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Review

Drought Dynamics in Sub-Saharan Africa: Impacts and Adaptation Strategies

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Abstract: The escalation in both frequency and severity of drought events has significantly amplified the vulnerability of numerous countries, particularly in developing ones, imposing substantial economic, environmental, and social pressures. This article presents a systematic review of drought occurrences in Sub-Saharan Africa (SSA), examining historical trends, current impacts, and projected future implications. Through this comprehensive assessment, a clear trend of intensifying drought phenomena emerges across SSA, leading to crop failures, drying of water sources, loss of pasture, food shortages, and an increase in food prices. This review also highlights the concerning potential for worsening conditions in certain regions, resulting in consequences such as migration, food insecurity, malnutrition, family disintegration, crop losses, and increased disease prevalence, notably HIV/AIDS. This study further reveals that current adaptation measures by governments and NGOs should be improved to effectively adapt to the diverse impacts of drought, and it contributes to a deeper understanding of drought dynamics in Sub-Saharan Africa and assesses its critical impacts on food security and social well-being. It also evaluates adaptation measures across different countries, highlighting their strengths and weaknesses and enabling quick identification of areas for improvement. Additionally, it informs resilience-building efforts in vulnerable communities.

Keywords: drought mitigation; food security; water scarcity; Sub-Saharan Africa; socio-economic vulnerability; drought severity

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1. Introduction

Droughts in Sub-Saharan Africa extend beyond mere environmental disruptions, posing a complex network of challenges that deeply affect multiple sectors. These events significantly impact human health, food security, economic stability, infrastructure, natural ecosystems, and even national and global security. Their contribution to malnutrition and famine is particularly concerning, disproportionately affecting vulnerable communities, such as women, children, and the elderly [1,2].

Drought emerges as a critical issue in Sub-Saharan Africa, where most of the population relies on rain-fed subsistence agriculture and traditional water management systems. Identifying and mitigating drought impacts in hotspot areas is critical, demanding adaptation strategies for a growing population in a changing climatic landscape [3]. The global reach of drought, affecting more people than any other natural hazard, underlines its complexity and the uneven distribution of its impacts. This necessitates a nuanced understanding of the phenomenon and the diverse coping strategies employed by affected communities [4].

The insidious nature of drought transcending simple water scarcity to include the imbalance between demand and supply highlights the need for a comprehensive understanding of its impacts. As Wilhite [5] suggests, effective drought management requires considering the long-term balance between precipitation and evapotranspiration, emphasizing the importance of integrated water resource management strategies.

Beyond physical and economic distress, drought significantly impacts the psychological well-being of individuals, with emerging evidence pointing to a range of mental health issues stemming from climate extremes, such as post-traumatic stress disorder (PTSD), depression, and anxiety [6]. These challenges, difficult to quantify yet fraught with long-term societal and intergenerational implications, underscore the complex nature of drought [7].

In Sub-Saharan Africa, drought acts as a catalyst for socio-economic disasters, magnified by the region's vulnerability to climate change, characterized by erratic rainfall, prolonged dry seasons, and endemic poverty. This intensifies the adverse effects on food production, water resources, and millions of livelihoods [8]. The recurrence of droughts, leading to humanitarian crises, underscores the urgency for robust and proactive interventions [9].

Furthermore, drought's economic and social ramifications extend into the community fabric, manifesting in survival strategies that amplify disease vulnerability, such as transactional sex, highlighting the severe consequences of inadequate response mechanisms [10]. The anticipated increase in drought frequency and intensity, with implications for food and water security and potential conflict escalation, demands immediate attention to rainfall pattern deviations and resource competition [11].

The narrative is further humanized by the experiences of communities in regions like the Angola–Namibia border, where persistent drought conditions often force families into desperate searches for their needs, showcasing the urgent need for effective mitigation and adaptation strategies [12,13].

The recurrent nature of droughts, especially in the Horn of Africa, underscores the shift towards reliance on groundwater resources and the necessity for resilient infrastructure and institutional frameworks [13]. With droughts occurring with an alarming frequency (every three to four years), it becomes imperative to develop strategies that go beyond crisis management, addressing the root causes of vulnerability in rain-fed agricultural communities [14].

This article analyzes past, present, and future drought events in Sub-Saharan Africa, assessing their impact on key sectors such as agriculture, conflict, health, and social issues. This approach fills existing gaps in the literature by examining drought adaptation strategies across various regions, presenting a holistic view of drought impacts and management. In contrast to previous studies, which have often focused on specific regions, such as East or Southern Africa, or concentrated on individual sectors like water management, health, or agriculture, this bibliographical review expands its scope to cover the entire Sub-Saharan region and all sectors. It also includes both governmental- and community-level management strategies. This comprehensive approach provides deeper insights into the complex relationship between environmental challenges and human resilience.

2. Method

2.1. Introduction of Study Area

This study focuses on Sub-Saharan Africa (SSA) (Figure 1), a vast region defined by the borders of more than 40 countries in the south of the Sahara Desert. SSA encompasses a wide range of climatic conditions, from humid equatorial regions to arid areas in the north and south. Rainfall and temperature patterns vary significantly across this diverse region. Countries within the 10° N–10° S latitude, such as those in Central Africa and the Ethiopian Highlands, receive over 1500 mm of annual rainfall, while other parts of SSA receive less than 500 mm. Temperature variation is mainly influenced by elevation, with higher altitude regions like the Great Rift Valley and southern Africa experiencing cooler average temperatures of around 15 °C, while equatorial regions average 25 °C, and areas near the Sahara can reach up to 30 °C [9,15].

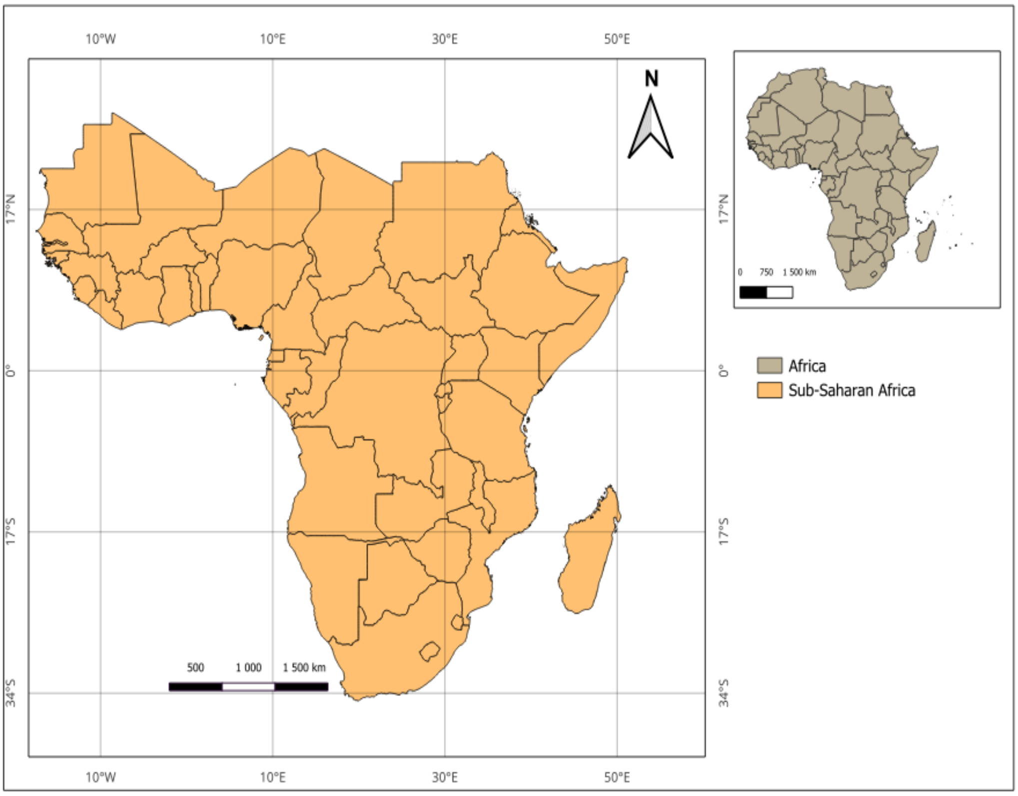

Figure 1. Study area. Adapted from AMCOW (2018).

2.2. Literature Review

In this study, a structured approach was used to conduct the systematic review, guided by the PRISMA 2020 framework (Figure 2). It systematically outlines the process undertaken, starting from the formulation of a robust search strategy to the selection of relevant databases, criteria for inclusion and exclusion, and the approach for assessing the quality of the studies included. The electronic search was conducted across the following databases: Science Direct, Google Scholar, PubMed, and Web of Science. Inclusion and exclusion criteria were carefully followed for article selection. As a result, a total of 93 studies, ranging from 2010 to 2024, were included in this review after the screening and assessment process based on predefined eligibility criteria.

The inclusion criteria considered were as follows:

- Regional focus: articles have a direct and specific emphasis on SSA or its countries, ensuring the review's relevance to the region;
- Drought examination: a thorough investigation of drought phenomena within SSA, including their characteristics, causes, impacts, and different types of droughts such as meteorological, agricultural, hydrological, and socio-economic drought;
- Causative factors: an in-depth analysis aimed at identifying and understanding the various factors contributing to drought conditions in SSA to provide insights into the complexity of these phenomena;
- Impact assessment: a systematic analysis of drought's effects across different sectors within SSA, covering socio-economic, health, environmental, and humanitarian aspects;
- Geographical variability: acknowledgment of the region's geographical diversity, recognizing that the causes and impacts of drought may differ significantly across various locales.

On the other hand, the exclusion criteria considered were as follows:

- Generalist nature: articles that lack depth and specificity on SSA, veering towards a global narrative that dilutes the focus on the region;
- Vague or ambiguous discussions: studies that offer indistinct or unclear discussions, hindering a precise comprehension of drought-related issues specific to SSA;
- Emphasis on article quality: research overly concentrated on critiquing the study quality rather than providing a detailed examination of drought's causes, impacts, and future scenarios in the region;
- Repetition in databases: exclusion of duplicate entries or repetitive studies across databases to ensure novelty in the review and the inclusion of a broad spectrum of viewpoints.

This refined approach aims to capture a comprehensive and nuanced understanding of drought within SSA, leveraging a systematic review process to identify key themes, factors, and impacts associated with this critical issue.

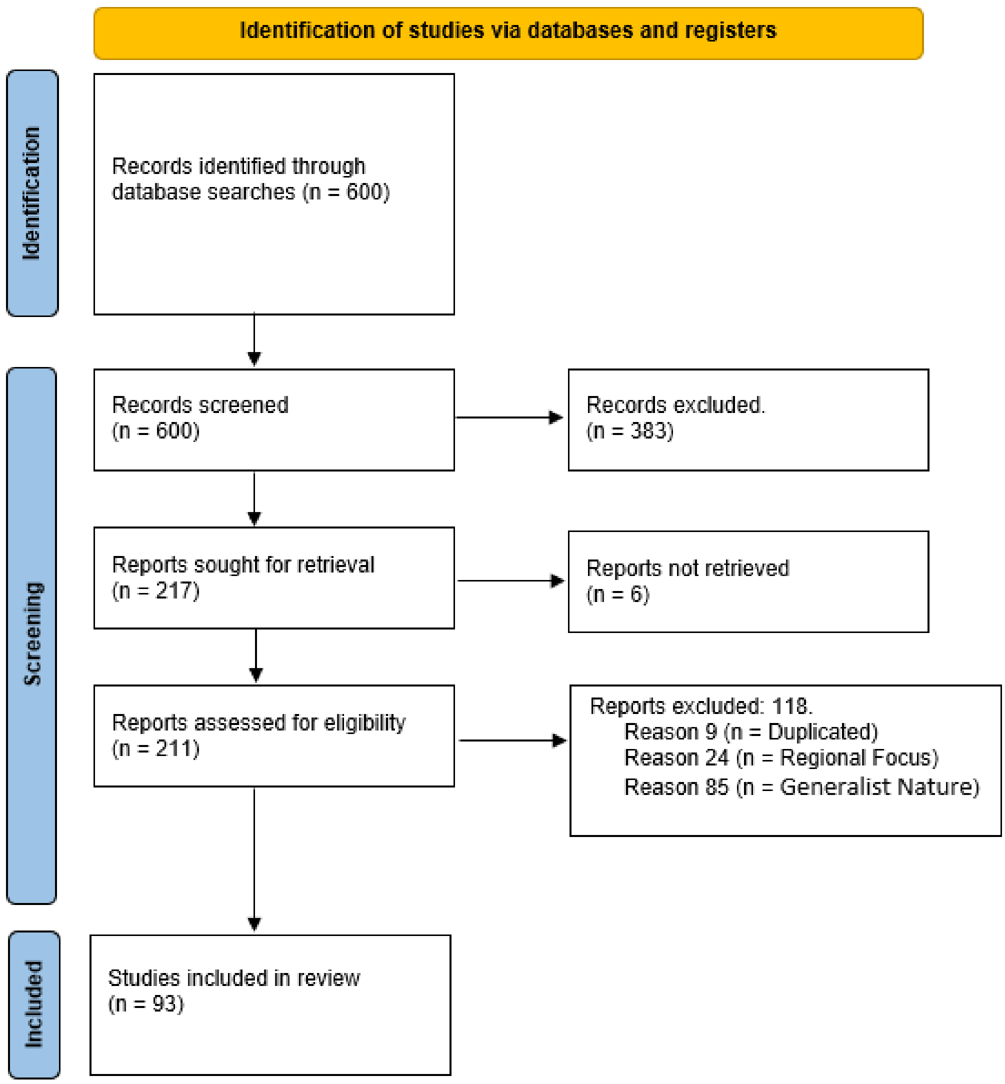

Figure 2. Flow chart used for systematic review based on PRISMA 2020: https://prisma-statement.org, accessed on 4 November 2024.

3. Drought in Sub-Saharan Africa

The occurrence of droughts in SSA constitutes a significant challenge with far-reaching implications for societies, economies, and ecosystems. Masinde [16] underscores the severity of this challenge, highlighting that droughts are responsible for over 88% of all disaster-related impacts in Africa. Over the past century, the frequency, intensity, and spatial extent of drought events have seen a noticeable increase across the continent [15]. Extreme droughts such as those in 1972–1973, 1983–1984, and 1991–1992 have left lasting impacts and are unparalleled in available records. Moreover, recent decades have witnessed severe and prolonged droughts in various regions, including the northwest, western Africa (Sahel), eastern Africa (Horn of Africa), and southern and southeastern Africa [17].

The Equatorial East Africa (EEA) region, located in East Africa, encompassing countries like Kenya, Uganda, Tanzania, Rwanda, and Burundi, has experienced widespread drought events throughout history. From 1900 to 2020, drought-affected areas fluctuated significantly, with magnitudes ranging from 0% to 95%, across the EEA [18]. In East Africa, specifically in the Greater Horn of Africa (GHA), drought severity has risen over the past 52 years, with notable occurrences in countries like Sudan, Tanzania, Somalia, Ethiopia, and Kenya. The extreme droughts in 1973–1974, 1984–1985, and 2010–2011 underscore the persistent nature of these events. Seasonally, droughts have increased in winter, spring, and summer, although a decrease has been observed in autumn [19].

Southern Africa, known for its regular droughts, suffered extensive impacts during the 1981–2005 period, particularly in the central parts of South Africa, Namibia, and Botswana [20]. The intensity of droughts in SSA varies widely, necessitating assessments at the country or regional levels. Studies have revealed varying precipitation patterns over decades, with some regions experiencing drier conditions in the 1980s and 2000s compared to the 1990s. Ethiopia and Kenya have shown increasing trends in drought severity, while Tanzania exhibits a non-significant decreasing trend. Notable drying trends are observed in certain areas, emphasizing the localized nature of drought impacts [21].

The occurrence of drought in Sub-Saharan Africa is a multifaceted issue with far-reaching consequences. Understanding historical patterns and trends is crucial for effective adaptation and mitigation strategies to address this persistent challenge.

In their study, Kalisa et al. [22] delved into the dynamics of droughts across East Africa, leveraging Climate Research Unit (CRU) precipitation data from 1920 to 2016 and employing the standardized precipitation index (SPI). Their analysis revealed distinct patterns, revealing the most prolonged drought periods spanning from 1926 to 1929 and from 1958 to 1961, enduring three to four years.

The Congo Basin experienced prolonged and severe multi-year droughts during both the early (1901–1930) and later (1991–2014) decades of the previous century. These droughts had far-reaching impacts, affecting over 50% of the basin from 1901 to 1930 and approximately 40% during the 1994–2006 period. Examination of the most recent decades (1991–2014) suggests that compared to the two climatological periods between 1931 and 1990, the Congo Basin has become somewhat drier [23].

Adejuwon and Dada [24] analyzed drought characteristics in the semi-arid tropics of Nigeria from 1981 to 2012 and observed a decline in drought frequency over the study period, with the northeastern area experiencing the most extreme drought events. Drought intensity varied across stations, with the highest intensity observed in Nguru in June 2004. Drought duration ranged from one month to eighty months, and both absolute probability and recurrence interval showed wide variability. The study conducted by Okal et al. [25] focused on assessing the temporal and spatial patterns of meteorological drought in the Upper Tana River watershed, which encompasses critical water towers like Mt. Kenya and Aberdare Ranges in Kenya. Utilizing remotely sensed data from 1981 to 2018, the researchers employed GeoClim to retrieve the SPI and obtained Standardized Precipitation and Evapotranspiration Index (SPEI) data from the SPEI Global Drought Monitor. Analysis revealed a severe meteorological drought period from 2007 to 2009, spanning three consecutive years across the entire watershed. Temporally, drought incidences were noted in 1982, 1989, 1994, 2000, 2006, 2011, and 2017, with both SPI and SPEI indices indicating similar drought years.

As previously noted, the frequency, intensity, and spatial extent of drought events have been rising across Sub-Saharan Africa, especially in areas like the Sahel, the Horn of Africa, and Southern Africa. The expansion of drought-affected areas is strongly linked to rising temperatures, especially after the 1970s. For instance, East Africa saw a 30% increase in drought-affected areas between 1981 and 2020, primarily driven by moderate and severe droughts associated with El Niño cycles. In Central Africa, prolonged droughts affected over 50% of the Congo Basin from 1901 to 1930 and around 40% between 1994 and 2006, leading to significant hydrological changes. From 1981 to 2005, Southern Africa, including central South Africa, Namibia, and Botswana, experienced recurrent droughts that severely impacted agriculture and water resources. In Nigeria, from 1981 to 2012, mild droughts accounted for 58.9% [19], [20–22], [23–25]. Figure 3 highlights the drought dynamics in Sub-Saharan Africa, illustrating its impacts across agriculture, health, and social sectors, as well as the adaptation strategies being employed, such as agricultural diversification, access to credit, and the use of technology to monitor and forecast drought.

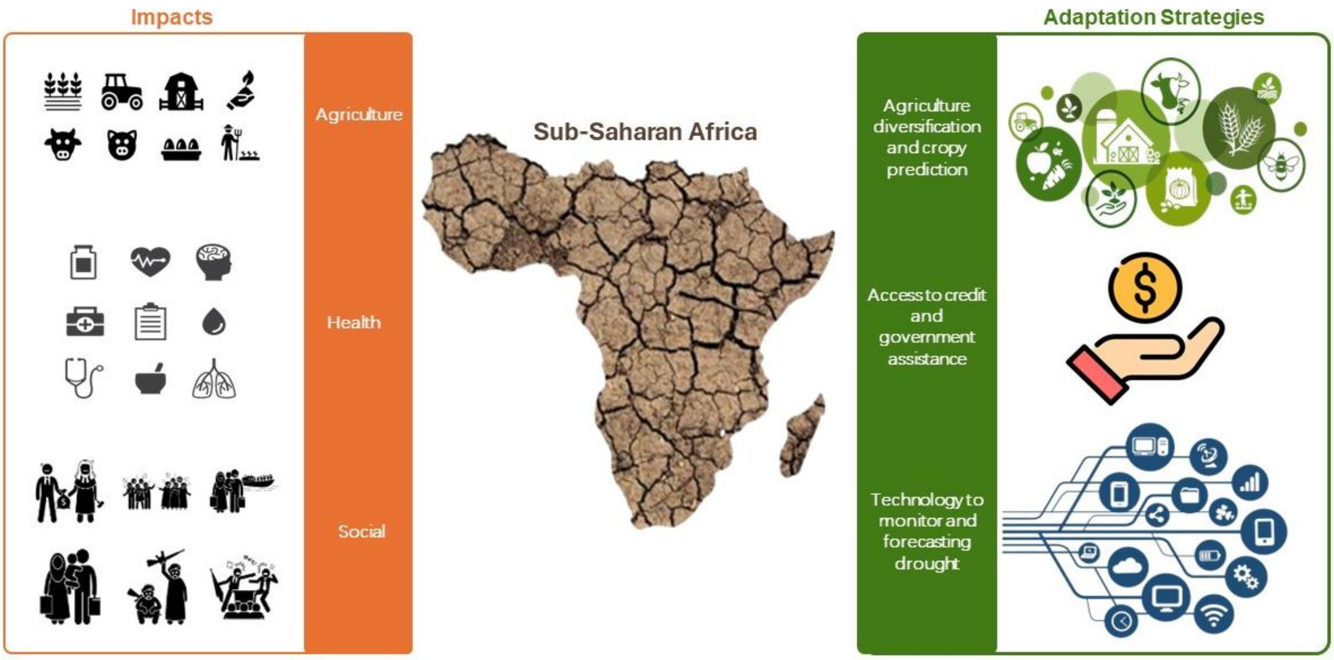

Figure 3. Drought dynamics in Sub-Saharan Africa.

4. Drought Impacts

This chapter makes a comprehensive analysis of the impacts of drought within SSA, focusing on critical sectors such as agriculture, conflict, health, and social aspects. Through an exhaustive literature review, it attempts to build a comprehensive understanding of the multifaceted ramifications of drought across the region. This work also aims to underscore the scope and complexity of these consequences by employing illustrative examples. Figure 4 summarizes these key impacts, demonstrating how drought can lead to reduced agricultural productivity, increased health risks, heightened conflict, and various social challenges.

Figure 4. Drought impacts in Sub-Saharan Africa, based on Busker et al., (2023) [26], Gebrechorkos et al., (2020) [21], Kamali et al., (2018) [27], Orimoloye, (2022) [28], Von Uexkull, (2014) [29], Orievulu et al., (2022) [30], Bell and Keys, (2016) [31], Treibich et al., (2022) [10], Shukla et al., (2021) [32], Andriano and Behrman, (2020) [33], Haile et al., (2020) [34], (Ajayi and Ilori, 2020) [35].

4.1. Drought Impact on Agriculture

The agricultural sector in SSA is severely affected by drought, directly impacting both this sector and the households that rely heavily on agriculture for their livelihoods in the region. Droughts have a profound influence not only on the quantity but also on the quality of produced foods, posing significant threats to food and nutrition security, especially in regions reliant on local food markets or semi-subsistence farming practices. Severe droughts have led to a dual impact, causing a simultaneous decrease in yield and quality [26]. Since 2015, SSA has experienced an unprecedented rise in acute food insecurity, with climate-driven drought emerging as a primary contributing factor [32].

A meticulous examination of staple crops maize, millet, and sorghum revealed their specific responses to drought events. These crops, widely cultivated and adapted to the environmental conditions of SSA, showed significant dependence on rainfall for yield. The Copula theory was applied to articulate the relationship between drought and crop yield anomalies for these rainfed crops in the region [27]. The study found that the severity of yield loss due to drought often exceeded the severity of the drought itself, amplifying the negative impacts on agricultural productivity [27].

Orimoloye [28] highlights the disparities in yield loss across regions, demonstrating a heightened probability of crop failure with increasing drought frequency. In South Africa's Free State Province, a study investigating drought impacts on maize and sorghum production between 2011/12 and 2020/21 found that extreme drought events in 2015 and 2018 significantly reduced yields. Similarly, severe droughts occurred in 2011, 2016, and 2019, leading to substantial declines in crop output [28].

Additionally, a probabilistic method employed by Jayanthi et al. [36] to estimate drought risk for maize in Kenya, Malawi, and Mozambique, as well as millet in Niger, revealed substantial periodic losses. For example, in Kenya's Rift Valley, maize losses were estimated at 35,000 metric tons annually (2.3% of total production), while Malawi reported annual losses of 6250 metric tons (1.2% of total production). Mozambique experienced the highest maize production losses, with 42,500 metric tons lost annually. In Niger, millet losses amounted to 146,000 metric tons once every five years, with severe droughts occurring every ten years resulting in losses of up to 390,000 metric tons.

4.2. Drought and Conflicts

Drought in SSA has diverse impacts, including migration, domestic violence, and conflict potential. Muconga [37] highlights the link between drought and extremist violence, showing that drought significantly reduces economic activity, resulting in a substantial increase in extreme violence rates. Detges [38] emphasizes that the impact of drought on political violence depends on both social and political factors, with politically marginalized individuals more likely to endorse violence during droughts. On the contrary, Bell and Keys [31] argue that drought does not exacerbate increase conflict risk in vulnerable states; instead, it destabilizes stable states with generally favorable conditions. Uexkull [29] suggests that drought substantially increases the risk of civil conflict in subnational regions with rainfed croplands. Exploring these varied perspectives helps provide a comprehensive understanding of the complex interplay between drought and conflicts in SSA (Table 1).

Table 1. Drought and conflicts in Sub-Saharan Africa.

Aspect	Detges [38]	Bell and Keys [31]
Key Insights	Drought's impact on civil disobedience depends on the social and political conditions. Vulnerability is linked to the relationship with the government. Politically marginalized individuals are more prone to endorse violence during droughts.	Drought does not exacerbate risks of conflict in vulnerable states. Stable states with favorable conditions are destabilized during drought, leading to equalized conflict risk.
Methodology	Use of Afrobarometer survey data from 2002 to 2013 across 35 countries.	Analysis of drought severity and civil conflict onset in SSA from 1962 to 2006. Analysis of socio-political conditions influencing the relationship between drought and conflicts.
Data Source	Afrobarometer survey data.	State-year sample data covering 39 states from 1962 to 2006.
Variables Analysed	Attitudes towards political violence.	Drought severity, state adaptive capacity, socio-political conditions.
Conclusions	Drought alone does not significantly increase the likelihood of political violence. However, during severe droughts, political marginalization and distrust in the government become more influential factors, increasing the risk of conflict.	Drought destabilizes states with improved living standards and more effective governance, contradicting conventional wisdom by equalizing conflict risk during droughts, even in states that are normally more peaceful and robust.

Table 1 highlights the varying perspectives on the relationship between droughts and conflicts in SSA. It underscores the complexity of this relationship, where the impact of droughts on conflicts is not universally agreed upon. Analyzing this connection requires the application of diverse methodologies to determine their interplay definitively. Moreover, it emphasizes that social and political factors, alongside adaptation and information, play crucial roles in influencing the outcomes, making the analysis multifaceted and context-dependent.

4.3. Drought Impacts on Health

Drought profoundly affects health, encompassing a spectrum from economic repercussions to human well-being. In SSA, its impacts on health are diverse, manifesting themselves in child malnutrition, mental health challenges, the spread of HIV/AIDS, and outbreaks of diseases (e.g., cholera). The severe drought experienced by South Africa in 2015 stands out as one of the most devastating in 35 years, significantly disrupting economic activities and undermining individual and community well-being, especially in the rural communities of northern KwaZulu-Natal [39]. This event revealed that drought had detrimental effects on individual and community livelihoods, creating challenges for people living with HIV to consistently access care due to economic losses, such as livestock deaths. Findings from Orievulu and Iwuji [30] indicate a critical need for dam infrastructure, as competition between humans and animals for drinking water emerged as a significant issue.

Treibich et al. [10] conducted a study in Malawi, uncovering a noteworthy link between drought and transactional sex, particularly affecting women in agriculture. The research indicates that each drought doubles the likelihood of engaging in transactional sex among unmarried young women in this sector, contributing to the increased risk of HIV transmission. Expanding this perspective across 10 SSA countries, Epstein et al. [40] associate drought with lower rates of HIV testing and increased risky sexual behaviors. The Lesotho Population-Based HIV Impact Assessment, conducted after the severe drought of 2014–2016, revealed concerning associations between drought and higher HIV prevalence, especially among young females (aged 15–19) in rural areas. Low et al. [41] highlight a range of adverse outcomes, including reduced condom use, higher odds of selling sex, and increased vulnerability to forced sex among females during drought.

Shifting the focus to cholera outbreaks, Rieckmann et al. [42] conducted an analysis across 40 SSA countries from 1990 to 2010. Contrary to expectations, the study found that while floods are more strongly associated with cholera outbreaks, the prevalence of cholera outbreaks is higher during droughts due to their prolonged durations. The study recommends recognizing drought periods as higher-risk times for cholera outbreaks, urging increased vigilance in preventive measures at local and international levels.

Mason et al. [43] utilized FAO's food production index (FProdI) to analyze the impact of drought across Southern Africa and the Greater Horn of Africa. Areas with higher HIV prevalence demonstrated lower malnutrition rates before drought, but during drought, high-HIV areas had a more significant increase in malnutrition rates compared to low-HIV areas. In Southern Africa, proximity to major towns, including peri-urban areas, correlated with heightened HIV impact during drought, possibly exacerbated by vulnerability to poverty and food insecurity, potentially amplified by migration. In Eastern Africa, drought led to deteriorating nutrition in low-HIV areas, with a 5 to 12% increase in underweight prevalence, while high-HIV areas experienced less significant differences in malnutrition rates compared to non-drought periods.

4.4. Social Implications of Drought

Sub-Saharan Africa is a region deeply intertwined with its environmental conditions, and drought events have profound and multidimensional impacts that extend well beyond their immediate physical effects. These impacts significantly influence the region's cultural, socio-economic, and political spheres. The disruption caused by drought affects agriculture and food security, leads to water scarcity, increases health risks, strains economies, and accelerates environmental degradation. It further intensifies social and political tensions, impacts education, exacerbates heightened gender disparities, and is compounded and made worse by the effects of climate change [19].

Drought is a critical natural factor contributing to malnutrition and famine across the region. Its impacts are not just limited to reducing crop productivity or degrading rangelands and forests but extend to increasing fire hazards, lowering water levels, and elevating mortality rates in livestock and wildlife. This cascade of effects culminates in this series of events and leads to a range of socio-economic challenges, including reduced incomes for farmers and agribusinesses, increased food prices, unemployment, reduced tax revenues, and a rise in conflict and displacement. These consequences threaten the economic and development gains achieved in recent decades [2].

The Horn of Africa, encompassing Kenya, Somalia, and Ethiopia, has faced an ongoing multi-year drought worsened by consecutive failed rainy seasons. This climatic event has unprecedented impacts, including the starvation of millions of livestock and high food insecurity, affecting close to 23 million individuals in 2023 in these countries alone [26].

Persistent droughts in the southern African dryland regions have had significant impacts on people, their domesticated animals, rangelands, and cropped lands [44]. Similarly, in Central Africa, in the Diamare division in Cameroon, a study covering rainfall data from 1970 to 2019 revealed the recurrence of droughts with varying intensities, from mild to extreme. These drought events have led to crop failures, drying of water sources, loss of pasture, food shortages, and a spike in food prices. Consequently, the Diamare division has experienced malnutrition, water scarcity, health problems, and loss of livestock. Ntali et al. [45] highlighted that such conditions contributed to increased emigration, particularly among the youth, in search of better opportunities.

In the Tsavo protected area of southern Kenya, research indicates that prolonged drought has led to the death of several elephants, illustrating the broader ecological and social implications of these extreme weather events [46]. The study conducted by Andriano and Behrman [33] provides insight into the specific social dynamics altered by drought. In Malawi, experiencing drought during teenage years has been associated with young women entering relationships and having their first children sooner. These relationships are more often cohabitations rather than marriages, largely because of limited resources.

5. Drought Projections in Sub-Saharan Africa

Drought is a critical and escalating challenge in SSA, significantly impacting socio-economic and environmental stability. This section analyses the future projections of drought in the region, highlighting the anticipated changes in drought patterns, frequencies, and intensities influenced by global warming and shifts in greenhouse gas emissions. The vulnerability to drought in Africa is expected to rise due to factors such as rapid population growth, higher water demands, and land degradation. In Kenya, research utilizing the SPI and regional climate models has forecasted an increase in both rainfall and moderate drought occurrences, with severe droughts becoming more prevalent by the late century. The study anticipates a substantial rise in the risk of severe to extreme droughts towards the end of the near-century period [47]. This projection underscores the variable impacts across different regions, indicating the need for region-specific adaptation strategies.

East Africa's future drought patterns have been assessed using an ensemble of five Global Climate Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The findings reveal an increase in drought area by 9%, 17%, and 16% in the 2020s, 2050s, and 2080s, respectively, under the Representative Concentration Pathways (RCP) 2.6 scenario. More significant increases are projected under RCPs 4.5 and 8.5, with changes in drought areas of up to 36% and 39% by the 2080s. These projections also indicate consistent trends across different drought severity levels, emphasizing the dry gets drier and wet gets wetter pattern in East Africa [34].

Figure 5 presents the projected changes in drought dynamics across Sub-Saharan Africa from 2000 to 2080 under the RCP4.5 and RCP8.5 climate change scenarios. The figure highlights significant shifts in drought intensity, as measured by the Palmer Drought Severity Index (PDSI), across different regions. For instance, Southern Africa and parts of West Africa are projected to transition from near-normal conditions to moderate drought by the 2050s, with even more severe drought conditions expected by the 2080s, particularly under the RCP8.5 scenario. In contrast, some parts of East Africa, including areas in the Horn of Africa, may experience a shift towards wetter conditions by the late century. This figure illustrates the increasing frequency and intensity of droughts in Sub-Saharan Africa [9].

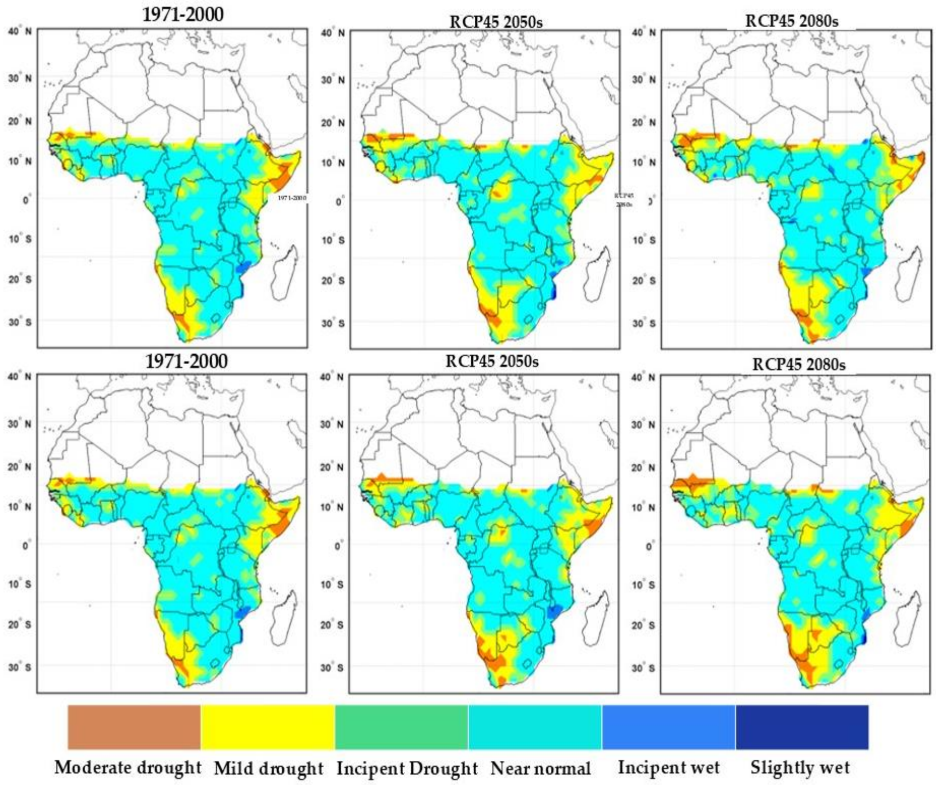

Figure 5. Drought projections in Sub-Saharan [9].

The Volta River Basin study utilized the standardized precipitation index (SPI) and the Standardized Precipitation and Evapotranspiration Index (SPEI) to assess drought conditions, while the Standardized Runoff Index (SRI) was employed to quantify runoff. The analysis combined historical data (1970–2013) with regional climate model simulations to project future drought patterns. The research aligns with previous studies, with the results showing that both drought intensity and spatial extent are projected to increase. Drought frequency is expected to intensify, with events per decade magnified by a factor of 1.2 by the mid-21st century (2046–2065) and 1.6 by the late 21st century (2081–2100) relative to current conditions. The coupling between runoff and drought episodes was found to be strong, particularly for the 4–8-year band, underscoring the hydrological sensitivity of the basin to precipitation changes [48].

Further research in East Africa by Tan et al. [35,47] employed four different scenarios (SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5) to investigate drought patterns. The study suggests an increase in the frequency and intensity of extreme drought events during the mid-future (2041–2070), indicating a heightened risk of drought occurrence. However, projections for the late century (2071–2100) show a decrease in severe and extreme drought events, shifting towards moderate drought frequency. This indicates a complex interplay of drought patterns, with more frequent and intense drought events expected in the mid-future, followed by potential improvements in drought conditions by the late century under different climate change scenarios.

In West Africa, Ajayi [35] utilized SPI and SPEI to project drought trends under RCP4.5 and RCP8.5 scenarios. The projections indicate that areas north of 12° N will be hotspots for mild and moderately dry events, while the southern part will experience pronounced severe and extreme dry events under both RCPs. Notably, SPEI projects a significant decreasing trend in drought events over the three climatic zones and almost all seasons under the RCP8.5 scenario, illustrating a shift towards drier conditions.

The Greater Lake Malawi Basin study predicts a significant increase in meteorological droughts' intensity and duration, with projections indicating a rise in drought intensity by +25% to +50% between 2021 and 2050 and by +131% to +388% between 2071 and 2100.

These results translate into +3 to +5 and +7 to +8 more drought months per year during both periods, respectively. These models predict that droughts under the high-emission scenario will be 1.7 times more severe than those under the moderate scenario, highlighting an urgent need for effective water management and climate change adaptation measures [49].

Collectively, these studies stress the critical need for SAA to implement robust adaptation and mitigation strategies in response to the projected increases in drought frequency, intensity, and duration across various regions and timeframes. The insights derived from this comprehensive analysis of future drought projections serve as the foundation for developing policies and strategies to enhance the region's resilience against the adverse impacts of climate change.

6. Drought Management Strategies

Droughts in Sub-Saharan Africa (SSA) have significant economic, social, and environmental impacts. Various stakeholders, including governments, NGOs, and local communities, have adopted strategies to mitigate these effects. Drought adaptation measures vary significantly across regions, reflecting the unique financial capacities and resilience of different areas. These strategies include adjusting crop varieties; expanding irrigation systems [4]; and adopting coping mechanisms such as splitting herds, household migration to urban areas, and selling resources like charcoal and fuelwood [50]. Institutional support from NGOs and governments plays a vital role in providing emergency aid, veterinary services, safety nets, and credit services. In addition, government programs offer weather forecasts, livestock management training during agricultural droughts, and regular farm visits by extension officials [51]. Access to credit for crop cultivation [52], early drought detection [53], and continuous monitoring of drought conditions [54] are also essential components of effective drought management.

Additionally, the construction and rehabilitation of water management infrastructures play a crucial role. For instance, in southern Angola, the Angolan government has implemented a project in Cunene Province to divert the Cunene River to alleviate the water scarcity affecting the region's residents, livestock, and agriculture. This initiative is benefiting around 235,000 people and 250,000 livestock by irrigating 5000 hectares of agricultural land. The main canal is 47 km long, and the project includes 30 reservoirs with a water storage capacity of between 25,000 and 30,000 m^3 [55].

Farmers in the region employ various drought mitigation strategies, including migration in search of pastures and water, supplementing livestock feed with crop residues and homemade rations, and using borehole water [56]. These approaches also involve cultivating drought-tolerant crops and diversifying crop varieties [57]. To enhance comprehension of the strategies aimed at mitigating the impact of drought in SSA, Table 2 summarizes the measures proposed or implemented by governments, NGOs, and local communities. It also provides geographical context by indicating the countries where these strategies have been applied.

Table 2. Strategy to mitigate the impact of drought.

Reference	Country	Methodology	Strategy and Mitigation Measures
[50]	Ethiopia	Standardized precipitation index (SPI) of annual rainfall calculated for 35 years. A total of 216 surveys and interviews to randomly selected sample households.	Herd diversification, livestock product sales, migration, charcoal selling, water distribution, emergency aid and safety nets, livestock health training, veterinary services, credit services.
[51]	South Africa	Data collection from 207 smallholder livestock farmers and the probit model. Construction of an agricultural drought resilience index (ADRI) as an outcome variable.	Access to credit, government assistance (training, feed), and co-operative membership, funding, farm inputs, weather prediction information, livestock management training.

Table 2. *Cont.*

Reference	Country	Methodology	Strategy and Mitigation Measures
[52]	Uganda	A questionnaire-based study with 140 farmers in Isingiro district. Binomial and multinomial logistic regression models.	Food and water storage, small-scale irrigation, and access to credit.
[57]	Zimbabwe	Monthly rainfall data and questionnaires from 60 different households (surveyed between May and December 2013).	Drought-tolerant crop production, crop variety diversification, purchasing cereals through asset sales, non-governmental organizations' food aid, and gathering wild fruit.
[58]	Ethiopia, Kenya, Tanzania, Malawi, Zambia, Zimbabwe	Survey of 4351 farm households in 2018.	Diversifying income through seeking alternative employment, enhancing bolstering savings, preserving food, replanting with drought-resistant crops, optimizing food consumption, exploring alternative job opportunities, accessing credit, membership in farm associations, and agricultural training.
[59]	Ethiopia (South East)	Data collected in 2013 from vulnerable rural households. A total of 1402 households participated in this study (use of a population-proportionate sampling technique).	Consumption of less-preferred and less-expensive food, borrowing food from relatives and friends, consuming seed stock, prioritizing feeding children, searching for alternative employment, and access to agricultural credit.
[60]	Ethiopia, Tanzania, Uganda, Malawi, Zambia, Zimbabwe	Drought-tolerant maize was tested between 2007 and 2013 in experimental and farmers' fields.	The use of drought-tolerant maize.

In SSA, some regions and countries have developed and implemented drought monitoring and early warning systems (EWS). The availability of timely and easily understandable information about upcoming droughts is essential for helping stakeholders plan and mitigate the impacts. However, SSA faces significant challenges in drought planning and food security due to the lack of integrated monitoring tools, inadequate EWS, and limited information flow between countries at the governmental level. To address these issues and enhance food security, there is a need to integrate existing drought monitoring tools specifically designed for SSA. Additionally, enhancing the capacity to monitor and disseminate critical drought-related information using modern technologies such as satellites, computers, and advanced communication systems will enable timely and appropriate preventive responses. Besides supporting food security, this will also promote sustainable development in SSA [16].

Drought remains a persistent and challenging natural disaster in SSA, affecting millions of lives and livelihoods every year. In response, researchers and scientists have developed innovative drought monitoring and forecasting systems. Among the most impactful tools is FEWS NET (Famine Early Warning Systems Network), which was established to address famines in East and West Africa by providing early warnings for potential food security crises. Operating in almost all of SSA, FEWS NET monitors regions with high food insecurity risks and enhances forecasting capabilities. A key feature of the system is its use of agroclimatology data, including remote sensing, rainfall data, and climate forecasts, to monitor and project seasonal progress. This information is integrated into regular food security outlooks and reports. FEWS NET collaborates with experts from USGS, CHC, NOAA, NASA, and USDA to provide critical early warning and humanitarian response guidance, as demonstrated by Kenya's effective management of the 2016/17 drought crisis [61,62].

Two noteworthy contributions in this domain are the drought monitoring systems presented by Masinde [16] and Sheffield et al. [63]. These systems share a common goal: to monitor and forecast drought events in SSA. However, what makes them particularly interesting are their methodologies and approaches.

Sheffield et al. [63] collaborated on the development of the African Drought Monitor (ADM), which has evolved through a partnership with UNESCO's International Hydrological Program (IHP). This system incorporates statistical and dynamical climate predictions, hydrological models, and remote sensing data to provide real-time drought monitoring and seasonal forecasts. The ADM, driven by a multidimensional approach, aims to support sustainable regional development by addressing the pressing drought issue.

On the other hand, Masinde [16] introduced the ITIKI drought monitoring system, which stands for Information Technology and Indigenous Knowledge with Intelligence. This system takes a unique approach by reconciling indigenous knowledge with modern technology. It leverages mobile phones, wireless sensor networks (WSNs), and artificial intelligence (AI) to enhance the accuracy and cultural relevance of drought forecasts. Masinde's ITIKI system aims to provide culturally acceptable early warning information to communities and decision-makers in SSA, effectively mitigating the adverse effects of drought through a holistic approach. This system is operational in three countries—Mozambique, Kenya, and South Africa—where it has significantly improved agricultural productivity. In Mozambique, ITIKI has reached 2382 farmers and households, covering 17,000 ha and producing 1500 tons of food. In Kenya, the system supports 6058 farmers and households across 46,000 ha, resulting in the production of 4000 tons of food. Similarly, in South Africa, ITIKI has extended its services to 1952 farmers and households, covering 1000 ha and yielding 1000 tons of food [64].

Therefore, conducting a comprehensive comparative analysis of these two systems is essential for gaining insights into their methodologies for monitoring and predicting drought in SSA. This analysis explores various aspects such as geographical coverage, data inputs, temporal resolutions, predictive capabilities, and both the advantages and disadvantages of each system. Table 3 provides a detailed comparison of the methodologies used, highlighting the main differences. By identifying the strengths and weaknesses of each system, this effort aims to deepen the understanding of the strategies employed to combat the persistent drought challenges in SSA.

Table 3. Drought monitoring systems in Sub-Saharan Africa.

Aspect	ITIKI Drought Monitoring System	African Drought Monitor (ADM)
Methodology	Integrates indigenous knowledge with modern technology. Utilizes mobile phones, wireless sensor networks, and artificial intelligence (AI). Reconciles indigenous and scientific forecasts for enhanced accuracy.	Merges statistical and dynamical climate predictions, hydrological models, and remote sensing data. Combines historic multidecadal reconstructions, real-time monitoring driven by remote sensing, and seasonal forecasts based on climate model predictions.
Spatial extent	Focuses on Kenya, Mozambique, and South Africa.	Targeted specifically for SSA.
Data Inputs	Utilizes wireless sensors for weather data, manual rainfall data, indigenous knowledge, published weather data, and input from indigenous experts.	Relies on remotely sensed precipitation, atmospheric analysis data, satellite data on soil moisture and vegetation indices, and bias-corrected climate model forecasts.
Temporal Resolution	Provides forecasts at different temporal resolutions, including short-term (a few hours to two weeks) and longer-term.	Offers real-time monitoring (2009-present) and seasonal forecasts extending up to 6 months.

Table 3. *Cont.*

Aspect	ITIKI Drought Monitoring System	African Drought Monitor (ADM)
Monitoring and Forecasting	Uses output of the Effective Drought Index (EDI). Artificial Neural Networks (ANNs) predict future values of drought indices. Fuzzy Logic System monitors and forecasts droughts using indigenous knowledge.	Uses the VIC Land Surface Hydrologic Model, statistical and process-based crop yield models. Data from TRMM, GFS, and other sources are bias-corrected and downscaled for accurate forecasting.
Advantages and Disadvantages	Culturally relevant, locally accepted, and resilient due to the integration of indigenous knowledge. Affordable, sustainable, and effective.	Provides timely and useful information on drought. Merges historical data, real-time monitoring, and seasonal forecasts.
	May require manual reconciliation for longer-term forecasts.	Relies on satellite data and bias-correction methods for climate model forecasts.
Operational Use	Aims to provide early warning information to communities and decision-makers in Sub-Saharan Africa.	Evolved in collaboration with UNESCO's International Hydrological Programme (IHP) and supports sustainable development in the region.

7. Discussion

7.1. Implications of Drought Dynamics

Droughts in SSA result from a dynamic interplay between natural atmospheric phenomena, such as El Niño, and human-induced factors like desertification and land degradation. This complex relationship significantly heightens the region's vulnerability to drought, posing substantial challenges to sustainable development efforts across the continent. The severity and impact of droughts are magnified by this interplay, affecting vast areas and multiple sectors [1,65].

Droughts are the most prevalent disasters in Africa, accounting for over 88% of all disasters that occur on the continent. Their reach extends far beyond physical scarcity, affecting the societal fabric and livelihoods with devastating consequences. The region's history is marked by numerous severe and prolonged droughts, particularly during the 1970s, 1980s, and early 2000s, highlighting a longstanding vulnerability to such climatic extremes [17].

Data from 1960 to 2007 show an alarming increase in the frequency and intensity of droughts, contributing to escalating food and water insecurity. This trend is particularly concerning given the region's dependence on climate-sensitive sectors like agriculture, hydro-energy, and fisheries, which amplifies the susceptibility to humanitarian crises during drought periods [66].

7.2. Drought Intensity and Trends

From 1980 to 2012, SSA experienced numerous severe to extreme drought periods. Notably, between 1982 and 1984, droughts were nearly universal across the region. Southern and western African regions faced severe to extreme drought conditions in 1987, while central and southern African countries encountered similar situations between 1992 and 1995. Despite these challenges, the last decades have seen southern and central Africa experiencing relatively regular rainfall periods, although the threat of drought remains ever-present [66].

The Congo Basin's exposure to prolonged and severe droughts during the early 20th century and again between 1991 and 2014 illustrates the diverse temporal and spatial distribution of droughts across the region. Furthermore, countries like Ethiopia have faced severe droughts in recent years, with events recorded in 2002, 2004, 2009, 2015, 2016, and 2017. This highlights the varied impact of droughts within SSA, affecting countries differently based on geographic and climatic conditions [23,67].

An analysis of historical droughts reveals the severity and widespread nature of these events, with significant portions of the region experiencing extreme drought conditions. Countries such as Burkina Faso, Ghana, Togo, Mali, Benin, and Ivory Coast have all faced substantial drought challenges, emphasizing the need for comprehensive strategies to address this recurring issue [68]. The Horn of Africa, northern Kenya, and most of Sudan also experienced rainfall significantly below normal levels between 2008 and 2011, worsening the region's already challenging climate conditions [69].

The need for robust and proactive interventions is underscored by the recurring nature of droughts and their far-reaching impacts. The negative repercussions on food production, water resources, and livelihoods of millions necessitate strategic measures to mitigate the ensuing humanitarian crises [8,9,70].

Grasping the historical patterns of drought is essential for devising effective strategies to adapt and mitigate their impacts, as [70] highlighted. With SSA being the most vulnerable region to droughts [71], the expected rise in their frequency and intensity poses significant threats to food and water security and may even escalate conflicts, necessitating immediate action [71]. The recurrent nature of droughts, striking every three to four years, emphasizes the urgency of developing comprehensive strategies. These strategies should not only focus on crisis management but also tackle the underlying causes of vulnerability, particularly in communities dependent on rain-fed agriculture [65,72]

The region experiences droughts more frequently than anywhere else in the world, yet the current mitigation approaches offer limited quantitative data and insufficient lead time for decision-making, hindering an effective drought intervention [73]. Moreover, the economic and social impacts of drought penetrate deeply into the well-being of communities, leading to survival strategies that increase vulnerability to diseases, such as transactional sex, which underscores the urgent need for improved response mechanisms [10]. Addressing and mitigating drought impacts in vulnerable areas is imperative, calling for adaptive strategies to support a growing population amidst the challenges of climate change [3].

In addition to physical and economic strains, droughts also profoundly affect individuals' psychological well-being. Emerging research indicates a spectrum of mental health issues linked to climate extremes, namely post-traumatic stress disorder (PTSD), depression, and anxiety [6]. These mental health issues, although difficult to quantify, carry significant long-term societal and intergenerational consequences, highlighting the multifaceted nature of droughts [7,74].

7.3. Drought Adaptation

Drought represents a significant challenge to societies across Sub-Saharan Africa, primarily because most of the population relies on rain-fed agriculture and traditional water systems for their subsistence, making them highly vulnerable to water scarcity during droughts [3]. Recognizing this critical need, a variety of adaptation and mitigation strategies have been developed within the region. Central to these efforts is the enhancement of drought monitoring and early warning systems. Integrating existing tools is crucial for strengthening food security measures, thereby mitigating the adverse effects of drought and preventing famine [75].

Moreover, leveraging modern technologies such as satellite imagery, computing, and advanced communication methods is key to enhancing the dissemination of vital drought-related information. This approach not only facilitates timely and effective preventive actions but also supports the broader goals of food security and sustainable development in SSA [75]. Furthermore, there is a growing emphasis on combining traditional knowledge with scientific forecasting techniques in drought early warning systems, aiming to create a more resilient and responsive strategy to anticipate and combat drought conditions [16].

Effective strategies to improve food security and reduce vulnerability among rural households include the adaptation of agricultural practices, the adoption of irrigation techniques, and the introduction of drought-tolerant crops [57,60]; such measures, tailored to meet the specific needs and priorities of local communities, are essential for building resilience against the impacts of drought and hunger [59].

The diversity of coping strategies reflects the varied impacts of drought, which differ significantly by country and region within SSA. A comprehensive review of these strategies and their limitations, as summarized in Table 4, highlights the importance of a multifaceted approach to effectively mitigating the effects of drought across the region.

Table 4. Drought mitigation strategies and their challenges in Sub-Saharan Africa.

Category	Adaptation Strategy	Description of Adaptation Strategies	Challenges and Barriers to Mitigate Drought
Agriculture	Drought-tolerant crop production	Adaptation of agricultural practices, implementation of irrigation systems, and encouraging livelihood diversification. Provision of agricultural credit and cultivation of drought-resistant maize varieties. Cultivation of drought-tolerant crops, diversification of crop varieties, and securing cereals through asset sales Migration in search of water and pastures, supplementing diets with crop residues and homemade rations, and relying on borehole water [4,56,57,60].	High costs and maintenance demands of agricultural adaptation and irrigation systems are difficult to meet by small-scale farmers. Effectiveness of measures is compromised by water scarcity and distribution issues. Livelihood diversification requires access to skills and resources not available in all communities. Agricultural credit, essential for adopting new practices, is limited in reach. High costs and scarcity of drought-resistant seeds hinder their widespread use. Reliance on crop residues for food can affect long-term nutritional health and soil fertility. Use of borehole water requires considerable investment and careful management to avoid depleting groundwater resources.
Community-Based Adaptation	Casual labor	Migration for employment and alterations in family dynamics. Households may sell livestock or engage in food-for-work initiatives. Community members resort to casual labor and charcoal production as sources of immediate income. The economic strain forces young children into labor and drives young girls to early marriages due to the inability to afford educational expenses. Men leave for prolonged periods to seek employment in construction or other sectors, sometimes relocating to regions with better rainfall for more viable farming, thereby providing financial support to their families from afar. Reliance on non-governmental organizations for food assistance and foraging for wild fruit becomes essential survival tactics [4,57,72].	Migration may result in overcrowding and increased competition for resources in more agriculturally productive regions. Early marriages and child labor disrupt education and future prospects. Selling livestock reduces long-term agricultural productivity. Casual labor or food-for-work programs may distract from essential agricultural activities, impacting future food security. Charcoal production worsens environmental degradation. Reliance on NGO food aid, risks creating dependency and undermining local agriculture. Foraging for wild fruit underscores the critical lack of reliable food sources, highlighting these strategies' unsustainable nature in addressing drought's challenges.

Table 4. *Cont.*

Category	Adaptation Strategy	Description of Adaptation Strategies	Challenges and Barriers to Mitigate Drought
Technology and Innovation	Drought monitoring and early warning systems	Implementation of advanced drought monitoring and early warning systems to mitigate drought effects. These systems track key indicators (e.g., soil moisture, precipitation, and vegetation), provide drought indices normalized against historical records, and forecast drought risks months in advance. Information Technology and Indigenous Knowledge with Intelligence—a novel approach that integrates technological solutions with indigenous knowledge (IK) to enhance early drought detection and response strategies. This method underscores the importance of local wisdom in observing natural cues for drought prediction [16,53,63,76,77]	Drought monitoring systems face critical challenges in accessibility due to limited data acquisition capabilities and language barriers. Many regions, especially rural areas, suffer from a lack of comprehensive coverage by meteorological and hydrological stations, compounded by the destruction of infrastructure through armed conflicts. Predominance of English in disseminating information fails to accommodate the linguistic diversity of the region, hindering the effective use of these systems by local communities at greatest risk. Low utilization rates and the overlooking of at-risk communities.

The strategies adopted in SSA to fight drought are vital but underscore the multifaceted challenges involved, including financial, technical, and socio-economic obstacles. Addressing these issues necessitates a comprehensive strategy that combines policy reform, capacity building, and the creation of sustainable, community-centric solutions aimed at bolstering the long-term resilience of the region's agricultural frameworks. The difficulties families encounter in drought-afflicted areas highlight the critical need for holistic, sustainable interventions that tackle both the direct effects and root causes of drought. Such an approach demands enhancements in educational access, adoption of sustainable agricultural methods, expansion of economic opportunities, and reinforcement of environmental conservation efforts to build resilience against future drought occurrences.

A concerted effort to bridge data gaps and language disparities is essential to improve the utility of drought monitoring and early warning systems across SSA. Initiatives to create multilingual platforms and streamline data presentation will render these systems more user-friendly and broadly accessible. Moreover, marrying indigenous knowledge with scientific research can elevate the pertinence of these systems while engaging local communities directly in drought response activities. Overcoming these hurdles requires collaborative endeavors from government bodies, NGOs, and the international community, underscoring the importance of investing in inclusive, flexible, and locally tailored drought management strategies.

8. Conclusions

In conclusion, drought continues to be the most prevalent natural disaster in Sub-Saharan Africa, contributing to a wide range of socio-economic and health challenges. The increasing frequency and severity of droughts have resulted in severe agricultural losses, water scarcity, livestock deaths, and rising food prices. These effects have led to mass emigration, especially among the youth, exacerbating the region's economic and social fabric.

Drought also profoundly affects health, covering a wide range of impacts, from economic repercussions to direct effects on human well-being. In SSA, drought contributes to child malnutrition, mental health issues, the spread of HIV/AIDS, and outbreaks of waterborne diseases such as cholera. These health crises worsen the vulnerability of already fragile communities.

Droughts have profoundly impacted agriculture, particularly in rain-fed farming areas, leading to crop failures and declining yields. The study highlights that while various mitigation strategies such as drought monitoring systems, crop diversification, and community-based adaptation methods have been introduced, some of these approaches, like charcoal production and migration, may worsen long-term environmental and social challenges. Practices like early marriage and water sharing between humans and animals exacerbate current disparities, especially among vulnerable populations.

As drought projections for SSA indicate worsening conditions due to climate change, population growth, and land degradation, it is crucial to focus on strengthening adaptation strategies. This includes expanding drought-resistant crop adoption, improving irrigation infrastructure, and promoting sustainable land and water management practices.

The findings highlight the need for a holistic, integrated approach to mitigate the multifaceted consequences of drought in SSA. By stimulating resilience through improved agricultural techniques, water conservation, and socially equitable policies, the region can better navigate the growing challenges posed by climate extremes.

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