Review of Meteorological Drought in Africa: Historical Trends, Impacts, Mitigation Measures, and Prospects

BRIAN AYUGI,1,2,3 EMMANUEL OLAOLUWA ERESANYA,3,4,5 AUGUSTINE OMONDI ONYANGO,6 FAUSTIN KATCHELE OGOU,7 EUCHARIA CHIDINMA OKORO,8,9 CHARLES OBINWANNE OKOYE,10,11 CHUKWUMA MOSES ANORUO,8 MOJOLAOLUWA TOLUWALASE DARAMOLA,14 RICHARD MUMO,15 and VICTOR ONGOMA16

Abstract—This review study examines the state of meteorological drought over Africa, focusing on historical trends, impacts, mitigation strategies, and future prospects. Relevant meteorological drought-related articles were systematically sourced from credible bibliographic databases covering African subregions in the twentieth and twenty-first centuries (i.e. from 1950 to 2021), using suitable keywords. Past studies show evidence of the occurrence of extreme drought events across the continent. The underlying mechanisms are mostly attributed to complex interactions of dynamical and thermodynamical mechanisms. The resultant impact is evidenced in the decline of agricultural activities and water resources and the environmental degradation across all subregions. Projected changes show recovery from drought events in the west/east African domain, while the south and north regions indicate a tendency for increasing drought characteristics. The apparent intricate link between the continent’s development and climate variability, including the reoccurrence of drought events, calls for paradigm shifts in policy direction. Key resources meant for the infrastructural and technological growth of the economy are being diverted to develop coping mechanisms to adapt to climate change effects, which are changing. Efficient service delivery to drought-prone hotspots, strengthening of drought monitoring, forecasting, early warning, and response systems, and improved research on the combined effects of anthropogenic activities and changes in climate systems are valuable to practitioners, researchers, and policymakers regarding drought management in Africa today and in the future.

Keywords: Drought, rainfall, agriculture, health, environment, economy, Africa.
1. Introduction

Weather and climate have a huge impact on our lives, affecting practically every socio-economic area. As a result, many countries, particularly those whose economies rely significantly on rain-fed agriculture, are vulnerable to climate variability and change. This is the situation in most African countries (Niang et al., 2014). Unfortunately, the majority of these countries are extremely vulnerable to climate change and have limited adaptive capacity to cope with the impacts of climate change. Hydrological extremes, especially droughts and floods, are responsible for the loss of lives and destruction of property. Drought occurrence is mostly determined by rainfall performance in a given location, with droughts occurring in areas of both low and high rainfall (Wilhite & Glantz, 1985). As a result, it impacts people and the environment in all climatic zones, as well as practically every socio-economic sector. Droughts are projected to become more frequent and have a greater impact due to climate change in areas of Africa that are already water-stressed (Dai, 2011a, b; Hulme, 1992; IPCC 2014, 2018; Niang et al., 2014). For instance, Ogou et al. (2017) showed that drought frequency has increased over northern sub-Saharan Africa. Similarly, due to continuous global warming, widespread droughts have been identified in various locations, with a noteworthy increase in recent decades (Dai, 2011a; Dai, 2013; IPCC, 2014; Sheffield et al., 2012; Trenberth et al., 2014). Drought has affected several nations in Europe (Bradford, 2000; Hoerling et al., 2012; Spinoni et al., 2015), North America (Agha-Kouchak et al., 2014; Cook et al., 2007; Swalm et al. 2012), Asia (Cai et al., 2015; Liang et al., 2014; Sun et al., 2016), Australia (Chiew et al., 2014; Rahmat et al., 2015), and Africa (Dai, 2011a; Hulme, 1992; Lyon & DeWitt, 2012). Most significantly, Africa, southern Europe, and eastern Australia have recorded an increase in drought events, owing primarily to decreased precipitation associated with decadal fluctuations in the Pacific and western Indian Ocean (Dai, 2013; Dai & Zhao, 2017; Hua et al., 2016).

Different definitions have been put forward in connection to the varying conditions under which droughts occur depending on the discipline. Regardless of the contextual differences, it is clear that most droughts are associated with rainfall deficiency that results in water shortages in all cases. Similarly, droughts are best described based on their geographical coverage, intensity, and duration. Droughts are broadly categorized into four groups: meteorological, agricultural, hydrological, and socio-economic. Meteorological droughts are quite common, and they are primarily classified by the extent of dryness in a given location and the length of the dry period. Although agricultural drought is linked to a lack of water needed to support crops, the drought does not always coincide with meteorological drought. On the other hand, hydrological drought is limited to the level of streamflow that can meet the demand. A study by Wilhite and Glantz (1985) gives a detailed description of this specific drought phenomenon. In a recent study, Adisa et al. (2019) noted that three-quarters of the total publications on drought over Africa between 1980 and 2020 focused on agricultural and hydrological droughts, while the remaining fraction was based on socio-economic and meteorological studies.

In this review, the case studies and discussions are based on meteorological drought. This is because most agricultural activities that support over 80% of livelihoods across the African continent are regulated solely by weather and climate. Climate change can influence precipitation (meteorological) droughts through changes in atmospheric water-holding capacity, circulation patterns, and moisture supply (Ukkola et al., 2020). Furthermore, changes in atmospheric dynamics and modes of variability such as the El Niño–Southern Oscillation (ENSO) can further influence regional precipitation patterns together with changes in evapotranspiration that show trends over lands and oceans (Roderick et al., 2014; Trenberth et al., 2014). Thus, meteorological droughts can result in negative anomalies in water supply, and changes leading to more drought occurrences at regional scales influenced by the complex interactions of the different processes. Meanwhile, in comparison between agricultural, hydrological, or socio-economic drought, meteorological drought is most prevalent and thus affects all sectors of the economy and ecosystem.
Given that drought is dependent on many factors, its measurement remains a challenge. Several indices are utilized in measuring it. The common indices include the Standardized Precipitation Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010), Palmer Drought Severity Index (PDSI, Palmer, 1965), Standardized Precipitation Index (SPI, McKee et al., 1993), Standardized Anomaly Index (SAI, Katz & Glantz, 1986), Soil Moisture Anomaly (SMA, Bergman et al., 1988), Palmer Z Index (Palmer, 1965), Aridity Index (AI, Baltas, 2007), Combined Drought Indicator (CDI, Sepulcre-Canto et al., 2012), and Normalized Difference Vegetation Index (NDVI, Tarpley et al., 1984). Previous studies have discussed these indices at length (Wilhite et al., 2007; WMO and GWP, 2016). The indices chosen are determined by the dataset available and the accuracy required. Although drought is difficult to quantify because it is challenging to predict, its monitoring, policy reform, and asset management are critical for avoiding drought emergencies (Thomas et al., 2020). Seasonal weather forecasts that are specially tailored to drought monitoring systems are crucial to mitigating the impacts of droughts. Inadequate and reliable climate data, as Naumann et al. (2014) point out, create difficulty in drought monitoring in Africa and globally.

Some studies that investigated drought events over the African continent as a whole leave out countries that are prone to drought (Adisa et al., 2019; Masih et al., 2014). For instance, Adisa et al. (2019) noted that the continent experienced droughts in the years 1984, 1989, 1992, and 1997; however, this pattern varied based on the climate zone. Masih et al. (2014) investigated the drought occurrences over the continent between 1900 and 2013. Their study showed that drought has increased in frequency, intensity, and spread in the last 50 years. The study pointed out the years 1972/1973, 1983/1984, and 1991/1992 as extremely dry years across the continent. In a recent study, Ngcamu and Chari (2020) reported that droughts pose a high risk to people’s nutritious food security across sub-Saharan Africa. However, the past, actual, and future states of drought, along with their historical trends, impacts, mitigation, and prospects, are still poorly covered across the entire continent. Meanwhile, an extensive understanding of droughts across Africa is necessary for decision- and policymaking for both regional and continental organizations.

Therefore, this study aims to review case studies that address the occurrence of meteorological drought over Africa (Fig. 1), focusing on observed and underlying causes, impacts, mitigation measures, and prospects in the future. Given that Africa’s rainfall varies greatly in space, the continent is divided into regions of nearly homogeneous climate: West Africa (WAF), East Africa (EAF), Southern Africa (SAF), and Northern Africa/Sahara (SAH). This study is among the pioneer studies to focus on this topic, especially the projections and mitigation of drought impacts over the entire continent. The outcome of this study will help identify successful adaptation case studies as well as the analysis of projected drought for informed decision-making.

2. Data Collection Methods

Data were sourced from existing peer-reviewed studies and book chapters published in various databases (search engines), namely Web of Science, SCOPUS, Google Scholar, JSTOR, and AGRIS. The search engines utilized were chosen for their broad coverage of up-to-date studies and interdisciplinary academic content (Spires et al., 2014). The data were sourced for the period covering 1950 to 2021, representing the unequivocal historical warming of the climate system as represented by the Intergovernmental Panel on Climate Change (IPCC, 2014) and the current period of observed and projected changes in climate. Therefore, the review of the recent decades suitably provides for reflection on significant trends and progress made in understanding the meteorological drought across the continent. Moreover, the global dataset from the Emergency Events Database (EM-DAT) website (https://public.emdat.be/) was assessed for the relevant information on drought situations at the country/regional/continental levels, focusing on estimating the impact of drought events on livelihoods and food security. From the available data collected, the study employed a systematic literature review (SLR) technique to assess the historical trends, impacts, mitigation measures,
and future prospects of meteorological drought across the African continent. SLR is a literature review method that is mainly used to examine the state of knowledge related to a topic (Ford et al., 2011). The approach is increasingly being employed in climate change discourse in order to understand the most up-to-date state of knowledge and to identify directions for further research exploits (Mcdowell et al., 2016). The present study followed the standards of the SLR technique in selecting and examining literature found in the selected literature database. For instance, we conducted the SLR following identification of literature using keywords including “Drought”, “Rainfall”, “Agriculture”, “Health”, “Environment”, “Economy”, and “Africa” for the selection of publications. Subsequently, the selected studies were analysed using both qualitative (thematic analysis) and quantitative (descriptive statistics) methods to explore all possible responses using the defined research questions for this study. A similar approach was employed in a study that systematically reviewed how smallholder agricultural systems’ vulnerability to changing climate is assessed in Africa (Williams et al., 2018).

3. Results

3.1. Observed Variations and Underlying Causes of Drought Over Africa

3.1.1 West Africa

The West African Sahel is a semi-arid transition zone located between the Sahara Desert and humid tropical
Africa. The region is characterized by a strong inter-annual meridional rainfall gradient and high rainfall variability. The annual rainfall amounts vary across the latitudes, from the humid Guinea coast to the northernmost locations. Rainfall variability over the region is mostly associated with the West African monsoon, which is the advection of moisture from the Gulf of Guinea, occurring during the summer months (July to September) as a result of the northward migration of the Intertropical Convergence Zone (ITCZ, Nicholson et al., 2018). The rainfall pattern is known to have been affected by a pronounced multi-decadal drought episode with unprecedented severity in recorded history between the late 1960s and early 1980s (Losada et al., 2012; Nicholson 2018; Nicholson et al., 2018; Ogou et al., 2019).

The drought events have caused numerous deaths and destroyed property, hampering development and economic growth in the region, as farming activities in the region are largely dependent on rainfall. The plight of the affected population attracted the attention of international aid organizations as well as the scientific community, which have encouraged research activities aimed at understanding the characteristics of the extreme in terms of causal mechanisms and future prospects. Nonetheless, ensuing studies attributed the Sahel drought to a number of factors. Early concerns focused on the influence of land-use practices (Charney, 1975), but later observational (Folland et al., 1986) and modelling (Biasutti et al., 2008; Caminade & Terray, 2010; Hoerling et al., 2006; Rowell, 2001) studies related both inter-annual and decadal-scale Sahel drought changes to sea surface temperature (SST) changes. In particular, strong links were found with inter-hemispheric (north–south) temperature gradients in the tropical Atlantic and SST in the tropical Pacific and Indian oceans. This relationship between the north–south SST gradient (the south and north oceans warmed and cooled after 1970) on a global scale is thought to have forced the Sahel drought on a decadal timescale. Hastenrath (1990) suggested that the increase in the cross-equatorial SST gradients in the Atlantic with the ITCZ location is also important. On the other hand, Herceg et al. (2007) highlighted the influence of the homogeneous warming of the tropical SST on the Sahelian drought through a warming of the free troposphere, affecting deep convection over West Africa.

Bader and Latif (2011) presented evidence that the dry conditions that persisted over the west Sahel in 1983 were mainly forced by high Indian Ocean SST that were probably remnants of the strong 1982/1983 El Niño event. The study further demonstrates that the Indian Ocean significantly affects inter-annual rainfall variability over the west Sahel and, as such, is the main forcing for the drought over the western Sahel. Indeed, several investigations have associated teleconnection between ENSO and rainfall variability over the Sahel (Rodríguez-Fonseca et al., 2015; Rowell, 2001), and the significance of this link during the observed drought was highlighted by Janicot et al. (2001).

Interestingly, both observational and numerical-modelling studies in recent years have suggested a recovery in precipitation over the Sahel (Fontaine et al., 2011; Lebel and Ali 2009; Nicholson et al., 2018; Sanogo et al., 2015; Sylla et al., 2016a; Sylla et al., 2016b). This implies that, in contrast to the widespread drying of the 1960s–1980s, the Sahel may have witnessed significant increases in precipitation during the subsequent years (Dike et al., 2020).

### 3.1.2 East Africa

The study of drought characteristics over equatorial East Africa (EAF) is particularly important owing to the region’s large inter-annual variability in the amount of rainfall received. Additionally, a large portion of the EAF landmass is classified as arid and semi-arid land (ASAL) despite being in the tropics and, as such, is susceptible to extreme rainfall variations, especially during the drought. Observational evidence over EAF shows that the mean rainfall for the major season, the long rains [March to May (MAM)], is on the decline over recent decades, and with it a widespread trend towards an arid condition (Lyon, 2014; Ongoma and Chen, 2017; Seleshi & Zanke, 2004). Nicholson (2014) reported widespread below-normal rainfall in the years 1998, 2000, 2005/2006, 2007, 2008, 2009, and 2011 for both the long and short rain seasons. The long local rains are locally referred to as masika in Kenya and Tanzania and gu in Somalia. Over the Ethiopian
region, it is usually termed belg. On the other hand, October to December (OND) rain is known as short rain, locally known as vuli, der, and krempt over Kenya, Somalia, and Ethiopia, respectively (Nicholson, 2018). Such a trend is particularly worrying, as the population largely depends on rain-fed agriculture for food production, and the sector still has one of the largest shares of employment (Salami and Kamara, 2010).

Each drought event has a visible impact on the region’s economy, poses threats to lives, and degrades the natural environment. As an example, recent drought episodes of 2010/2011 and 2016 created a food shortage for over 10 million people, leading to the loss of lives and livelihoods (Uhe et al., 2017). Haile et al. (2020a, b) reported increased drought frequencies in Eritrea, parts of Ethiopia, South Sudan, Sudan, and Tanzania, while Rwanda, Burundi, and parts of Uganda experienced smaller droughts in the second half of the twentieth century. The study also reported that a longer-timescale drought (SPI 6) persisted longer than the short-timescale droughts. Future projections of drought also paint a grim picture, as drought events are likely to increase by 16%, 36%, and 54% under the low, medium, and high emission scenarios, while extreme droughts are expected to cover a larger area (Haile et al. 2020a, b; Tan et al. 2020).

The observed increase in drought extremes is the subject of heightened research effort, and different theories have been advanced in an attempt to explain the phenomenon. Most studies point to ENSO as the primary factor causing seasonal drought, with El Niño (La Niña) episodes enhanced (suppressed) in the region. However, Lyon (2014) found that even during the OND season when ENSO influence is strongest, it accounts for less than half of the rainfall variance, thus pointing to influence from other sources. Their study reported that the post-1998 decline in the MAM was strongly driven by natural multi-decadal variability in the tropical Pacific Ocean. There has been a debate as to whether human intervention has played a role in creating the situation. However, considering that the drying trend experienced in the region is small compared to natural variability, Yang et al. (2014) attributed the cause of this trend to human-induced climate change, especially over a period as short as a few decades. Similarly, Lott et al. (2013) revealed that the impact of the 2010–2011 droughts was worsened by human intervention but did not find any evidence of human influence. However, Funk et al. (2014) do not completely exonerate the anthropogenic influence.

The aforementioned study argues that warming of the western Pacific because of human influence may enhance SST gradients along the tropics that are associated with the cold phase of the Pacific Decadal Oscillation (PDO), thereby increasing the drought during the MAM season. Williams and Funk (2011) attribute the decreasing rainfall trend to increased warming of the Indian Ocean SST, which extends the warm pool and Walker circulation westward, causing anticyclonic moisture flow over east Africa and disrupting moisture influx into the region. On the other hand, Hastenrath et al. (2007) linked the 2005 drought to the fast-moving westerlies that are often accompanied by anomalously cold waters in the northwestern and warm anomalies in the southeastern Indian Ocean. Recently, Wainwright et al. (2019) linked the reduction to the delayed onset and earlier withdrawal of the rain band over the region. A detailed study of the recent progress of drought occurrences, causes, impacts, and resilience was well enumerated in a recent study (Haile et al. 2019).

3.1.3 Northern Africa/Sahara

Due to its geographical location and climatic conditions, North Africa (NA) is typically a dry region by nature. Approximately 70% of the area is desert, which is hostile to life and normal anthropological activities, with annual precipitation of less than 50 mm and an arid climate with annual precipitation of less than 150 mm (Babaousmail et al., 2021; Radhouane, 2013). Drought is thus a recurrent phenomenon in the NA region, causing civilizations to collapse and mass migrations. In the past four decades, drought episodes in NA have gradually become more widespread and prolonged, with worrying socio-economic and environmental effects (Kaniewski et al., 2012; World Bank, 2017). Drought trends over Northern Africa have been caused by the interaction of complex processes and feedback mechanisms. Examples include El Niño events,
increased vertical thermal instability from the warming troposphere, and changes in the Atlantic Ocean that result in below-normal summer rainfall (Caminde & Terray, 2010; Dai & Zhao, 2017). Meanwhile, many studies have concluded that the drought episodes in the Sahel are mainly driven by southward warming of the Atlantic Ocean and persistent warming of the Indian Ocean. Moreover, the shift in the ITCZ contributed to the region’s dry anomaly (Caminade & Terray, 2010; Giannini et al., 2008; Zeng, 2003). Human influence as a result of land-use change, which alters the land surface feedback mechanism, is also noted as a factor (Zheng et al., 1997). Other studies have suggested the impact of aerosol emissions as a key driver of the Sahel droughts (Moulin & Chiapello, 2004). In addition, human-induced greenhouse gas emissions are considered a contributory factor to ocean warming (Dai, 2013).

3.1.4 Southern Africa

Drought is among the most destructive natural disasters in Southern Africa, with the region experiencing an escalation in the spatial extent of drought since the 1970s (Rouault & Richard, 2005). The bulk of the current research in the region has concentrated on the protracted droughts of the 1980s and 1990s (Jury & Levey, 1992; Landman & Mason, 1999; Lindesay & Vogel, 1990; Mason & Jury, 1997; Tyson & Dyer, 1978). The consequences of drought over Southern Africa vary across regions. The socioeconomic impacts are usually severe in a region with annual rainfall of less than 500 mm (Mason & Jury, 1997; Richard & Poccard, 1998; Rouault & Richard, 2003). Consequently, drought is a risk to water management and agriculture in the region. Knowledge of the effects of droughts in Southern Africa is of utmost importance because agriculture is the basic economic activity for the majority of the population in these countries (Jury, 2002; Washington & Downing, 1999). ENSO warm events have been associated with drought, resulting in diverse impacts over much of Southern Africa (Cane et al., 1997; Enfield, 1989; Ogallo, 1980). The 1982–1983 ENSO event, for instance, helped to exacerbate the prevailing dry conditions in much of the subcontinent (Bhalotra, 1985; Dent et al., 1987; Taljaard, 1989). Rainfall unpredictability in Southern Africa has been connected with atmospheric circulation configurations and interchanges in easterly and westerly flows, the connections between tropical and temperature structures, and the difference in pressure systems over Marion and Gough Island. Prolonged heat waves and droughts are interconnected, in most cases, by the prevalence of fundamental anticyclonic circulation over the country. A study on drought characteristics within the twenty-first century showed that ENSO caused over 66% of the extreme drought occurrences in Southern Africa (Rouault & Richard, 2005). The effect of ENSO on the region’s climate was also reported to have intensified since the 1970s. The ENSO SST effect on dry conditions in Southern Africa was examined by Gore et al. (2020), who revealed a weakening effect of El Niño and a strengthening effect of La Niña on the Walker circulation, resulting in drier and wetter conditions, respectively. It was reported that the El Niño and La Niña conditions altered the moisture flux circulation, thus impacting the drought characteristics over the southern region of Africa.

4. Impacts of Drought on Agriculture, Water, Environments, and Human Health

According to the International Disaster Database (EM-DAT), the drought occurrences between 1950 and 2021 affected close to half a billion people on the African continent, with about 700,000 recorded deaths and damage of about 6.6 billion USD (Fig. 2). This gradual shift is probably the consequence of climate change. Generally, agricultural activities, such as livestock, forestry, and fisheries, are prone to droughts, which severely affect food supplies and livelihoods, especially for smallholder farmers and the rural poor. When drought occurs, it is the primary sector to be influenced and the most significantly affected of all economic sectors. Moreover, the drought impacts have led to a decline in crop output, an upsurge in fire hazards, increased livestock mortality, and decreased water volume and level (World Bank, 2017). It can also act as a risk multiplier, destabilizing populations, amplifying uneven access
to water services and water resources, and reinforcing perceptions of marginalization (World Bank, 2017). Low-income earners are more vulnerable to droughts than average members of the population (World Bank, 2017).

4.1. Impacts of Drought on Agriculture

Agricultural activities are Africa’s main source of revenue, particularly in the sub-Saharan region. The long-term viability of agricultural activities is limited by their reliance on hydro-climatic variability. This has led to either dry or wet conditions for crop survival. The dry (drought) condition is the most devastating of agricultural activities (Habiba et al., 2012; Narasimhan & Srinivasan, 2005). Hence, researchers have evaluated the various impacts of drought on Africa. Droughts are a frequent occurrence in the agricultural areas of Eastern and Southern Africa (Winkler et al., 2017).

Droughts have caused enormous damage in many regions of Africa. According to the World Bank (2012), the 2000 drought caused a decline in peanut revenues from 68.4 to 17.4 billion FCFA, accounting for a 74% decline over WAF alone. In the same year, revenues from millet and sorghum fell from 30 to 12 billion FCFA, a 60% decrease (World Bank, 2012). Droughts are reported to affect crops not only through a decline in productivity but also through a reduction in the quality of the grains produced (Gautier et al., 2016). Hazard events have a negative impact on agriculture (Rojas et al., 2011). The main staple food

Figure 2
Drought impacts in Africa from 1950 to 2021 (EM-DAT; https://public.emdat.be/)
in sub-Saharan Africa, in particular maize, has been vulnerable to drought based on the drought exposure index (DEI) and crop sensitivity index (CSI) (Kamali et al., 2018). These authors noted that a higher (lower) crop drought vulnerability index (CDVI) indicated lower (higher) vulnerability (Fig. 3). One of the most popular strategies implemented by governments in the region to cushion the effect of drought is the provision of emergency endowments in the form of food aid, school feeding programmes, and the creation of temporary employment for people in the region hard-hit by the drought. This is imperative for reducing starvation as well as saving lives, but this approach has been shown to have several limitations. A paradigm shift of focus to a more proactive strategy that is more effective in risk reduction and social resilience is highly needed.

4.2. Impacts of Drought on the Environment

In Africa, population growth has become a serious concern, leading to a scarcity of natural resources and worsening socio-economic development (Ahmadalipour & Moradkhani, 2018; Ahmadalipour 2018). Drought impacts have led to poor soil fertility, affecting agricultural productivity in most sub-Saharan African countries. Environmental stresses emanating from drought vulnerability are the leading cause of biodiversity losses in most African agro ecosystems (Horn & Shimelis, 2020; Abdelmalek & Nouiri, 2020). For instance, South and West African countries have experienced severe drought impacts on their environment, which included the deracination of the region’s vegetation from their prototype biomes, significant loss of biodiversity, and plant mortality (Lawal et al., 2019).

At present, some parts of Southern and Eastern Africa have witnessed a rapid decrease in precipitation, and critical irrigation supply is on the verge of collapse due to a lack of environmental monitoring and assessments by stakeholders (Ayugi et al., 2020). Moreover, Mediterranean areas have experienced severe impacts such as water scarcity stress, rainfall variability, and decreased agricultural production, which may worsen under the perceived climate change prognosis (Abdelmalek & Nouiri, 2020).

Recent studies have suggested incorporating several strategies such as environmental reclamation involving the advancement of ecosystem services, biodiversity improvement, and soil and water conservation and management suitable for Africa to adapt to drought conditions. In addition, improved monitoring and assessments and understanding of the sources and impacts of droughts are essential for developing resilience to the environmental consequences of drought (Haile et al., 2019). Meanwhile,

![Figure 3](image_url)

Spatial distribution of maize drought vulnerability based on the five types of crop drought vulnerability indices (CDVI). CDVI is based on linking a DEI_{PCP} to CSI and b DEI_{PCP,PET} to CSI. PCP and PET stand for precipitation and potential evapotranspiration, respectively. The figure is adapted from Kamali et al. (2018)
most African countries have developed mitigation initiatives on food security and environmental issues emanating from drought and climate change. Examples include the West Africa drought-monitoring centre, on behalf of the Economic Community of West African States (ECOWAS), which incorporates several international initiatives on climate change, food security, and environmental monitoring that allow them to be updated on the best accessible and applicable technologies and procedures, similar to their counterparts in Eastern and Southern Africa (Traore et al., 2014).

4.3. Impacts of Drought on the Economy

According to Livingston et al. (2011) and the Organisation for Economic Co-operation and Development (OECD)/Food and Agriculture Organization (FAO) (2016a; b), with the exception of Southern Africa and the majority of North African countries, nearly all of Africa is dependent on subsistence agriculture. Although the share of agriculture in the gross domestic product (GDP) has been declining, the sector still accounts for about 30% of GDP and employs about 70% of the African labour force. This practice involves direct dependence on annual rainfall, natural vegetation, and water reserves for livelihood. The economic landscape of most African countries depends heavily on the dynamics of climate change, of which drought is an integral part. The vulnerability of the African economy and key sectors driving economic performance, such as agriculture, forestry, energy, tourism, and coastal and water resources, to climate change has been substantial (Abidoye & Odusola, 2015; Abidoye et al., 2012).

The IPCC (2014) has predicted an average increase of 1–3 °C in temperature for most parts of Africa, with a corresponding increase in surface evapotranspiration and a decrease in average annual precipitation. The impacts of this trend will result in an increase in drought conditions across most parts of the continent. Drought episodes in many African countries adversely affect both energy security and economic growth across the continent. This is so because the majority of African nations still depend on hydrothermal power plants for electricity and waterways for transportation of goods and services, as well as agricultural practices. There are probably no other factors that affect agricultural production as much as adverse weather conditions, especially droughts. Some areas that have experienced extreme droughts in the last few years include the Horn of Africa, East and Central Africa, and parts of Southern Africa (Masih et al., 2014). Even where droughts have not been as severe, rainfall tends to be unreliable, resulting in lower agricultural outputs and economic decline. Dell et al. (2012) considered the economies of 136 countries over a period of 54 years (1950–2003). They found that the impact of higher temperatures on economic growth in poor countries was significant, with a 1 °C rise in temperature in a given year reducing economic growth by 1.3% on average. Besides, it affects growth output, but it also reduces growth rates. Lastly, higher temperatures have wide-ranging effects, reducing agricultural and industrial output and increasing political instability (fallout from migration).

4.4. Impacts of Drought on Human Health

With the recent climate change projections, the occurrence of drought, intensifying in severity, duration, and the way people are adversely affected, is speculated to be on the increase in the coming decades (Christenson et al., 2014; IPCC, 2013; Rockström & Falkenmark, 2015). Drought is among the most severe phenomena that disturb the world today, particularly in Africa. It seems a formidable task to document the effects of drought on human health due to its complexity in assigning a start and end time and knowing that the generated impacts tend to accumulate over a long period (Stanke et al., 2013). Most of the increasing drought impacts on human health in Africa could be attributed indirectly to several factors, for instance, civil wars, bad political policies, adverse weather trends, and diseases like COVID-19 and HIV. However, some of the effects of prolonged drought can have an immediate and direct impact on health as a result of severe heat waves that cause heat stroke and other health issues (Smith et al., 2014).

According to Stanke et al. (2013), the drought-related health effects are strongly dependent on the severity of the drought, baseline population
vulnerability, existing health facilities, and the availability of resources to migrate the affected population during the events. Some of the drought-related health impacts include nutrition-related effects (general malnutrition and mortality, micronutrient malnutrition, and anti-nutrient consumption), water-related diseases (including *E. coli*, cholera, and algal bloom), airborne and dust-related diseases (including silo gas exposure and coccidioidomycosis), vector-borne diseases (including malaria, dengue, and West Nile virus), mental health effects (including distress and other emotional consequences), and other health effects (including wildfire, effects of migration, and damage to infrastructure). Indirect health hazards that relate to large-scale migration and forced displacement result from extreme weather events such as drought in African countries or cross-border (Kumari et al., 2018; Serdeczny et al., 2017). On the other hand, the severity of the 2011 and 2017/2018 droughts experienced in Eastern Africa led to famine, increased malnutrition in children under age 5, and enhanced mortality (ACAPS, 2018; National Drought Management Authority, 2018).

Kristina et al. (2020) inferred that the countries situated in the Horn of Africa, namely Somalia, Kenya, and Ethiopia, are highly vulnerable to climate change, such as prolonged droughts. They concluded that internally displaced persons (IDPs) are more exposed to health challenges such as malnutrition, undernutrition, lack of vaccination, gender-based violence, and mental health disorders. Besides, the treatment of some of these diseases is inadequate, which results in insufficient access to vital health services for the IDPs. Low-income areas, for example, sub-Saharan Africa, exhibit a low adaptive capacity to the multiple underlying factors caused by droughts, such as food insecurity that threatens the livelihoods of people, and inadequate access to clean water, health care, and education (Hartmann & Sugulle, 2009; Niang et al., 2014; Opiyo et al., 2015).

### 4.5. Mitigation Strategies

The vulnerability of Africa to climate change is driven by a range of factors that include weak adaptive capacity, high dependence on ecosystem goods for livelihoods, and less developed agricultural production systems. Efforts towards drought resilience via policy approaches, environmental rehabilitation, and agricultural productivity and water resources development are thus needed. Designing active responses to drought is more important than reactive responses, and the active responses should be based on risk management rather than crisis management (Haile et al., 2019). Examples of cases where key resources meant for the infrastructural and technological growth of the economy are being diverted to develop coping mechanisms to adapt to climate change effects should be discouraged. In contrast, drought mitigation interventions should be made in terms of preparedness for coping, and the creation of early warning awareness and the development of skilled personnel should be encouraged.

In response to the anticipated changes, the following proposed mitigation measures may be undertaken to avoid the loss of lives and societal infrastructure. Steps such as collaborating with countries that have advanced agricultural technologies suitable for harsh climates, deepening collaboration in areas of research on agricultural technologies and water conservation, and focusing on climate change mitigation strategies, as well as capacity-building, education, training, and public awareness on climate-related issues, should be prioritized and appropriately coordinated across African countries. Clearly, rain-fed agriculture has limits and is insufficient to feed the world’s growing population or to generate long-term economic growth. In addition, there is increasing competition for water for various uses, especially with the rapid growth of urban populations.

Moreover, an increase in land vegetation cover will be of great importance. With anticipated changes in various regions, such as an increase (decrease) in drought events (rainfall occurrences), measuring such enhanced tree coverage will likely retain soil moisture and help reduce such impacts. Meanwhile, plans to create new settlement schemes may be put in place to avoid more loss of lives. This is due to the expected surge in the frequency of landslides in regions that will experience flood extremes due to earth mass movements, especially in the hilly areas, which could eventually affect dams and riverbanks. Other measures could be prioritized, such as creating
new opportunities for research centres to find suitable crops to be grown in new land areas to enhance food security. This is because climate change will create a shift in farming systems. Regions that are predominantly arid and semi-arid (ASALs) will likely experience an increase in rainfall, thereby creating new opportunities for agricultural activities. New crops that are able to survive in new areas will enhance food security in the region that is considered food-insecure.

The impact of climate change on infrastructures, such as the lost resilience of buildings, roads, and other artefacts owing to an increase in temperature and precipitation, will call for new innovative approaches in engineering science to find suitable materials that can withstand high temperatures and more rainfall as compared to the traditional raw materials used over the last century. In the health sector, the health risk associated with climate change will vary according to age and gender. Anticipated climate-related health risks either directly or indirectly influence the vulnerable population, such as those that depend on climatic conditions (malaria, diarrhoea, and cholera). This will require more financial, human, and technological resources to be allocated to the health sector to research and improve awareness campaigns on possible adaptation measures. Lastly, the increase in drought severity towards the end of the century calls for far-reaching measures to ensure appropriate coping mechanisms are put in place. For instance, the hotspot regions in most African countries will affect the community that is already reeling from the ASAL environment’s unbearable conditions. With the projected changes of an intense increase in aridity conditions, the support systems of community livelihoods will be affected. Thus, African countries must increase their investment in irrigation infrastructure and water-conserving technologies such as drip irrigation, dam construction, and rainwater harvesting so as to avoid more catastrophic impacts.

5. Future Prospects of Drought Observation and Monitoring

5.1. West Africa

Accurate monitoring of drought situations remains a challenge due to the lack of ground-based datasets across most parts of Africa. Moreover, the modelling uncertainties continue to persist in most global climate models, mainly from the Coupled Model Intercomparison Project (CMIP3/5/6). For instance, in simulations of future climate variations and changes over West Africa, most of the CMIP3 models project modest increases (or decreases) in summer precipitation (Cook, 2008) over the Sahel (Guinea coast). Subsequent generations of CMIPs have strengthened our confidence in this notion (Ajayi & Ilori, 2020; Almazroui et al., 2020; Monerie et al., 2020), albeit with some notable uncertainties (Bichet et al., 2020; Monerie, et al., 2020; Sylla et al., 2016a, 2016b). Using downscaled climate models, a number of studies reached a consensus that the region is prone to significant drought hazards in the future (Ahmadalipour et al., 2019; Ajayi & Ilori, 2020), with a more severe impact under global warming (Quenum et al., 2019; Sylla et al., 2016a, 2016b). Nevertheless, drought events are projected to increase in the coastal parts of Liberia, Cameroon, Mali, Burkina Faso, Niger, Ivory Coast, Benin, Nigeria, and Chad (Quenum et al., 2019). This indicates that by the end of the twenty-first century, drought will be more severe over the region than it was in the recent past (Ahmadalipour et al., 2019), while global warming will intensify its impact even in the near future (Diaso & Abiodun, 2018; Klutse et al., 2018).

Meanwhile, studies that have also employed a subset of extreme rainfall indices (consecutive dry days and total precipitation; CDD/PRCPTOT) as defined by the World Meteorological Organization (Zhang et al., 2011) to investigate future prospects of drought over West Africa have reported significant changes in CDD and PRCPTOT (Akinsanola & Zhou, 2019; Akinsanola et al., 2020; Klutse et al., 2018; Quenum et al., 2019). To illustrate, Akinsanola and Zhou (2019) reported a statistically significant decrease in total summer precipitation and a significant increase in CDD over the region, which
underscores that drought events will be more pronounced in the future. Interestingly, Klutse et al. (2018) also concluded that enhanced warming would reduce mean precipitation across the region and increase CDD over the Guinea Coast subregion known for its humid features. In terms of changes in future precipitation variability over the region, Akinsanola et al. (2020) projected a remarkably robust increase in CDD over West Africa over a wide range of timescales.

The foregoing demonstrates that drought events will be more severe in the future as a result of a significant decrease in mean precipitation and a robust increase in CDD. Notably, the projected increase in drought occurrence may influence already fragile ecosystems and agriculture in the region (Klutse et al., 2018). Although there is an inter-model spread, which implies uncertainties in the presented projections, multi-model ensemble projections strengthen our confidence in the projected increase in drought events over West Africa. Using an ensemble of ten members, Ahmadalipour et al. (2019) quantified drought risk ratios across Africa and found that an increase in future drought risk across the continent is probable. This indicates that if no climate change adaptation policy is implemented, the unprecedented drought hazard will impact more severely on the vulnerable population (Ahmadalipour et al., 2019; Akinsanola & Zhou, 2019; Klutse et al., 2018). Furthermore, mitigation strategies such as reforestation have the potential to reduce future warming by 0.1–0.8 °C while increasing precipitation by 0.8–1.2 mm per day over the region (Diasso & Abiodun, 2018). As a result, this could serve as a wake-up call to relevant stakeholders to take a broad approach to mitigate the impact of increased drought events over West Africa.

5.2. East Africa

Existing studies have noted emerging issues related to possible changes in the drought situation over the East African region. Most studies show consistent results, with a likely increase in drought duration and moderate incidence, with fewer occurrences of extreme events across possible scenarios (i.e. RCP4.5 and 8.5) (Gidey et al., 2018; Haile et al., 2020a, 2020b). Examination of projected changes in drought frequency and severity depicts possible manifestations of severe to extreme drought occurrences that are expected to intensify during 2071–2100 (Haile et al., 2020a, 2020b; Tan et al., 2020). For instance, using CMIP5 models, most studies projected an increase in drought episodes towards the end of the century by 16%, 36%, and 54% under RCP 2.6, 4.5, and 8.5 scenarios, respectively (Haile et al., 2020a, 2020b). Spatially, drought events, duration, frequency, and intensity would intensify in regions such as Sudan, Tanzania, Somalia, and South Sudan, but generally decrease in Kenya, Uganda, and Ethiopian highlands. Interestingly, Nguvava et al. (2019) noted an increase in the intensity and frequency of SPEI droughts over East Africa, while SPI demonstrated a weak change for intensity and frequency of droughts. Overall, projections show that the drought changes over East Africa follow the concept of the “dry gets drier and wet gets wetter”. The findings agree with the recent similar studies that were based on recent GCM output of CMIP6 models (Ayugi et al., 2022). The resultant implications of projected changes will affect cross-cutting sectors that support livelihoods (i.e. economy, infrastructure, health, agriculture, and energy).

5.3. Northern Africa

Most of North Africa is dry because of its terrain (geographical location) and climatic conditions. Many parts of the region are covered by desert, which is unfriendly to anthropogenic activities due to its harsh weather. These harsh conditions are expected to worsen if necessary steps are not taken to curb the nemesis. The effects of drought manifest in the reduced rainfall from the established long-term average that spreads over a specified spatial scale for a definite period and negatively influences human activities (FAO, 2018). The drought problem in North Africa has existed for several hundreds or thousands of years. Mauritania experienced severe drought over the Sahel region in the 1910s, 1940s, and again in 1968. This was referred to as “the great famine” and “exchanging children for maize”. A similar severe drought in 2011 resulted in poor harvests, high food prices, and the loss of livestock, and in 2013, the
The worst drought in 15 years contributed to the food crisis.

Under the Representative Concentration Pathway (RCP) 8.5 scenario, Northern African countries, particularly Morocco, Algeria, and Tunisia, are unmistakably projected to become global hotspots for drought by the end of the twenty-first century (Dai, 2013; Orlowsky & Seneviratne, 2013; Prudhomme et al., 2014; Sillmann et al., 2013). Moreover, recent studies based on socio-economic pathways (SSPs) of CMIP6 equally project a sharp decline in precipitation trends over the region and a steady increase in aridity, leading to an intense upsurge in ecological droughts with medium confidence (IPCC, 2021). It is worth noting that the projections of future droughts suffer from outsized model uncertainties and also fundamentally depend on the methodology and baseline periods chosen. The projections for more severe and intense drought conditions around the Mediterranean and Northern Africa are consistent across various research (IPCC, 2012; World Bank, 2014).

5.4. Southern Africa

There is an emerging concern that the current global warming may intensify the severity of droughts in Southern Africa. Studies have shown that drought severity escalates with temperature increase (Dai et al., 2004, 2011a, b; Sheffield & Wood, 2008; Vicente-Serrano et al., 2010; Washington & Preston, 2006). For example, Dai et al. (2004) revealed that between 1972 and 2004, global warming increased global dry areas by 20–38%, and reported that the temperature rise of 1–3 °C in 1950–2008 reduced the annual rainfall in most regions of Africa, including Southern Africa (Dai, 2011a). Furthermore, precipitation characteristics are anticipated to continue to vary towards stronger and intermittent spells, which are expected to transform into more recurrent and severe water-related life-threatening events (Simonovic, 2009). Subsequently, most studies project a robust drying signal but with varying magnitudes from one location to another (Kusangaya et al., 2014; Maúre et al., 2018). To illustrate, recent studies that analysed the impacts of

| Drought drivers               | Drought characteristics | Impact type          | Key mitigation strategies | Future prospects                  |
|-------------------------------|-------------------------|----------------------|--------------------------|-----------------------------------|
| **Climate variability**       | Intensity, duration,    | Impact on water      | Efficient service delivery| Drought-prone hotspots in         |
|                               | magnitude, timing,     | resources             | to drought-prone hotspots | EAF, WAF, SAH, and SAF            |
|                               | and spatial coverage   | Impacts on           |                          | Environmental rehabilitation      |
|                               |                        | Drought management   |                          |                                   |
|                               |                        | strategies            |                          |                                   |
| **Anthropogenic effects**     | Sediment, and rocks in  | Impacts on            |                          |                                   |
|                               | and rocks in association with their climatic climax |                       |                          |                                   |
|                               |                        | Agricultural         |                          | Improved research on combined    |
|                               |                        | productivity          |                          | effects of anthropogenic activities and changes in climate systems |
|                               |                        |                      |                          |                                   |
|                               | Atmosphere circulation | Impact on human      |                          |                                   |
|                               | via atmospheric         | health                |                          |                                   |
|                               | teleconnections         |                      |                          |                                   |
|                               | Written and oral        | Impact on economy     |                          |                                   |
|                               | histories               | Impact on            |                          |                                   |
|                               | Tree rings              | environment           |                          |                                   |

*SST* sea surface temperature, *ITCZ* Intertropical Convergence Zone, *ENSO* El Niño–Southern Oscillation, *EAF* East Africa, *WAF* West Africa, *SAH* Northern Africa/Sahara, *SAF* Southern Africa
global warming levels on regional drought showed that the decrease in precipitation is insignificant at 1 °C, but the magnitude and spatial extent of the decrease becomes larger as global warming increases to 2 °C and 4 °C warming, respectively (Abiodun et al., 2019). Despite the extensive research conducted over this region on possible changes in drought, further studies still need to establish how to reduce the uncertainty in most models and thereby improve the credibility and applicability of the results. Moreover, future studies could examine the contribution of the atmospheric processes to the different drought projections and also extend more studies on hydrological droughts (i.e. stream flows) in the most vulnerable rivers in the Southern African regions. Table 1 documents the summary information of drought impact type, main characteristics, key mitigation measures, and future prospects over Africa.

6. Conclusion

The impacts of changing climate have consequences on nearly all socio-economic sectors that are dependent on it. This leaves many African countries vulnerable to climate variability and change, especially those whose economies are heavily reliant on rain-fed agriculture. Drought occurrence is mainly dependent on rainfall performance in a given locality, with occurrence in low and high rainfall areas. This work reviews meteorological drought over Africa, focusing on the past occurrences, their impacts, the projected changes, and mitigation of drought impacts on regional scales over Africa. Well-documented drought occurrences over most regions of Africa have played a critical role in developing tailor-made coping mechanisms. However, few studies have so far established a clear pathway for the expected changes, due to various limitations. Projected changes show recovery from drought events in the west and east African domain, while the south and north regions indicate a tendency for increasing drought characteristics. Progressive developments in climate models with limited uncertainty call for a more in-depth analysis of mechanisms regulating projected drought patterns. The proposed adaptation case studies are well-documented studies on projected drought occurrences for informed decision-making. Key resources meant for the infrastructural and technological growth of the economy have been diverted to develop coping mechanisms to adapt to climate change effects, which in itself is changing. Thus, in the long term, African countries must increase their investment in areas that deal with environmental conservation, healthcare infrastructure, smart agribusiness approaches, and water-conserving technologies such as drip irrigation, dam construction, and rainwater harvesting. This review adds to the existing information and scientific understanding with proposed mitigation measures to curb the adverse impacts of drought over the continent.

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Author Contributions

This study was initiated by EOE and BA. Conceptualization and methodology were developed by all members. Subsections were drafted as follows: VO and RM wrote the introduction section and reviewed the first draft. VND and COO wrote observed variation and underlying causes of drought over West Africa. AOO and BA wrote on East Africa, while EOE drafted sections for South Africa and North Africa. Impacts of drought; Agriculture was drafted by KFO and OEC, Environment by COO, Economy by APC and RM, and Health by AOR. The section for future prospects and challenges in Africa was drafted by VND, BOA, EOE, COO, and MA. The conclusion and abstract were drafted by BA.

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