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Impact of climatic variabilities and extreme incidences on the physical environment, public health, and people's livelihoods in Ethiopia

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Ethiopia's vulnerability to climate change is exacerbated by high poverty rates, rapid population growth, increasing prevalence of vector-borne diseases, and heavy reliance on rain-fed agriculture. This narrative review aims to compile existing data on the impacts of climate extremes on the physical environment, public health, and livelihoods in Ethiopia, thereby highlighting the significance of this region for such a study. Data were sourced from peer-reviewed journal articles from databases like PubMed, Scopus, and Web of Science, as well as reports and other unpublished documents. Results show that Ethiopia is facing increasing frequency, severity, duration, and timing of climate-related extreme events. Key challenges include environmental degradation, reduced crop yields, recurring floods, droughts, famines, increased heat waves, and spread of infectious diseases. Average daily rainfall is projected to decrease from 2.04 mm (1961–1990) to 1.97 mm (2070–2099), indicating a worsening climate trend. Moreover, the average annual temperature has risen by 1.3°C since 1960, at a rate of 0.28°C per decade. Flood records indicate a sharp rise, with 274 flood incidents recorded in 2020, causing extensive damage, including an annual soil loss of 1 billion tons in the Ethiopian highlands, reducing land productivity by 2.2% annually. Droughts from 1964 to 2023 affected 96.5 million people, reduced GDP by 4%, decreased agricultural output by 12%, and increased inflation rates by 15%. The regions of Afar, Somali, Gambella, and Benshangul Gumuz exhibit extreme vulnerability to health impacts due to rising temperatures. Addressing climate extremes is critical to mitigate their adverse effects on Ethiopia's environment, public health, and livelihoods.

KEYWORDS

climatic variability, extreme weather events, environmental impacts, public health effects, livelihood vulnerability

Introduction

Since the pre-industrial revolution era, climatic hazards such as global warming, El Niño, La Niña, cyclones, droughts, hurricanes, floods, and forest fires have significantly impacted ecosystems, human life, and property due to the Earth's diverse weather patterns (Aghakouchak et al., 2020). These events have escalated in frequency and intensity, underscoring the global relevance of climate change as one of the most urgent challenges facing humanity today. For instance, Zscheischler et al. (2020) emphasize that rising global temperatures have resulted in increasingly erratic rainfall patterns, while Norris et al. (2016) highlight the continuous melting of ice sheets and glaciers, which are causing fluctuating ocean levels. The effects of these climatic changes have become most apparent through the increased occurrence of extreme weather events such as devastating storms, catastrophic floods, intense heatwaves, and frequent droughts (Tiruneh and Tegene, 2018). Furthermore, such events are often accompanied by secondary risks like earthquakes, pest infestations, landslides, tsunamis, and land degradation (Zhou, 2014). The distribution and severity of these climatic hazards, however, vary significantly across different geographical and socio-economic contexts. As Mora et al. (2018) indicate, some regions are more vulnerable due to technological gaps, socio-political structures, and unequal distributions of weather patterns. This is particularly true for low-income nations, especially in sub-Saharan Africa, where climate variability exacerbates environmental degradation, agricultural losses, and recurring natural disasters (Yalew and Yalew, 2020; Aryal and Marenya, 2021).

Ethiopia, a low-income country in sub-Saharan Africa, is especially vulnerable to climate extremes. As Conway and Schipper (2011) note, the country's dependence on rain-fed agriculture and high poverty rates, combined with limited adaptive capacity, leave it disproportionately exposed to climatic variability. The frequency, duration, and intensity of climate-induced disasters in Ethiopia have surged in recent decades. For example, Mekuyie et al. (2018) observe that floods, droughts, and frosts have become more frequent, resulting in increased soil erosion, food insecurity, and infectious disease outbreaks. More recently, Tofu et al. (2023) report that in 2024, over 590,000 people in Ethiopia were directly impacted by floods, with 95,000 displaced, over 60,000 hectares of agricultural land damaged, and the loss of 2,900 livestock. A defining characteristic of Ethiopia's climate is its marked variability in both temperature and rainfall, contributing to recurrent floods and droughts. McSweeney et al. (2010) document a 1.3°C rise in average temperature since 1960, with projections indicating that average annual rainfall will decline from 2.04 mm (1961–1990) to 1.97 mm by 2070–2099. These changes are regionally diverse: the western parts of the country are experiencing increased daily rainfall, while central regions remain relatively stable, further complicating predictions for farmers and heightening the risk of crop failures (EPCC, 2015).

Food insecurity remains a critical issue in Ethiopia, driven by climatic variability and compounded by recurring droughts, vector-borne diseases, and soil degradation. Ayenew (2016) and Belay et al. (2021) highlight that the agricultural sector, which forms the backbone of the Ethiopian economy, is particularly vulnerable to these climatic stressors. Ethiopia's low *per capita* income (approximately US$ 1,608) reflects the broader economic constraints that exacerbate these challenges (Debebe and Zekarias, 2020; Wolde et al., 2022). While localized studies on climate change impacts in Ethiopia exist, their scope is often limited, failing to provide a comprehensive analysis across multiple sectors. This review addresses this gap by synthesizing a wide range of evidence on the major climatic extremes affecting Ethiopia and their impacts on the physical environment, public health, and livelihoods. Specifically, the review evaluates the effects of climate variability on land degradation, soil erosion, forest and water resource degradation, and the associated public health risks, including morbidity and mortality. The study also examines the impacts on agricultural productivity and livestock, key pillars of Ethiopia's economy. By synthesizing this broad range of evidence, this review offers crucial insights into the socio-economic impacts of climate change in Ethiopia, with a particular focus on agriculture, forestry, health, and environmental sustainability. Furthermore, it provides practical strategies for climate adaptation and mitigation, aimed at enhancing the resilience of vulnerable communities. The findings of this review are intended to inform policymakers, environmentalists, and climatologists, thereby supporting the development of sustainable strategies for addressing the complex challenges posed by climate change in Ethiopia.

Methodology

Study area

Ethiopia, a landlocked country in the Horn of Africa, is home to around 132 million people and is the second-most populous country in Africa after Nigeria. The country's diverse geography includes highlands, plateaus, valleys, and deserts, with the Ethiopian Highlands being the dominant feature. These highlands shape the country's ecological diversity and influence climatic patterns, which affect the environment, public health, and livelihoods of the population.

The climate of Ethiopia is highly varied, influenced by topography and regional differences. It ranges from equatorial rainforest climates in the southern and southwestern regions to the Afromontane climate in the high-altitude regions of the Semien and Bale Mountains. The northeastern, eastern, and southeastern parts experience arid and semi-arid climates, with hot temperatures and minimal rainfall.

This climatic diversity creates distinct environmental and socio-economic challenges across Ethiopia (Figure 1). The highlands, which support the majority of the population through agriculture, are vulnerable to soil erosion and degradation due to extreme rainfall variability. The arid and semi-arid regions face recurrent droughts that threaten water availability, agriculture, and livestock.

Review design

The narrative review design has been selected for this study to synthesize and analyze the diverse impacts of climatic variability and extreme incidences on Ethiopia's physical environment, public health, and livelihoods. This approach offers the necessary flexibility to integrate various types of evidence, including quantitative data, qualitative insights, and case studies. Given the multifaceted nature of climate change and its far-reaching effects across multiple sectors, a narrative review is well-suited for capturing these complex interconnections. Unlike a systematic review, which adheres to strict protocols and is typically used for answering specific research questions, a narrative review allows for a broader exploration of wide-ranging issues. This flexibility is particularly crucial for studying climate change, where the interactions between environmental, socio-economic, and public health factors are deeply interwoven and cannot always be neatly categorized (Collins and Fauser, 2005). Narrative reviews are especially effective in emerging fields like climate change, where knowledge is continuously evolving, and findings are often context-dependent. As Siddaway et al. (2019) explain, narrative reviews are well-suited for synthesizing diverse

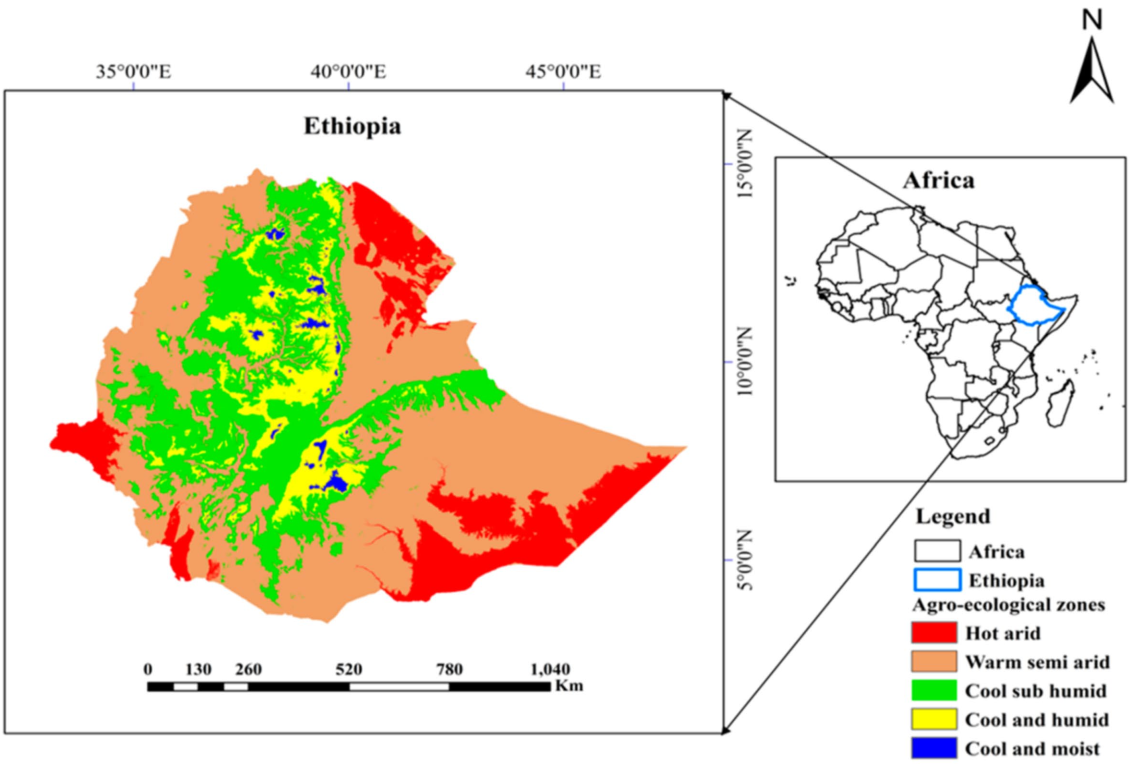

FIGURE 1
Agro ecological zones of Ethiopia (source: Wubaye et al., 2023).

sources of information to provide a holistic understanding of a topic. Given the interdisciplinary nature of climate change research, which encompasses environmental science, economics, public health, and socio-political studies, the narrative review methodology allows for the integration of diverse bodies of literature (Grant and Booth, 2009). This approach enables the study to draw connections across different fields and offer insights that a more rigid methodology might overlook, especially in a country like Ethiopia, where climate variability affects multiple sectors in interconnected ways.

Search strategy and databases

The review covered literature published between 2000 and 2024, a period selected to capture both historical trends and recent developments, particularly as climate extreme impacts have gained attention during these years. This timeframe allows for a comprehensive evaluation of long-term changes and the evolution of responses over the past two decades. The search was conducted manually across several academic databases, including Google Scholar, PubMed, Science Direct, Springer, Web of science, Scopus and JSTOR, along with institutional repositories from organizations such as the United Nations, World Bank, and Ethiopian government agencies. The specific keywords used included combinations such as "climate change in Ethiopia," "extreme weather events Ethiopia," "public health impacts," "livelihoods and climate," "environmental impacts of climate variability," and "adaptation strategies in Ethiopia." Boolean operators like AND and OR were used to refine the search results and ensure the retrieval of relevant studies.

Data extraction process

The data extraction process was conducted manually, without specialized software, given the narrative nature of this review. Key information extracted included study objectives, methodology, major findings, and relevance to Ethiopian climatic issues. To ensure reliability in data extraction, each source was reviewed for content alignment with the thematic focus areas namely, impacts on the physical environment, public health, and livelihoods. During the extraction, the rationale for including each study was documented to maintain transparency in why each piece of literature was deemed relevant.

Study screening, inclusion, and exclusion criteria

To minimize selection bias, a clear set of inclusion and exclusion criteria was applied during study selection. The inclusion criteria were: (1) studies published between 2000 and 2024, (2) literature that specifically addressed climate variability and/or extreme events in the Ethiopian context, including both peer reviewed articles and gray literatures and (3) studies that covered at least one of the following themes environmental impacts, public health effects, or livelihoods. Additionally, research that explored adaptation strategies or socio-economic implications was included to provide insights into response mechanisms. Exclusion criteria involved studies focusing solely on regions outside Ethiopia, outdated literatures, and content that lacked relevance to the main themes. To further enhance rigor, only publications in English were included, ensuring accessibility to the intended audience. The screening, inclusion, and exclusion criteria are clearly illustrated in the flow diagram presented in Figure 2.

Quality assessment

To assess the quality of included studies, a qualitative assessment approach was employed. For peer-reviewed journal articles, factors such as methodological rigor, sample size, and relevance to Ethiopia were considered. For gray literature including reports from international organizations each source was assessed for credibility, based on the institution's authority and the report's citation frequency in academic literature. The inclusion of gray literature was deemed necessary due to the often-limited peer-reviewed data available on specific localized climate impacts in Ethiopia. These sources provide valuable context and supplement gaps in the academic literature, but their quality was carefully scrutinized to ensure relevance and reliability.

Results and discussion

Major climate extremes in Ethiopia

According to IPCC (2012), climate extremes are defined as the occurrence of a weather or climate variable value that is above or below a threshold value close to the upper or lower extremities of the variable's range of observed values. The frequency, severity, length, duration, and timing of weather and climatic extremes are all affected by changing climate conditions, which can lead to previously unheard-of extremes (Seneviratne et al., 2012). This implies that Changing weather patterns, or those that occur in periods ranging from a few weeks to less than a day, are generally linked to extreme weather events whereas, extreme climate events take place over longer time periods.

Furthermore, even though weather or climatic events are not statistically severe, they can nevertheless have an extreme effect by happening concurrently with other events or by surpassing a critical threshold in a social, ecological, or physical system (Omondi et al., 2014). Since mean future conditions for some variables are predicted to lie within the tails of current conditions, changes in extremes can also be directly correlated with changes in mean climate (Seneviratne et al., 2012). It can be the result of a number of (severe or not) extreme weather occurrences building up over time (Asaminew and Jie, 2019). This means that, a season's worth of considerably below average rainy days might result in significantly below average cumulative rainfall and drought conditions (Seneviratne et al., 2012). So, the most consistent variable for the extreme climate conditions in Ethiopia are temperature and rainfall.

Temperature

Extremes in temperature frequently happen on meteorological time intervals that necessitate daily or longer time scale precision data in order to precisely analyze potential changes (Mohammed et al., 2022; Seneviratne et al., 2012). Because of these varied effects, it is critical to distinguish between the daily mean, maximum (daytime) and minimum (nighttime) temperatures as well as between cold and warm extremes.

According to Seneviratne et al. (2012) Temperature has an impact on human health, the physical environment, ecosystems, and energy consumption, among other extremes, i.e., heat waves and cold spells. In Ethiopia the lowest temperature ever recorded at Fitche station was 20.4°C, and the highest recorded temperature at Degahabur station was 36.7°C (Gedefaw, 2023). According to this study between 1980 and 2016, there was an increase in the maximum temperature of 0.3–6.4°C. However, at a rate of 9.9°C, the hot temperature extreme was recorded at the Degahabur station (Gedefaw, 2023). In the other studies from 1980 to 2010 the annual mean maximum and minimum temperatures over Addis Ababa, Jimma, and Combolcha, respectively, showed a moderate increasing trend at 0.02 and 0.05, 0.03 and 0.027, and 0.015 and 0.013°C at each decade (Asaminew and Jie, 2019). Similarly in South Gonder Zone the average yearly temperature at the Addis Zemen, Nefas Mewcha, and Mekane Eyesus stations is 17.8–22.6, 11.8–14.7, and 15.6–18.7, respectively (Getachew, 2018).

According to the studies of Gedefaw (2023), the majority of stations which are located in the northeast and southeast of Ethiopia showed that there was a rise in the highest daily maximum and minimum temperatures (TXx and TNx) between 1980 and 2016. Statistically the monthly maximum value of the daily maximum temperature (TXx) grew at roughly 73.5% of stations, while 26.5% of the stations show a rising tendency for (TNx) (Gedefaw, 2023). Additionally, there is an increasing tendency over Jimma and a declining trend over Combolcha in the monthly minimum values of the daily maximum temperature (TXn) and minimum value of the daily minimum temperature (TNn) extremes. The increase was highest over Combolcha (Asaminew and Jie, 2019).

In the western region of Tigray the average annual maximum temperature increased by 0.04–0.051°C between 1983 and 2016 (Abadi et al., 2020). A rise in warm nights and days between 0.31 and 0.62 days and 0.38 and 0.71 days/year, respectively was also shown by this studies. The other studies that indicate the trend of temperature in Ethiopia is in upper Blue Nile of Ethiopia there was an increase of 2.65 and 2.04 days/decade for the average number of hot days (TX90p) and nights (TN90p), respectively (Mohammed et al., 2022). All these states are generally stated as since warm extremes are rising and cold extremes are falling in Ethiopia, these series unmistakably show a considerable warming (Omondi et al., 2014) also, in this study approximately 50% of the available statistics show that this indicator significantly increased between 1971 and 2004.

Generally we have reviewed that Ethiopia is exposed to warming climate conditions like an increasing of annual temperature in all sampled station. So, this shows that there is a temperature extreme in Ethiopia which exaggerated the socio economic, physical and natural impacts in the country.

Rainfall

The trend of rainfall or precipitation is another parameter used to assess climate extremes in Ethiopia. Numerous studies have demonstrated that the amount of rainfall in Ethiopia exhibits a diverse trend. The study conducted by Omondi et al. (2014) found that in East Africa, the equatorial sector around Lake Victoria and the northwestern sector (western Ethiopia and southern Sudan)

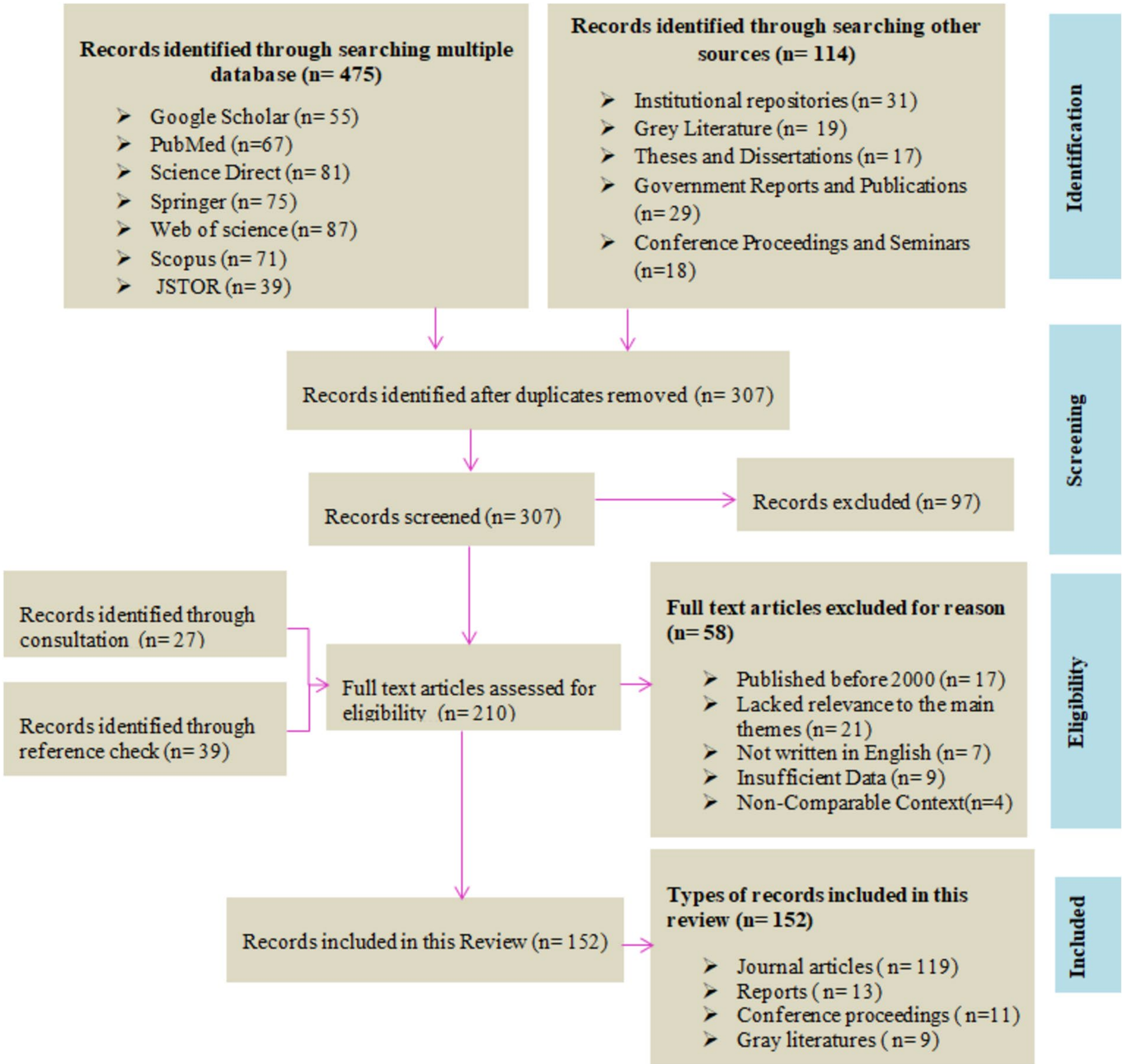

FIGURE 2
Flow diagram illustrating the selection process of included records.

experienced a decline in total precipitation on rainy days (>1 mm), while a significant increase was observed in much of Ethiopia from 2000 to 2010. Gedefaw (2023) study revealed that 63.8% of climate stations indicated an increasing trend in annual total rainfall, with Assosa, Bahir Dar, Bonga, Debre Birhan, and Fiche showing particularly notable increases. On the other hand, 32% of the stations exhibited a decreasing trend, while 4.2% showed no trend. This implies that all regions of the country, including the central, northern, southern, and western areas, witnessed an increase in the number of rainy days contributing to the annual total (Gedefaw, 2023). Among these regions, the central region displayed the strongest trend of increase.

In a similar vein, the research conducted by Getachew (2018), revealed that the total annual rainfall data for the South Gonder Zone demonstrated a decline of 13 mm in Mekane Eyesus every 10 years. However, there was an upward trend of 357.08 mm in Addis Zemen and 18 mm in Nefas Mewucha. Other studies conducted in Adiremets, Humera and Dansha, Maygaba, Maytsebri and Sheraro, and Adigoshu also indicated a significant ($p < 0.05$) decrease in annual total rainfall by 13.34 mm, 13.8 mm, 14.65 mm, 10.9 mm, and 8.4 mm, respectively (Abadi et al., 2020). Furthermore, the average annual rainfall in the western region of Tigray decreased by 8.45 to 14.7 mm between 1983 and 2016, as observed in this study. Conversely, the northern part of the Blue Nile basin (Gondar station) experienced an increase in annual rainfall, while the central parts of the basin witnessed a significant decrease (Mohammed et al., 2022). These findings suggest that the variability in rainfall events in the western central portion of the Blue Nile basin may have adverse effects on ecosystems and socioeconomic activities. Overall, based on the reviewed studies, it can be concluded that the northwestern and western regions of Ethiopia exhibit a declining trend in rainfall or precipitation, whereas other parts of the country show insignificant increases or fluctuations in annual rainfall.

Major effects of climatic variabilities and extreme incidences in Ethiopia

Flood

Floods are one of the most frequent and destructive types of disasters, causing significant damage and disrupting the lives of many individuals in various regions of Ethiopia (Assefa, 2018; Nigusse and Adhanom, 2019; Edamo et al., 2023). As the most hazardous, frequent, widespread, and catastrophic event, flooding has claimed numerous human and livestock lives, leaving many injured, displaced, and homeless in Ethiopia (Erena and Worku, 2018; Beshir and Song, 2021). The country's diverse climate, complex terrain, and human activities have contributed to the recurrent devastation caused by floods (Robi et al., 2019). Heavy, untimely, and above-average rainfall, along with the backflow of lakes and overflow of major rivers such as Wabe Shebelle, Genale, Omo, Awash, and lakes like Tana, Awassa, and Besseka, have repeatedly exposed the country to the hazards of flooding (Yeshitila et al., 2019).

Ethiopia has several flood-prone areas, including the extensive plains surrounding Lake Tana, Gumara and Rib Rivers in the Amhara Regional State, areas along the upper, middle, and downstream plains of the Awash River in Oromia and Afar Regional States, downstream areas of the Wabe Shebelle, Genalle, and Dawa Rivers in the Somali Regional State (Figure 3), low-lying areas along Baro, Gilo, Alter, and Akobo Rivers in the Gambella Regional State, and downstream areas of the Omo River in Southern Ethiopia (Ukumo et al., 2023).

For instance, in 2006, over 500,000 people were vulnerable, and more than 200,000 people were affected, resulting in 639 deaths (364 in South Omo, 256 in Dire Dawa, and 19 in other parts of the country) (Erena and Worku, 2018). Thousands of livestock perished, 228 tons of crops were washed away, 147 tons of export coffee beans were lost (along with machinery), and 42,229 hectares of crops were submerged (Legese and Gumi, 2020). Consequently, Ethiopia suffered a loss of approximately 40 million Ethiopian birr (Beshir and Song, 2021). The year 2016 witnessed the impact on 1,057,448 individuals, with 460,354 people being forced to leave their homes (Erena and Worku, 2018).

According to an analysis of flood occurrence and related risks, the number of sites that are prone to flooding has increased since the 1990s, with a noteworthy shift occurring after the 2010s (Desta et al., 2024). Before the 1990s, anything from 6 to 23 locations was at risk of floods. That being said, the areas that experienced flooding increased gradually over time, peaking at 247, 306, and 540 in the 1990s, 2000s, and 2010s, respectively. In 1996, 2005, 2006, 2013, and 2018, numerous locations nationwide experienced devastating floods 90, 91, 74, 74, and 69 (Desta et al., 2024). A rise in the risk of floods in the recent past is suggested by the unusual 274 flood spots in 2020 that have affected large areas of the country (Desta et al., 2024).

Multi criteria suitability analysis indicates that approximately 32 million hectares of lowlands are appropriate for flood-based farming, with 61% being highly favorable and 39% being moderately suitable (Desta et al., 2024). Flooding caused by rainfall events has the ability to wipe out crops across a wide area (Biruk, 2018). Furthermore, other adverse consequences including soil water logging, anaerobicity, and stunted plant growth might result from an oversupply of water (Visser et al., 2003). The Omo-Gibe basin has 107,359 ha and 29,550 ha of flood zones suitable for flood recession farming, while the Mile sub-basin has 8,048 ha and 88 ha during the major and short rainy seasons, respectively, according to flood-recession zone mapping using a change detection approach (Desta et al., 2024). Moreover, numerous experts have highlighted the alarming trend and potential dangers posed by flood risks in Ethiopia's highland, rift zone, and low-lying floodplain regions (Legesse and Gashaw, 2008).

As "the worst flooding seen in decades," the Ethiopian Disaster Risk Management Commission (EDRMC) reports that the heavy rains and flooding that occurred in various areas in April and early May affected around 560,000 persons in Ethiopia overall (WHO, 2024). Around 240,000 people were affected or displaced by flooding and severe rain in the Somali, Oromia, and Afar regions starting in mid-March, according to the UN Office for the Coordination of

FIGURE 3
Floods in the Somali Region in Ethiopia May 2023. Photo: UN OCHA Ethiopia/Gul Mohammad Fazli (source: OCHA, 2024).

Humanitarian Affairs (OCHA, 2024). Of those affected, 29 individuals were reported dead. Since then, flooding has gotten worse and has resulted in substantial damage and displaced people. In the country, flooding has affected almost 190,000 households, forcing over 200,000 people to evacuate their homes, according to the most recent UN report (Flood List, 2024).

Drought

Approximately 60% of Ethiopia's land is covered by dryland, which is characterized by low rainfall and high inter annual variability (Adunya and Benti, 2020). Since the 1960s, the country has been regularly affected by severe droughts (Table 1). Drought is the most devastating climate-related hazard in Ethiopia, impacting all types of livelihoods including crop cultivation, agro-pastoralism, and pastoralism (Mera, 2018). It has significantly affected agricultural outputs, industrial production, infrastructure, and the health of both humans and livestock (Christenson et al., 2014). The historically drought-prone regions in Ethiopia include Wello, northern Shewa, Tigray, and low agro-pastoral areas (Temam et al., 2019). According to Kairu et al. (2021), millions of people in these regions have faced disruptions to their livelihoods, businesses, and environment due to drought, which has had varying effects on the country's major economic sectors. Small-scale farmers and pastoralists, who heavily rely on limited food stocks, have been particularly affected, leading to increased food prices and job losses. These communities also struggle to afford the necessary inputs to enhance agricultural production, and their resilience to drought shocks is low (Mera, 2018).

Specifically, the impact of drought in Ethiopia has been far-reaching, affecting various aspects of life in the country. Agriculture has suffered greatly, with the loss of livestock and crops (Serdeczny et al., 2017; Aryal and Marenya, 2021). Water resources have also been severely affected, with increased evaporation and decreased availability of freshwater, leading to water stress (Kahsay et al., 2018; Bekele et al., 2019). The industrial sector has faced challenges due to insufficient water supply (Adunya and Benti, 2020). Additionally, there has been a decline in electricity production from hydropower (Zegeye, 2018). The consequences of drought in Ethiopia have been devastating, resulting in human and livestock fatalities, food crises, economic deflation, and the spread of chronic diseases (Lamesgen, 2018). For example, the severe drought in 2003 affected approximately 12 million people, leading to 300,000 fatalities (Suryabhagavan, 2017). It also caused a 4% reduction in GDP, a 12% decrease in agricultural outputs, and a 15% increase in inflation rates (Abeje and Alemayehu, 2019).

Livestock losses in pastoralist areas have further exacerbated the problem, along with widespread starvation among the affected population (Temam et al., 2019). In 2015, an estimated 10 million people, accounting for 10% of the population, experienced hunger due to drought (Adunya and Benti, 2020). The impact on agriculture in Ethiopia has consistently resulted in significant losses in terms of both human lives and cattle (Zeleke et al., 2021). Vulnerability assessments have predicted that changes in rainfall patterns and rising temperatures will have severe negative effects on the environment, water resources, crops, livestock, human health, and other rural livelihoods in Ethiopia (Ginbo, 2022). These effects have far-reaching social and economic repercussions, including a decline in the country's GDP, migration, water disputes, and an increase in diseases among people and livestock (Abdo et al., 2009). Experts have even suggested that future droughts could lead to a reduction of over 10% in the nation's GDP by 2050 (Belay et al., 2021).

Impact of climatic variabilities and extreme incidences on the physical environment

Land degradation

Climate-induced land degradation in Ethiopia has resulted in various negative consequences, including the loss of agricultural productivity and the ability to support livestock (Leal Filho et al., 2023). Additionally, the depletion of soil fertility, soil biodiversity, and other land surface resources has further exacerbated the situation (Lamesegn, 2018; Mohammed et al., 2022). According to Hochrainer-Stigler et al. (2014), these detrimental effects have exposed the country to both direct and indirect costs. The direct costs include the expenses incurred due to the loss of nutrients through topsoil erosion, as well as the costs associated with deforestation and the subsequent

TABLE 1 Chronology of the effects of drought and famine on Ethiopia, 1964–2023.

Years	Regions affected	Impacts on human life and property
1964–1966	Tigray and Wollo	About 1.5 million people affected
1973–1974	Tigray and Wollo	About 200,000 people and 30% of livestock dead
1978–1979	Southern Ethiopia	1.4 million people affected
1983–1984	All regions	8 million affected, 1 million dead and many livestock lost
1987–1988	All regions	7 million people affected
1990–1992	Northern, eastern and southeastern Ethiopia	0.5 million people affected
1993–1994	Tigray and Wollo	7.6 million people affected
2000	All regions	10.5 million people affected
2002–2003	All regions	About 13 million people needed food assistance
2008–2009	All regions	5 million people were in harmful regions
2015–2019	Eastern and northern regions	10 million people had faced hunger
2020–2023	All regions	30 million people had faced hunger

Source: Degefu (1987), Weldlul (2016), FAO (2019), IRC (2023), and FEWS NET (2023).

reduction in livestock carrying capacity (Hochrainer-Stigler et al., 2014; Zeleke et al., 2021). On the other hand, the indirect costs encompass the loss of environmental services, the silting of dams and river beds, the increased irregularity of streams and rivers, and the reduction in groundwater potential (Bekele et al., 2021). It is important to note that the direct costs of land degradation alone, without considering the indirect costs, have been estimated to be approximately US$7 billion between 2000 and 2010 (Haile and Fetene, 2012). Consequently, climate-driven land degradation has disrupted the normal provision of essential resources, jeopardized the livelihoods of the population, and undermined the overall wellbeing of Ethiopia as a nation (Mekonnen et al., 2018; Zeleke et al., 2021).

Soil erosion

Approximately 2 billion tons of fertile topsoil are lost each year in Ethiopia due to erosion caused by heavy rainfall (Getu et al., 2022). This accounts for approximately 8% of the total land surface erosion in the country (Mohammed et al., 2022). The consequences of this are significant, as it costs the country 3% of its AGDP and results in a decrease of approximately 1 mm in the vertical soil depth across the entire country (Balabathina et al., 2019). Soil erosion is a major environmental and economic issue in Ethiopia (Fazzini et al., 2015), but it is particularly severe in the highland regions where heavy and unseasonable rainfall occurs (Legese and Gumi, 2020; Getu et al., 2022). Out of the total erosion-prone area in the highlands, which makes up about 50% of the entire region, nearly 14 million hectares have been significantly eroded and over 2 million hectares are in a state that is difficult to restore (Teshome et al., 2021). Due to the risk of soil erosion in the Ethiopian highlands, approximately 1 billion tons of net soil is lost annually (Hurni et al., 2015), resulting in a 2.2% decrease in land productivity each year (Tamene et al., 2023). As a result, around 6% of Ethiopia, mainly in the regions of Tigray, Amhara, Oromia, and South Ethiopia, is at potential risk of soil erosion (Andualem et al., 2020). It has been estimated that this erosion has caused a 2–3% reduction in agricultural GDP and a 1% reduction in the total GDP of the country (Gessesse et al., 2015; Ayalew et al., 2020).

Landslide

The recurrence of heavy and uncommon rainfall has resulted in landslides of various types and sizes, leading to significant economic losses, substantial injuries, loss of lives, destruction of infrastructures, and damage to land surface resources in Ethiopia (Mebrahtu et al., 2021). The primary triggering factor for most landslides in the hilly and mountainous terrains of the highlands of Ethiopia is heavy summer rainfall (Mewa and Mengistu, 2022). Landslides continue to be a major human tragedy and obstacle to development, causing significant impacts on people, livestock, settlements, infrastructures, and farmlands (Kycl et al., 2017). Overall, landslides caused by climatic variability and complexity, such as unusually intense rainfall, have become one of the key challenges affecting the livelihoods of the people and associated businesses, consequently impacting the country's AGDP (Abadi et al., 2020; Bezu, 2020; Bekele et al., 2021).

As of July 30, 2024 Ethiopia was experiencing the deadliest landslide on record, with 236 confirmed deaths. Given the ensuing mudslides that injured rescuers and humanitarian workers, it is anticipated that the death toll may grow as rescue operations continue. A total of 6,750 persons in Koncho Gozji Kebele and 7,765 in Koncho Wiza Kebele are among the 15,515 impacted individuals in the area. Over 5,600 people are in urgent need of being evacuated to safer regions because of the continuous risk of more landslides brought on by the nonstop rain (International Federation of Red Cross, 2024) (Figure 4).

Decreasing of water resources

Ethiopia, known as the water tower of Africa, possesses a diverse range of aquatic ecosystems, particularly numerous lakes that hold

FIGURE 4
Families search for their loved ones amidst the devastation caused by a tragic landslide on 21 July 2024 (source: International Federation of Red Cross, 2024).

significant scientific and economic value (Abdo et al., 2009). However, there is mounting evidence that Ethiopia's water resources are encountering numerous challenges, primarily due to climate change (Balcha et al., 2023). These changes directly impact evapotranspiration and the runoff component of the hydrologic cycle, which in turn affects crucial sectors such as agriculture, industry, and urban development (Belihu et al., 2018). The region frequently experiences issues related to changes in flow magnitude, variability in long-term mean annual stream flow, and water availability (Kahsay et al., 2018). Climate change is expected to exacerbate the already existing water scarcity, driven by factors like population growth, agricultural expansion, industrialization, and urbanization (Getachew and Manjunatha, 2022). The availability, stability, accessibility, utilization, and demand for water resources have all been negatively impacted by climate change events, leading to a declining trend (Gebremeskel and Kebede, 2018). While part of the blame can be attributed to the rapidly increasing demand, climate change and variability have significantly strained the water resources (Mechal et al., 2015). Recent studies have also highlighted Ethiopia's high sensitivity to changes in precipitation and temperature (Wubneh et al., 2022; Balcha et al., 2023). Consequently, river flows and runoff into lakes are projected to decrease in the future, posing challenges in meeting the water demands of the ever-growing population (Merga et al., 2022). Climate fluctuations also complicate the use of agricultural land for irrigation and pose challenges in the design, operation, and management of water-use systems (Rosell, 2011). This, in turn, has the potential to disrupt livelihoods, increase poverty, marginalize the poor, and escalate inequality (Seyoum et al., 2015). Overall, climate change is severely impacting the hydrological cycle and, consequently, water management, subjecting the country to water stress (Worku et al., 2018; Wubaye et al., 2023).

Degrading of forest resource

Ethiopia, a country heavily reliant on natural resources, possesses a significant forest resource that covers approximately 50.6% of its total land area, equivalent to 1.12 million km^2. These forests can be categorized into six main types: forestlands (3%), woodlands (23.4%), shrublands (20.4%), bushlands (1.9%), plantation forests (0.9%), and bamboos (1%) (Nune et al., 2013). Within these forests, it is estimated that there are around 7,000 plant species, with 12% of them being endemic (Assefa and Bork, 2014). This makes Ethiopia one of the six countries in Africa with rich plant biodiversity (Fashing et al., 2022). The forestry sector has played a significant role in Ethiopia's economy, contributing an average of 5.7% to the country's GDP between 1995 and 2005 (Nune et al., 2013). The forest resources provide various valuable products such as bamboo, fodder grass, honey, coffee, and medicinal plants (Ewunetu et al., 2021). Additionally, forests offer essential environmental benefits, including soil erosion prevention, flood control, protection of downstream ecosystems and watersheds, carbon sequestration, and preservation of biodiversity and recreational services (Mengist et al., 2021).

However, the forests and trees across Ethiopia are facing increasing challenges due to global climate change and human activities (Solomon et al., 2021). As a result, the forest coverage has significantly decreased compared to its previous extent (Othow et al., 2017). Climate change has had profound impacts on the composition, structure, productivity, disturbance patterns, water availability, nutrient retention, wildlife habitats, and overall provision of goods and services by forests in the country (Ewunetu et al., 2021). Changes in temperature, rainfall, weather patterns, and other interconnected factors directly and indirectly affect the expansion and productivity of forests (Solomon et al., 2021). Furthermore, elevated levels of carbon dioxide have influenced plant growth (Hishe et al., 2021). Climate change has also affected the geographic distribution of host trees and their associated insects and pathogens, leading to increased pest impacts from both native and invasive species (Ardalan et al., 2019). In general climate plays a significant role in Ethiopia, impacting various natural disruptions including insect outbreaks, invasive species, wildfires suppression, drought, and storms. These factors continue to be the primary drivers of forest degradation in the country (Simane et al., 2016; Belay et al., 2021; Leal Filho et al., 2023).

The impact of climatic variabilities and extreme incidences on the public health

The impact of climatic variabilities and extreme incidences on public health in Ethiopia has become increasingly serious, with detrimental effects on various aspects of health and wellbeing. Sub-Saharan Africa, including Ethiopia, is especially vulnerable due to its limited adaptive capacity (Gudi, 2023). In Ethiopia, climate extremes such as droughts and floods are exacerbating climate-sensitive diseases, malnutrition, and fatalities, directly affecting fundamental human needs, including air, water, food, and shelter (Ardalan et al., 2019).

Morbidity and mortality

Climate change is exerting a profound impact on morbidity and mortality in Ethiopia, with the country witnessing an escalating prevalence of climate-sensitive diseases and increasing mortality rates linked to extreme weather events (Funk et al., 2015). Malaria remains a significant climate-sensitive health issue, driven largely by rising temperatures and changing rainfall patterns that are expanding mosquito habitats. Reports indicate that Ethiopia experiences over 2.5 million confirmed cases of malaria annually, with a notable increase during periods of climatic anomalies, such as the 2015/2016 El Niño, which led to a 20–30% surge in malaria cases in regions like Oromia, Amhara, and SNNPRS (Gizaw and Gan, 2017). This indicates that climate variability is directly influencing vector-borne disease transmission, thereby increasing the overall burden on the healthcare system.

Heatwaves, an increasingly frequent extreme weather event, have also significantly impacted morbidity and mortality. From 2000 to 2019, heat-related illnesses, including dehydration, heat exhaustion, and heatstroke, have become more prevalent, especially in urban areas lacking adequate cooling infrastructure (Gedefaw, 2023). During peak heatwave years, excess deaths due to heat-related conditions rose by over 25%, with approximately 1,500 deaths attributed directly to extreme heat events (Gebrechorkos et al., 2019). This trend reflects how increasing temperatures are leading to greater health risks, particularly among vulnerable populations such as the elderly, young children, and those with pre-existing health conditions.

Waterborne diseases, including acute watery diarrhea and cholera, have also surged in recent years as a consequence of extreme flooding events. In 2019, over 14,000 cases of acute watery diarrhea were reported, predominantly in flood-affected regions like Afar and Somali, where access to safe water was compromised (Wolde-Georgis et al., 2022). These flood-induced outbreaks highlight the direct link between climate extremes and the spread of waterborne pathogens, which significantly contribute to morbidity, particularly among displaced and low-income communities with limited access to healthcare services. Drought-induced malnutrition remains another critical consequence of climate variability in Ethiopia. The severe drought of 2015/2016 had far-reaching health effects, particularly on children under the age of five. During this period, approximately 27% of young children were acutely malnourished, which contributed to over 35,000 child deaths (Funk et al., 2015; Kasie et al., 2020). This high rate of child malnutrition is indicative of the fragility of food security systems under the stress of prolonged dry spells, as well as the cascading effects of climate change on public health outcomes, including increased susceptibility to infections.

The adverse effects of climate change on public health in Ethiopia are not limited to physical health alone; they extend to mental health as well. Increasing rates of anxiety, depression, and post-traumatic stress disorder (PTSD) have been documented among communities affected by displacement due to flooding or drought (Simane et al., 2016). Despite the rising incidence of climate-induced mental health issues, access to mental health services remains limited, thereby exacerbating the overall health burden faced by affected populations. In conclusion, the impact of climate change on morbidity and mortality in Ethiopia is substantial and multifaceted. The increasing prevalence of vector-borne diseases like malaria, the rise in heat-related illnesses, the frequent outbreaks of waterborne diseases, and the alarming rates of malnutrition and mental health issues collectively underscore the grave health challenges posed by climate variability and extreme events. These findings highlight the urgent need for targeted interventions and robust adaptation measures to reduce the adverse health impacts of climate change in Ethiopia, particularly among vulnerable and underserved communities.

Vulnerability and susceptibility

The health impacts of climate variabilities disproportionately affect vulnerable groups such as children, women, the elderly, disabled individuals, and those with lower socio-economic status. Each of these groups faces unique challenges that make them more susceptible to climate-induced health risks, leading to heightened morbidity and mortality across Ethiopia (Assefa and Gebrehiwot, 2023). Table 2 provides summary of vulnerable groups and their susceptibilities to climate-related health impacts.

The impact of climatic variabilities and extreme incidences on the livelihoods of the peoples

Agricultural crop yield reduction

In many developing countries, especially in sub-Saharan Africa and some areas of Asia, crop productivity is predicted to decrease due to temperature changes, precipitation, and extreme weather events (Gornall et al., 2010). Increased CO_2 concentrations, longer crop growth seasons in higher latitudes, and montane ecosystems are among the benefits of climate change for agriculture; on the other hand, rising pest and disease incidence and soil degradation due to temperature changes are among the drawbacks (Lal, 2005). The total loss of agricultural productivity in Africa as a result of climate change is estimated to be between 17 and 28%, while the global loss is estimated to be between 3 and 16%. This suggests that climate change has a detrimental impact on the lives of Africans, including Ethiopians. According to, there has been a 33% decrease in wheat yield due to climate change.

For the reasons listed below, agriculture continues to be one of the most significant economic sectors in Ethiopia: It provides employment and livelihood for approximately 83% of the population directly; it contributes over 40% of the GDP of the nation; it generates approximately 85% of export revenue; and it provides approximately 73% of the raw materials needed for domestic agro-based industries like biofuels (AfDB, 2011). The agriculture sector in Ethiopia is dominated by smallholder farmers who employee largely rain fed and traditional practice stage which renders Ethiopian highly vulnerable to climate change (World Bank, 2007).

In Ethiopia drought related reduced precipitation, extremely high temperatures, and evapotranspiration are expected to have a negative effect on the production of crop yields (Muluneh et al., 2016). This is because, during extreme weather events, crop yields are highly correlated with temperature changes and the length of heat or cold waves. They also vary depending on the stage of plant maturity (Lemi and Hailu, 2019). Thus indicates that the amount of rainfall and temperature are key factors in determining crop yields. Unfavorable realization of crop yields, whether in terms of quantity or temporal distribution, leads to food shortages and famine (Singh, 2019). So, climate change will generally result in lower cereal crop yields in Ethiopia by reducing the length of the growing season, intensifying water stress, and raising the frequency of pest, water logging, flooding, disease, and weed outbreaks (Alemu, 2010). Thus, agricultural productivity and production, and consequently the GDP and the livelihoods of the local population, are significantly impacted by climate variability and change. Ethiopia's GDP is predicted to decrease by 2045 as a result of climate change, mostly due to decreased agricultural productivity (Bezu, 2020). Moreover, the effects of climate change may lower the country's revenue from agricultural exports.

According to estimates, the production of major cereals in sub-Saharan Africa could decrease by as much as 20% by the middle of the century due to the region's current warming trends (Schlenker and Lobell, 2010). The impoverished will be disproportionately impacted since they are less able to adapt and rely on agriculture for a living (World Bank, 2007). A 5.4% drop in wheat yield is predicted for every 1°C increase in temperature when these temperature increases are extrapolated to the global scale (Lobell and Field, 2007). The nation's extreme total yield loss has resulted in yield reduction due to the impact of climatic variability and change. For example, the 2006 flood in the Gambela region damaged roughly 1,650 hectares of maize, and the waterlogging of farmland caused a 20% reduction in crop productivity. This led to the nation losing money and made the region's food shortage and malnutrition issues worse (Tesso, 2019). The Climate change is projected to reduce shield of maize staple crop by 3–19% in Ethiopia (Jones and Thornton, 2003).These amount a

TABLE 2 Summary of vulnerable groups and their susceptibilities to climate-related health impacts.

Vulnerable group	Vulnerability and factors contributing to vulnerability
Children	Children are particularly vulnerable to climate-related health impacts due to their developing physiology and greater sensitivity to environmental changes. Malnutrition, for example, poses a significant threat to children during periods of drought. During the 2015/2016 drought, an estimated 27% of children under 5 years of age experienced acute malnutrition, leading to approximately 35,000 child deaths (Funk et al., 2015; Kasie et al., 2020). Moreover, children are at increased risk of waterborne diseases, which are more prevalent in the wake of extreme weather events like flooding. For instance, during the 2019 floods in Ethiopia, over 14,000 cases of acute watery diarrhea were reported, with a significant proportion of the cases affecting children under the age of five, who are less equipped to handle dehydration and nutritional loss (Wolde-Georgis et al., 2022). Additionally, vector-borne diseases like malaria pose a heightened risk for children, with higher mortality rates among this group during peak transmission seasons, exacerbated by fluctuating climatic conditions (Gizaw and Gan, 2017).
Women	Women also face unique vulnerabilities to climate-induced health risks, primarily due to socio-cultural and economic factors that limit their capacity to adapt to environmental changes. Women in rural Ethiopia are often responsible for securing water, food, and fuel for their households (Simane et al., 2016). During periods of drought or flooding, these responsibilities become more arduous and can lead to increased physical and mental health issues, such as musculoskeletal problems and stress-related disorders. Studies show that women are twice as likely as men to suffer from anxiety and depression during climate-induced disasters, largely because of their caregiving roles and limited access to resources (Assefa and Gebrehiwot, 2023). Furthermore, maternal health is severely impacted during climate crises. It is estimated that, during the 2015/2016 drought, maternal malnutrition led to increased rates of complications during pregnancy and childbirth, contributing to higher maternal mortality rates, particularly in remote areas with limited healthcare services (Kasie et al., 2020).
Elders	The elderly are highly susceptible to the adverse effects of climate variability, especially heatwaves, which are becoming more frequent and intense. Elderly individuals are less able to regulate their body temperature, making them more vulnerable to heat stress, heatstroke, and cardiovascular events during periods of extreme heat (Gebrechorkos et al., 2019). Between 2000 and 2019, excess deaths among the elderly due to heat-related illnesses rose by more than 25%, with approximately 1,500 deaths linked directly to extreme heat events in Ethiopia (Gedefaw, 2023). Additionally, older adults often suffer from pre-existing conditions that can be exacerbated by extreme weather events, such as respiratory and cardiovascular diseases, making them more vulnerable to air pollution and the spread of vector-borne diseases (Simane et al., 2016).
Disabled individuals	Disabled individuals face multiple barriers that make them more vulnerable to the impacts of climate change, including limited mobility, reduced access to healthcare, and social exclusion (Senbeta and Olsson, 2009). During emergencies such as flooding or drought-induced displacement, people with disabilities often struggle to access basic needs, including safe shelter, clean water, and medical care. Evidence suggests that individuals with disabilities are 1.5 times more likely to be left behind during climate-related disasters due to inadequate evacuation plans and inaccessible infrastructure (Simane et al., 2016). The lack of disability-inclusive disaster preparedness and response measures further exacerbates the vulnerability of this group, putting them at increased risk of morbidity and mortality during extreme weather events.
Lower socio-economic groups	Those with lower socio-economic status are also disproportionately affected by the health impacts of climate variability. Limited access to resources, healthcare, and education restricts their ability to prepare for, cope with, and recover from climate-related health risks (Senbeta and Olsson, 2009). Vulnerability assessments indicate that 70% of Ethiopia's population is moderately vulnerable to climate-sensitive diseases, while 9% is very highly vulnerable, largely reflecting the socio-economic disparities in coping capacity and adaptation (Simane et al., 2016). In regions like Afar, Somali, Gambella, and Benishangul-Gumuz, which have higher poverty rates and limited healthcare infrastructure, the Health Vulnerability Index scores above 0.1 indicate extreme susceptibility to climate-induced health risks (Yimam and Holvoet, 2023).

serious threat to food security and to achievement of the major development goals.

The study Rettie et al. (2022) revealed that in Ethiopia grain yield was clearly impacted by temperature, with wheat seeing a larger effect. A 6°C increase in temperature resulted in a 1.6–1.8 t ha^{-1} decrease in wheat grain yield, which corresponds to a 47–57% relative yield decrease. The effects on maize yield, however, were negligible. For a 6°C increase in temperature, the decrease was <0.2 t ha^{-1}, or <10%. Specifically, there was no discernible variation in the yield of maize grains with a 2°C temperature increase. When N fertilization was high, the temperature effect on wheat yield was greater. Under high N fertilization (160 kg ha^{-1}), a 6°C increase in temperature reduced wheat yield by 50–60%; in the absence of fertilizer, the corresponding decrease was 35–50%. This study similarly shown that the median maize yield decreased by approximately 0.5 t ha^{-1} ($p < 0.05$) with a 50% reduction in precipitation, but there was no discernible change with a 50% increase in precipitation. Conversely, wheat yield does not significantly change in response to changes in precipitation. However, wheat yield fell by roughly 0.1 t ha^{-1} for a 50% decrease in precipitation under high N fertilization, despite its weak relative strength. In another instance, under unfertilized treatment, wheat yield rose (decreased) by 0.3 (0.2) t ha^{-1} for a 50% increase (decrease) in precipitation.

According to the study of Solomon et al. (2021) in the projected scenario, where the national simulated crop production falls, decreases in production of all major crop species are simulated in the coming four decades. Teff, maize and sorghum are expected to decline by 25.4, 21.8, and 25.2%, respectively by 2050 compared to the base period. Barley and wheat production are highly affected by climate change (30 and 25.5%, respectively in 2050). On the other hand, major export crop items like pulse and oil seed production losses are estimated about 25.2 and 12.0%, while vegetable and fruit production to be 22.7 and 26.8%. The decline is due to the increase of mean temperature; changes in rain patterns; increased variability both in temperature and rain patterns; changes in water availability; the frequency and intensity of drought and floods (Alemu, 2010., Bezu, 2020). The extent of these impacts will depend not only on the intensity and timing (periodicity) of the changes but also on their combination, which are more uncertain, and on local condition. All of these will be improved through the best kind of farming may change, and modifications to current methods may be necessary to preserve production in the event that the mean climate shifts away from current states.

Livestock

About 10% of Ethiopia's foreign exchange earnings come from its livestock, which constitute the largest population of livestock in Africa and the tenth-largest producer in the world (MacDonald and Simon, 2011). Lamesegn (2018) reviewed that numerous social and economic values, including food, power, fuel, cash income, security, and investment in pastoral farming systems in the highlands and the lowlands, come from it also, the livestock industry makes up between 12 and 15% of the overall GDP and between 25 and 30% of the GDP from agriculture. Second only to coffee in terms of foreign exchange, it is also a significant source.

However, because meteorological factors like ambient temperature and rainfall patterns have a significant impact on pasture and feed resource availability, climate change has an impact on livestock production (Bezu, 2020). Ethiopia is prone to frequent and severe droughts, which have a substantial effect on the country's livestock production due to lower rainfall, less water available, and higher grassland productivity (Gashaw et al., 2014b). Temperature affects most important aspects of livestock production, including water availability, animal productivity, reproduction, and health (Singh, 2019; Lemi and Hailu, 2019).

Moreover, high temperatures may affect the metabolism and behavior of cattle, which may result in less food intake and a subsequent drop in productivity. Bezu (2020) reviewed that the lengthy dry season, when animals are in poor health from insufficient feed and water supplies and increased heat stress from the elevated temperatures, is when the incidence of livestock diseases is highest. The effect was felt during the preceding 20 years in the Borana zone of the Oromia region and in multiple districts of the Afar region. Climate variability has led to a decrease in the number of livestock per household (Thornton et al., 2011). Therefore pastoralists in those regions were consequently compelled to reduce the number of animals they kept. For example, the number of goats decreased from 33 to 6, the number of oxen from 10 to 3, and the number of cows from 35 to 7 (Bezu, 2020).

In the other case variability in rainfall and rising temperatures also expand the geographic range and increase the survival of flies and other infectious disease-carrying vectors in cattle populations (Thornton et al., 2011). Because of this, pastures are more plentiful and of higher nutritional quality during the rainy season, while during the dry season, pastures have low protein and high fiber contents, which frequently leads to a decline in animal productivity and starvation. Furthermore, the pattern of precipitation throughout the year has a significant impact on animal disease and parasite outbreaks, which in turn affects the animal production system. Floods have a substantial effect on livestock resources, just like drought does. Floods have the power to carry them away or drown them. For instance, in 2006, flooding in Ethiopia's southern region claimed the lives of over 15,600 livestock (abduljawad et al., 2011). Large tracts of grazing land are also submerged in flood, containing sediments and water that prevent the animals from finding food.

According to the future projection, in Ethiopia livestock productivity in the 2050s will be 50% less than in the scenario without climate change. In addition, the GDP of agriculture will decline by 3–30% by 2050. Moreover, it causes the GDP of the nation to decline by 2.6–6% by 2015 and by as much as 10% by 2045. Generally the immediate consequences of humidity, temperature, and wind speed that can also affect milk production, growth rate, and the reproduction and production of wool have been documented by (Lemi and Hailu, 2019). Quantity and caliber of animal feed ingredients, including climate change may have an indirect impact on pasture and fodder. Greatly influencing the cattle choices made by farmers. Climate change increased the frequency and intensity of parasites and illnesses affecting cattle.

Adaptation and mitigation strategies

Addressing the impacts of climatic variabilities and extreme incidences in Ethiopia requires a strategic combination of adaptation and mitigation measures. Adaptation strategies focus on enhancing the resilience of communities to climate-related challenges, while mitigation measures aim to reduce the underlying causes of climate change (Destaw and Fenta, 2021). Together, these approaches can help minimize the detrimental effects on the physical environment, public health, and livelihoods. One effective adaptation strategy involves enhancing agricultural resilience. Given the climate-induced variability in rainfall patterns and prolonged drought periods, farmers must be equipped with drought-resistant crop varieties and climate-smart agricultural practices (Feliciano et al., 2022). Techniques such as conservation agriculture, water harvesting, and the use of efficient irrigation systems have demonstrated success in maintaining agricultural productivity under changing climatic conditions (Destaw and Fenta, 2021). The promotion of agroforestry, which integrates trees into agricultural landscapes, is also beneficial for improving soil fertility, reducing erosion, and providing additional income streams for farmers (Zeray and Demie, 2016). These approaches not only sustain food production but also help buffer against the adverse effects of extreme weather events.

Improving water resource management is also critical to fostering resilience in Ethiopia (Alemu and Mengistu, 2019). With increasing occurrences of both droughts and floods, it is essential to develop infrastructure that can efficiently capture, store, and distribute water. Constructing small-scale dams and promoting community-based rainwater harvesting systems can improve water availability, particularly in arid and semi-arid regions (Chinasho et al., 2017). Additionally, restoring degraded watersheds can help mitigate both water scarcity and the effects of flooding. Proper management of water resources ensures that communities have access to clean water, which is vital for agriculture, household use, and maintaining public health (Gashaw et al., 2014a). Strengthening the healthcare system is vital to minimizing the public health impacts of climate variability. Investments in healthcare infrastructure, such as building new facilities and improving existing ones, can enhance the sector's capacity to cope with the increased burden of climate-sensitive diseases. Training healthcare workers and implementing community health programs focusing on prevention and early detection of diseases like malaria, diarrhea, and heat-related illnesses are essential. Moreover, improving access to healthcare services, particularly in rural areas, can significantly reduce morbidity and mortality rates associated with climate-induced health risks (Zegeye, 2018).

Community-based adaptation is an essential strategy for empowering local populations to take action against climate impacts. Involving communities in decision-making processes ensures that adaptation measures are context-specific and culturally appropriate (Ware, 2022). Education and awareness campaigns play a crucial role in helping communities understand climate risks and adopt sustainable practices. By integrating traditional knowledge with modern techniques, communities can build on existing resilience and adapt more effectively to changing climatic conditions (Regasa and Akirso, 2019). On the mitigation front, forest conservation and reforestation are important strategies to curb greenhouse gas emissions and enhance carbon sequestration (Feliciano et al., 2022). Forest ecosystems play a crucial role in regulating the climate and providing essential resources for communities. Reforestation efforts, along with the protection of existing forests, can help mitigate the impacts of climate change by absorbing carbon dioxide, reducing soil erosion, and enhancing local biodiversity. Additionally, promoting the use of renewable energy sources, such as solar, wind, and hydropower, can help reduce reliance on fossil fuels and decrease greenhouse gas emissions.

Policy interventions are also necessary to facilitate effective adaptation and mitigation. Developing and enforcing policies that promote sustainable land management, regulate deforestation, and encourage efficient water use can help reduce vulnerability to climate extremes (Zeray and Demie, 2016). Incentives for adopting climate-smart agricultural practices and renewable energy technologies can further support individuals and communities in making sustainable choices. Multi-stakeholder collaboration, involving government agencies, NGOs, local communities, and the private sector, is essential to ensure the successful implementation of these strategies and to promote long-term sustainability (Zegeye, 2018). Overall, a comprehensive approach combining adaptation and mitigation strategies is required to address the multifaceted impacts of climate change in Ethiopia. By enhancing agricultural and water management practices, strengthening healthcare systems, promoting community involvement, and implementing forest conservation measures, Ethiopia can build resilience to climatic variabilities and safeguard the wellbeing of its people and environment.

Limitations of this review

While this review provides a comprehensive evaluation of the impacts of climatic variabilities and extreme incidences on Ethiopia's physical environment, public health, and livelihoods, it is important to acknowledge several limitations. First, the scope of available data limited the ability to provide an exhaustive analysis of climate change impacts across all regions of Ethiopia. Much of the available data is region-specific or lacks sufficient granularity, which may not fully represent the varied conditions across the diverse climatic and ecological zones of Ethiopia. As a result, findings may not fully capture the localized impacts of climate extremes on specific communities. Second, the review heavily relied on secondary data sources, such as published studies and reports, which may present challenges related to data reliability, potential biases in reporting, and outdated information. A significant portion of the literature dates back to the early 2000s, and while efforts were made to incorporate recent studies, the evolving nature of climate dynamics may mean that some of the data used does not fully reflect the latest developments or emerging climate trends.

Furthermore, while this review aims to provide insights into adaptation and mitigation strategies, the effectiveness of these measures largely depends on specific local contexts, socio-economic conditions, and governance structures. The proposed solutions may not be universally applicable across all Ethiopian regions, especially considering the differing levels of vulnerability and adaptive capacities. Moreover, there is a lack of empirical evidence evaluating the long-term success of the suggested adaptation strategies, which may lead to an overestimation of their potential efficacy. Lastly, the inclusion of gray literature posed a challenge in assessing the quality and reliability of some of the evidence used. Although this inclusion helped to address gaps left by peer-reviewed studies, it also introduced potential biases due to the variability in the rigor of gray literature sources. These limitations suggest a need for more localized studies, real-time data collection, and quantitative assessments of climate impacts to improve understanding and tailor adaptive responses to specific needs. Future research should also focus on evaluating the long-term efficacy of adaptation strategies and seek to incorporate more diverse and current data to support a more nuanced understanding of the multifaceted impacts of climate variability in Ethiopia.

Conclusion and recommendations

Conclusion

Climate change poses a formidable threat to Ethiopia, impacting various sectors, particularly agriculture, public health, and environmental sustainability. The country's economy is largely dependent on agriculture, which is highly susceptible to climate fluctuations, including erratic rainfall and prolonged droughts. Additionally, vast areas of Ethiopia are classified as arid or semi-arid, heightening the risk of desertification. The fragile highland ecosystems face increasing pressure from population growth, while the nation's forests, water resources, and biodiversity are equally vulnerable to climatic changes. Compounding these challenges are inadequate healthcare facilities, limited adaptive capacity, and a shortage of qualified personnel. The vulnerability and susceptibility of children, women, the elderly, disabled individuals, and those with lower socio-economic status to climate-induced health impacts in Ethiopia are profound. The findings from this review underscore that these groups are at heightened risk of morbidity and mortality due to factors such as physiological sensitivity, socio-cultural roles, pre-existing health conditions, and limited access to adaptive resources. Addressing these vulnerabilities requires targeted interventions that prioritize these at-risk groups, improve healthcare infrastructure, and promote inclusive adaptation strategies to mitigate the adverse effects of climate change on public health. Therefore, addressing the multifaceted implications of climate change is essential to safeguarding Ethiopia's physical environment, public health, and the livelihoods of its population.

Recommendations and future suggestions for policymakers

Strengthen agricultural resilience

Policymakers should promote climate-smart agricultural practices that include the development and dissemination of drought-resistant crop varieties, efficient irrigation methods, and sustainable land management techniques.

Enhance water resource management

Effective water management strategies must be prioritized, including investments in water storage infrastructure, rainwater harvesting, and community-based management of water resources.

Invest in healthcare infrastructure

Improving healthcare facilities and services, particularly in rural areas will ensure communities for better preparation to cope with climate-sensitive health risks.

Integrate climate adaptation into policy frameworks

Climate change adaptation strategies should be integrated into national and regional development plans. This integration will promote a cohesive approach to addressing climate impacts across various sectors, ensuring that adaptation measures are context-specific and effective.

Promote environmental conservation

Implementing policies that support reforestation and sustainable land use practices can enhance carbon sequestration and protect biodiversity.

Foster multi-stakeholder collaboration

Engaging diverse stakeholders, including governmental agencies, NGOs, local communities, and the private sector, will facilitate the effective implementation of climate adaptation and mitigation strategies.

Vulnerability assessments

Research should examine the specific challenges faced by marginalized communities, including women, children, and the elderly, to develop targeted adaptation strategies.

Livelihood diversification

Encourage diversification of livelihoods to reduce dependence on climate-sensitive sectors such as agriculture and pastoralism. This could involve vocational training in sectors like renewable energy, small-scale manufacturing, or eco-tourism.

Strengthening early warning systems

Improving meteorological data and climate modeling will provide timely, accurate information on extreme weather, enhancing preparedness and reducing impacts.

Ethics statement

Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

DT: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. SE: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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