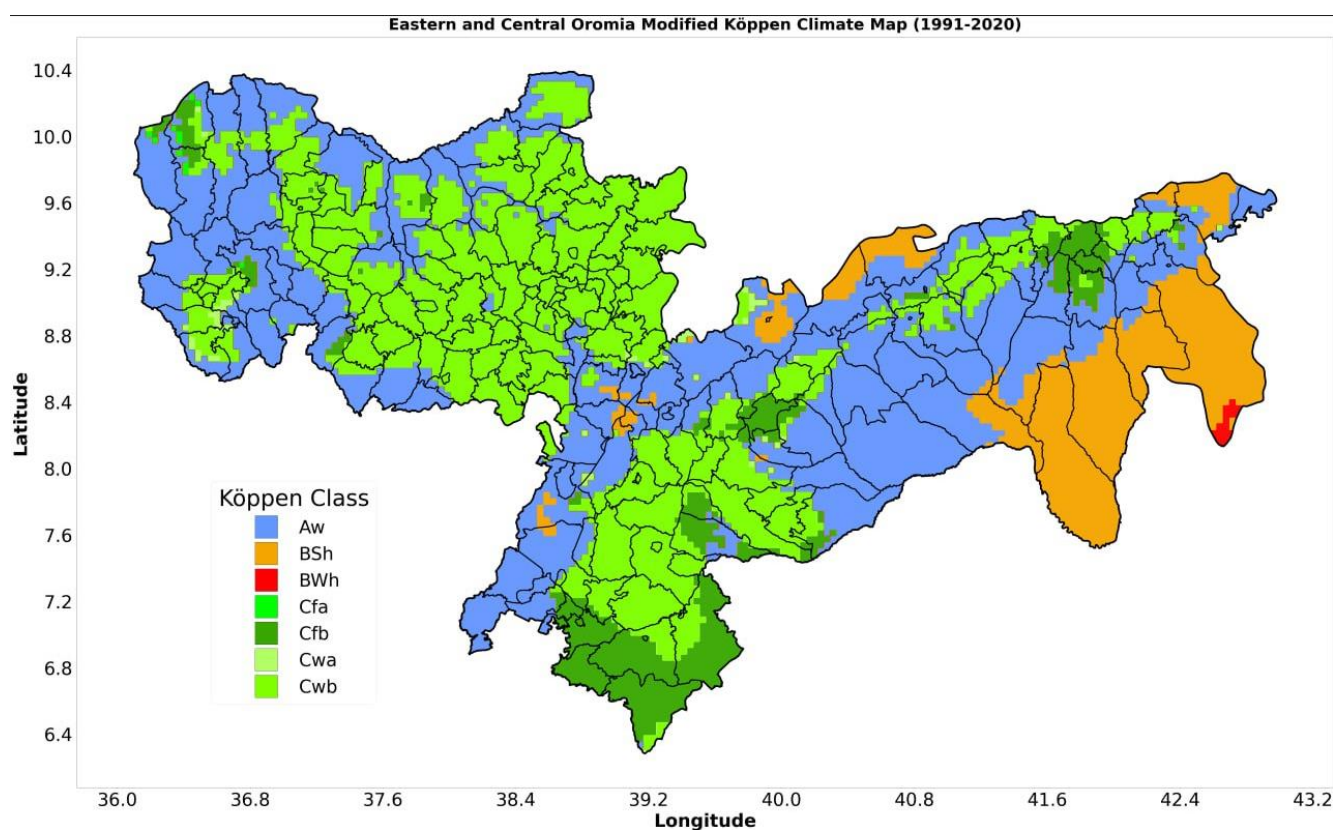


Figure 5. East and Central Oromia Köppen climate classification.

Table 2. Climate type shifted and change during the period 1991–2020.

Observed Climate types	Aw	BSh	BWh	Cfa	Cfb	Cwa	Cwb	Remark
1991-2000	39.7%	11.5%	0.0%	0.4%	11.9%	0.7%	35.7%	
2001-2010	39.7%	14.6%	0.7%	0.1%	15.5%	1.2%	28.2%	Semi-arid increased
2011-2020	42.3%	13.6%	0.1%	0.4%	2.3%	0.7%	40.5%	More Shift
1991-2020	42.0%	12.6%	0.2%	0.1%	7.8%	0.6%	36.0%	
Ranking by area coverage	1 st	3 rd	6 th	7 th	4 th	5 th	2 nd	
Change	+2.3%	+1.1%	+0.2%	-0.3%	-4.1%	-0.1%	+0.3%	Long dry and cold season area increased

The positive (+) sign shows the increase and negative (-) indicates decrease in climate types land areas percentage. In the above Table 2 the rank shows the current dominant climate types exist in the study areas.

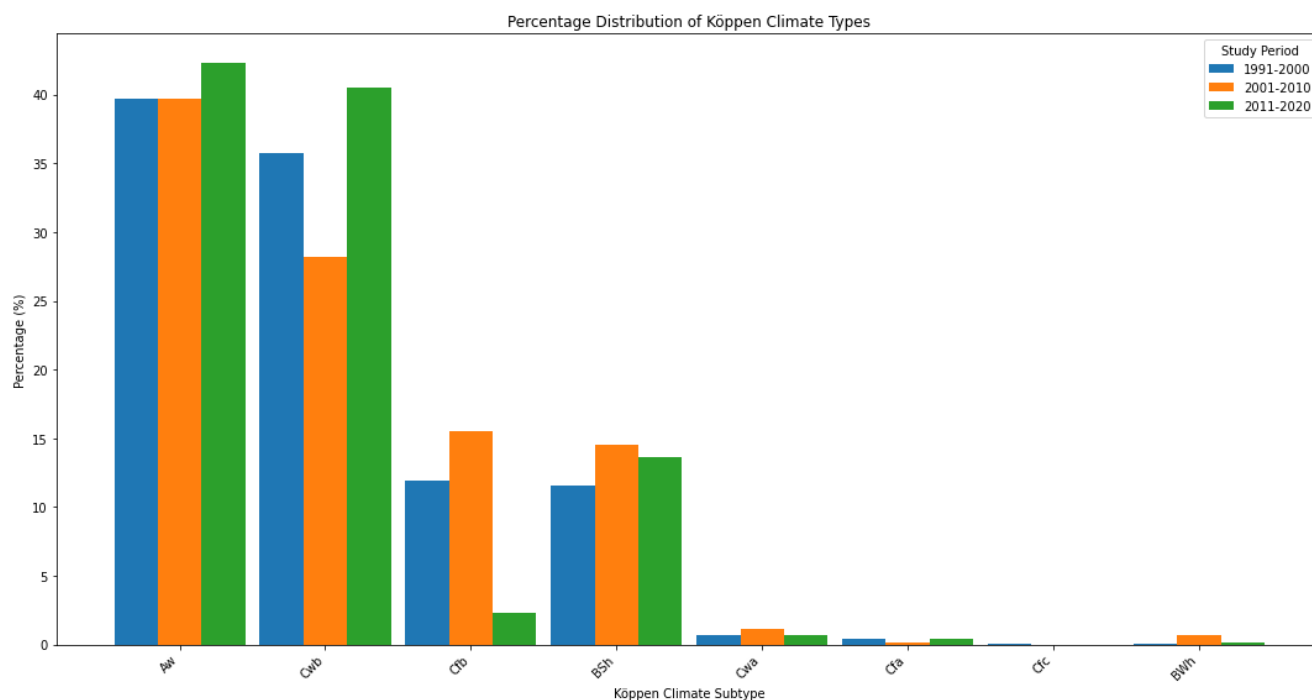


Figure 6. Distribution of sub-climate categories during 1991-2020.

Table 2 and Figure 6 presents the percentage area coverage of observed Köppen climate types during the periods 1991–2000, 2001–2010, and 2011–2020, as well as the overall change from 1991 to 2020. There is a clear shift in climate types across the study area, despite variations observed over the decades, as shown in Table 2 and Figures 2–6. Over the three decades, notable changes in the land area coverage of climate sub-types were detected (Figures 2–5). In the central, western, and eastern regions, climate types shifted from Cfb to Cwb and Aw. In the lowland and eastern peripheral areas, Aw transitioned to BSh, while BSh shifted to BWh sub-climate types.

Aw expansion area suggests a growing dominance of tropical savanna conditions. BSh climate type's area increments showed an expansion of semi-arid conditions. BWh found in a very small area of eastern portion that appears after 2000 reflecting an emerging arid condition in the eastern parts. Cfb in area coverage, decreased significantly from 11.9% in 1991–2000 to 2.3% during 2011–2020, showing the largest reduction (–4.1%). Similarly, Cfa and Cwa climates remain marginal and show slight decreases over time. Cwb, the second most dominant climate type, it's area varies across decades but shows a small net increase (+0.3%), indicating relative stability with minor expansion.

Overall, the observed changes reveal a shift from cooler and more humid temperate climates toward warmer and drier climate types. The increase in Aw, BSh, and BWh climates, combined with the decline in Cfb, suggests an expansion of long dry and cold-season areas across the study area during 1991–2020.

4. Conclusions

This study applied the Köppen–Geiger climate classification to assess climate category distribution and shifts among sub-climate categories in East and Central Oromia, using station and satellite-merged data obtained from the EMI for the period 1991–2020. By integrating temperature and precipitation data, the study classified climates based on their seasonal distribution patterns. The objective was to identify updated, reorganized climate types and to detect shift of climate types across the study area under the influence of climate change and variability. This approach helps to address the recent uncertainties in central Oromia's climate classification faced by researchers, decision makers, and agricultural planners and grant easily the usages of the updated climate zones for tourism purpose, investment, environmental protection and resource management and urban planning.

The analysis identified three major climate groups that are Tropical, Temperate, and Arid-and seven detailed subtypes, which are: Aw, Cwb, BSh, Cfb, BWh, Cfa, Cwa. The central area dominated by Aw and Cwb climates, while BSh and BWh characterize the eastern and Rift Valley pocket areas.

Changes in climate types identified by dividing the study period into 10 years, revealing both increases and decreases in land area coverage for specific climate types and there was shift of climate types over different parts. Overall, the observed changes reveal a shift from cooler and more humid temperate climates toward warmer and drier and from wet and humid to dry and cold climate subtypes. The increase in land

areas of Aw, BSh, and BWh climates, combined with the decline in Cfb, suggests an expansion of dry winter, warm and wet summer, long dry and cold-season areas increased across the study area during 1991–2020.

The study finding indicate that Cfb climate types varied between 1991 and 2000, increasing from 11.9% to 15.5% by the end of 2001–2010. However, it sharply declined from 15.5% to 2.3% during 2011–2020, demonstrating a radical shift in climate types with in the study area. The research further shows that the Aw, BSh, Cwb and BWh climate types increased by 2.3%, 1.1%, 0.3% and 0.2% of total land area, respectively. In contrast, Cfb, Cfa and Cwa climate types decreased by 4.1%, 0.3% and 0.1% of the total land area, respectively. This trend indicates long rainy periods have become shorter compared to previous periods.

Abbreviations

MSc	Master of Science
MAP	Mean Annual Precipitation,
MAT	Mean Annual Temperature
DEM	Digital Elevation Model
ECO MSC	Eastern and Central Oromia Meteorological Research Service Centre
ENACTS	Enhancing National Climate Service
EMI	Ethiopian Meteorological Institute

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Author Contributions

Gashawun Dereje Balcha: Data curation, Methodology, Formal Analysis, Resources, Software, Validation, Visualization, Investigation

Abdisa Hirko Wami: Conceptualization, Investigation, Writing – original draft, Writing– review & editing, Supervision, Resources

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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