CASE STUDIES

A Review of the Impact of Climate Change on Water Security and Livelihoods in Semiarid Africa: Cases From Kenya, Malawi, and Ghana

Dinko Hanaan Dinko[1] **and Ibrahim Bahati**[2]

[1]Department of Geology and Geography, Mount Holyoke College
[2]Human Sciences Research Council, South Africa

Keywords: water security, climate change, semiarid, Africa, political economy

ABSTRACT

Within semiarid Africa, precipitation is the most important hydrological variable upon which livelihoods are carved since it determines the cycle of rainfall and water security needed for agriculture. However, research shows that climate change has largely altered that. This article critically reviews the extensive literature on climate-water-livelihoods in semiarid sub-Saharan Africa, highlighting the common threads that underlie them. By comparing three cases in three different regions (Ghana for West Africa, Kenya for East Africa, and Malawi for Southern Africa), this article provides a basis for cross-comparison and a framework for understanding the impact of climate change on water security and livelihoods in semiarid Africa. A cross-country, cross-region comparison of the impact of climate change on water security is essential for long-term and medium-term preparedness for adaptation to climate-induced water insecurity. Crucially, this calls for a renewed focus on the synergies between climate change and social, ecological, political, and economic factors, which have often been ignored in the water insecurity and climate change discourse on semiarid areas.

INTRODUCTION

Water resources in Africa's semiarid regions have come under pressure over the last 4 decades, to warnings of reaching near "dangerous levels of water stress" (World Bank, 2022). Due to climate change, water insecurity in Africa and beyond has brought an existential debate about water ethics in terms of use, access rights, and sustainability (Groenfeldt, 2019). Water insecurity includes elements of water scarcity where the water demand exceeds water availability and lack of access to safe water supplies (Matchawe et al., 2022). Swelling urban growth, environmental degradation, and anthropogenic pollution continue to limit access for large populations in the region (Kahn, 2009). With livelihoods in semiarid Africa carved around rainfed agriculture, the impact of climate change and variability on food and income security remains uncertain, putting the discourse of water insecurity into the greater hydropolitics of water (Hellberg, 2018). For example, Kankam-Yeboah et al. (2013) have projected a 50% decrease in streamflow in the Volta Basin by 2050. Similarly, Barron et al. (2015) have discussed how agricultural water management interventions for smallholders in the Volta and Limpopo basins could be best utilized to build resilience against climate change. The impact of climate change on floods and droughts in terms of vulnerability and disaster risk reduction in the northern savannah has been explored (Armah et al., 2010; Douxchamps et al., 2014;

an open access journal

Citation: Dinko, D. H., & Bahati, I. (2023). A Review of the Impact of Climate Change on Water Security and Livelihoods in Semiarid Africa: Cases From Kenya, Malawi, and Ghana. *Journal of Climate Resilience & Climate Justice*, *1*, 107–118. https://doi.org/10.1162/crcj_a_00002

DOI:
https://doi.org/10.1162/crcj_a_00002

Supporting Information:
https://www.webofscience.com/wos/woscc/summary/9467d6e0-2549-40bc-9e76-89fdc0b08c72-596a127d/relevance/1

Corresponding Author:
Dinko Hanaan Dinko
hanaandinko.dinko@du.edu

The MIT Press

Poussin et al., 2015). While these are important in the climate-water-livelihoods discourse in semiarid Africa, they tended to be basin-specific (Abubakari et al., 2017; Kankam-Yeboah et al., 2013; Mahe et al., 2013; Niasse, 2005; Oyebande, 2013), model-oriented (Faramarzi et al., 2013; Muller, 2009; Nyadzi et al., 2018; Roudier et al., 2014; Thomas & Nigam, 2018), or subregion focused (Barry et al., 2018; Callo-Concha et al., 2013; Oyebande, 2013; Paeth et al., 2008; Yaro & Hesselberg, 2016).

Transcending these gaps, this article provides a rapid review of the climate-water-livelihoods literature in semiarid sub-Saharan Africa, highlighting the common thread that underlies them. The article first looks at individual case analyses of how Ghana, Kenya, and Malawi are dealing with climate-water-insecurity, followed by cross-comparison in understanding the impact of climate in semiarid Africa. The article aims to highlight how climate change and water insecurity are urgencies of both nation-states and regions, calling for short and long-term adaptation and preparedness to climate-induced water insecurity.

Furthermore, water security issues need to be tied to the greater debate on the political economy of tackling climate change (Fritz et al., 2021), including adaptation (Sovacool & Linnér, 2016), framing, and knowledge dissemination (Armstrong et al., 2018), and understanding the relationship between climate change and capital accumulation (Xie & Cheng, 2021). Developing countries, including those in semiarid Africa, have been the least contributors to climate change, yet still operate in the confines of the managerial climate change policy approach from the Global North (Arnall et al., 2014), including talks of “just transitions” (Newell & Mulvaney, 2013) to green economies. The political economy of climate change here deals with nuances between the social and political processes on how water insecurity has affected livelihoods and created urgencies of disaster preparedness in semiarid Africa.

METHODOLOGY

We conducted a rapid review of the literature on climate change and water security in the three countries. Unlike a systematic review, a rapid review does not require a double review of each paper. Additionally, a rapid review limits analysis to only the papers from the queried results database. Although it is less systematic, rapid reviews provide well-timed and data-informed contextualized summaries of the literature for policymakers to address evolving issues quickly (Kerr et al., 2022; Khangura et al., 2012; Sharpe et al., 2017), while shaping ongoing scholarly discourse. We conducted a systematic search in Web of Science using Boolean operatives and keywords as shown in the Supporting Information. Using the search criteria, 1,150 papers were refined further to journal articles, reviews, and book chapters. This process generated 1,030 papers (see the Supporting Information for details). The 1,030 papers were screened for contextual relevance, subject relevance, and credibility (see Figure 1). We used two main criteria to determine the credibility of papers. First, papers were deemed credible if methods, data, and conclusions logically flow into each other. Second, the papers were deemed credible if they were not published in journals on Beall’s List (Beall, 2022).

After screening for relevance, 154 papers were meticulously reviewed, and 84 ended up being used in the article. The 84 papers were then categorized into the three case studies and read immersively to allow key themes of differences and similarities to emerge. In addition, eight *grey literature* sources from government and the World Bank were included in this article to provide relevant contextual data for the three countries (see Table 1). We included all studies from 1990 to 2021 that addressed the relationship between climate change, water security, and impacts on livelihoods in the three countries. Papers that did not explicitly examine the intersections of climate change impacts on water insecurity and livelihoods were excluded.

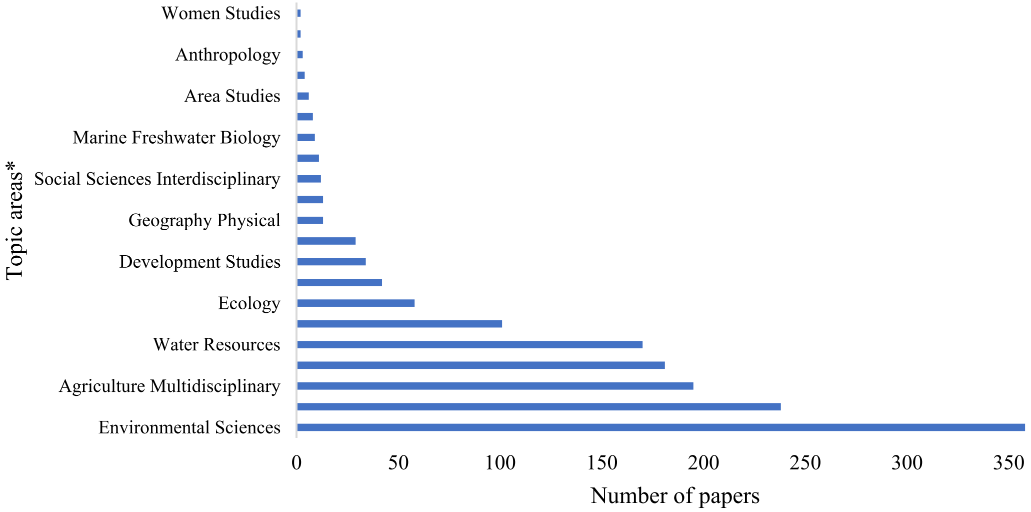

Figure 1. Summary of refined Web of Science database search. *Some papers are cross-listed across disciplines. Generated from Web of Science at Clarivate Query.

CASE STUDIES

The following subsections show how climate change has altered the cycle of rainfall and caused water insecurity in semiarid Africa. It presents literature by case analysis in the three countries, highlighting the trajectory of climate change evidence, projections on water insecurity, and regional implications on livelihoods.

Kenya Case Study

In Kenya, agriculture remains the main driver of economic growth and employs more than half of the labor force, which is reliant on the availability of water. The importance of agriculture is reflected in the fact that in 2017, agriculture contributed to 65% of merchandise exports (Wankuru et al., 2019). With 80% of the landmass being semiarid and less than 2% of arable land under irrigation (Mogaka et al., 2006), Kenya's economy is particularly vulnerable to climate change and variability. Compared to neighboring Tanzania and Uganda with 2,940 and 2,696 cubic meters of water per capita per year, respectively, Kenya has just about 1,700 cubic meters per capita per year (Wankuru et al., 2019). This makes Kenya a *water-scarce* country under the United Nations (UN) water classification system (UN-Water, 2013). The hydrology of Kenya is largely governed by the rainfall regime as there are very few transboundary rivers in Kenya. It is also determined by the movement of the Intertropical Convergence Zone (ITCZ), which produces two rainfall seasons and two dry seasons. The ITCZ has been disrupted largely

Table 1. Summary of Web of Science Searches and the Number of Papers Reviewed

Search type	Number of papers
Refined search count	1,150
Papers screened	1,030
Papers reviewed	154
Papers cited from the search	84
Grey literature outside of the search	8

by climate change. This is acknowledged by the government of Kenya, which asserts that the country is generally experiencing a warmer temperature trend over the past 5 decades (GoK, 2013). In addition, Nicholson (2016) reports a decreasing rainfall over the semiarid areas in Kenya since the 1970s. Nicholson (2014) further demonstrates that during the 2008–2011 drought in the Horn of Africa, rainfall in northern Kenya was 50–70% below normal seasonal rainfall the decade earlier.

Additionally, drought in Kenya is often driven by La Niña. With multiple consecutive years of droughts, a result of poor rains and dry spells over the past decade, there has been little to no recovery among affected households whose livelihoods are determined by the rhythm of the climate. This puts pressure on existing water resources and thus brews competition for access, control, and use rights to water bodies. In a region characterized by instability and uncontrolled arms circulation, such contestations have often resulted in violent armed conflicts (Dinko, 2022). In semiarid northern Kenya, Witsenburg and Adano (2009) have argued that rainfall does not just determine water availability, but it determines pasture, crop yields, and milk availability. As the water gets scarcer during drought seasons, pressure on shallow wells increases, and the propensity of people to fight for access similarly escalates. Beyond tensions in social relations, droughts have a significant impact on food and livestock production. For instance, the 1990/2000 drought resulted in a decline of one million tons in maize production (GoK, 2013). Such steep declines in a major food staple such as maize have had a knock-on effect on the prices of food, leading to nationwide food insecurity protests recently in July 2022 ("About 3.5 million Kenyans Facing Food Insecurity—WHO," 2022). Like the food crop sector, livestock production has suffered significant losses in drought years (Barrios et al., 2010; Hope et al., 2012; Mogaka et al., 2006; Sutherland et al., 1991).

Water insecurity resulting from climatic change and variability does not just manifest in droughts but also in floods. While floods may not be as frequent as droughts in Kenya's semiarid regions, their devastating impact cuts across key sectors of the economy. The flooding regime in Kenya is often associated with the onset of the El Niño warming effect on the tropical pacific region (Barrios et al., 2010; Dunning et al., 2018; Gebrechorkos et al., 2019; Otieno & Anyah, 2013; Nicholson, 2014). Unlike droughts whose onset is slow, and whose response could be planned, flash floods are often sudden, and in semiarid Kenya where there is little investment in climate science, floods can be devastating. Opere (2013, p. 13) reports that the 1997–1998 floods in Kenya "caused some US$151.4 million in public and private property damage" and several hundreds of lives lost. Aside from damage to life and infrastructure, floods also pose a significant threat to public health. Mogaka et al. (2006) show that after the 2003 floods, there was a 60% rise in waterborne diseases and a 32% increase in malaria cases. Wakeford (2017) notes that food and health security are not the only casualties of droughts in Kenya. With 35% of its energy needs dependent on hydroelectricity, the ramifications of droughts reverberate beyond food and ecosystem security to the entire economy (Karekezi et al., 2009; Wakeford, 2017). In 2018, the Sondu Miriu Hydroelectric Power Station with an installed generation capacity of 80 megawatts could only generate 10 megawatts (Gebrechorkos et al., 2019). Such a sharp reduction in generating capacity limits economic growth, which in turn has chain effects on well-being and human development in the long run.

Malawi Case Study

In Malawi, climate change poses a significant threat to the economic growth and livelihoods of poor and vulnerable populations. The vulnerability of Malawi to climate change emanates from the fact that agriculture, which supports the livelihoods of 80% of Malawians, is rainfed

(Arndt et al., 2019). In addition, Malawi's industrial front is predominantly agrarian, hence the entire economy is immensely vulnerable to the forces of climatic change. Malawi ranks 171 out of 189 on the league of wealth and poverty nations with a Human Development Index (HDI) of 0.477 (African Development Bank, 2018). Although its HDI increased by 40% between 1990 and 2017, more than half of the population (50.7%) live below the poverty line, while a quarter (25%) are chronically poor (United Nations Development Programme [UNDP], 2021). With more than 90% of the population dependent on rainfed agriculture, climate extremes as manifested in droughts and floods could significantly erode yields and consequently food security. Joshua et al. (2016) indicate that over 15% of Malawians were affected by the 2012/2013 flooding, translating into 2.31 million people in need of food and associated aid while 176 people were killed and a quarter of a million people were displaced.

With climate change expected to increase the frequency of weather extremes, the other climatic threat (besides floods) Malawi is expected to witness is droughts. Observed temperatures over Malawi in the past 50 years indicate an increasing trend of about 0.21°C per decade (Msowoya et al., 2016; Vizy et al., 2015). Nicholson et al. (2014) report a 1°C increase in temperature between 1960 and 2006. While there is a clear trend in temperature increases, the rainfall trend is less clear. Mughogho (2014), for instance, finds that farmers perceived a decreasing amount of rainfall with increasing within-season variability. Ngongondo et al. (2011) similarly report that increases in evaporation losses between 1971 and 2000 have led to a decreased runoff. When taken together, increased temperature and declining rainfall mean that Malawi has experienced less than the usual amount of water. This projection toward a hotter and drier climate is not limited to Malawi, but rather stretched to the whole of the Southern African region as per Intergovernmental Panel on Climate Change (IPCC, 2013), noting a likely increase of 5°C by the end of the century. This is similar to what Mariotti et al. (2013) suggest, that Malawi and other countries with a single rainy season will experience a delay in the onset of rains and when rains start, long dry spells will likely be common. In the context of Malawi, where the population growth rate is about 3% (African Development Bank, 2018), this could mean food insecurity and pressure on water resources in the face of a burgeoning population. For instance, Asfaw et al. (2015) suggest that maize production, the predominant food crop accounting for 70% of cropped land in Malawi, has been erratic due to a combination of climate change and other nonclimatic factors, including low technology uptake.

Finally, the food insecurity and poverty situation outlined above essentially highlights water availability or lack thereof (as manifested in floods and droughts) and its impact on agriculture output. De Wit and Stankiewicz (2006) contend that increasing temperature and a concomitant decline in rainfall could lead to a 10% drop in river flow in the Zambezi basin, which covers much of Malawi. This will have a direct impact on water availability for drinking, agricultural use, and hydroelectric power generation in Malawi. Similarly, Kumambala (2010) finds that water levels in Lake Malawi will decline due to increasing droughts and evaporative loss from warmer temperatures. With 92% of Malawians having access to water mainly through surface water sources, which are rain-dependent, changes in precipitation could increase the water insecurity situation.

Ghana Case Study

Surface water is crucial to agriculture and power generation in Ghana's semiarid region. Climate studies have increasingly indicated rainfall, the source of water upon which surface water sources depend, is decreasing in semiarid Ghana. For instance, Nicholson et al. (2000) reports a reduction of 15 to 40% in rainfall over 30 years (1968–1997) across semiarid

West Africa. These findings are consistent with assertions by Owusu and Waylen (2009) that the total amount of rainfall in northern Ghana has declined since the 1960s. The Government of Ghana's assessment of climate change further acknowledges that Ghana has experienced about a 1°C rise in temperature and a 20% overall reduction in rainfall since 1980 (U.S. Environmental Protection Agency [EPA], 2000). The above findings have been contested by Antwi-Agyei et al. (2017) and Appiah (2019) who observe an improvement in rainfall in recent years, albeit that the recovery has been in the southern forested areas of Ghana. While these contending findings are useful for academic debates, they both use mean annual temperature and rainfall, which may not be relevant because they fail to show within-season variability. In semiarid Ghana, what is important is rainy season variability. It is the unpredictability of seasonal variations that have serious implications on crop production and water insecurity issues. In other words, farmers' experiences of climate are not in annual averages, but crucially the distribution of rainfall during the rainy season, which has implications on staple crops and water security outcomes for households.

Generally, an overwhelming majority of local climate models in semiarid Ghana point to drying trends, where semiarid areas such as Ghana will get drier, while the wet tropical forest regions will get wetter. A key proponent of the drying thesis is reported by Amadou et al. (2018), who projects that the mean daily temperature over Ghana will increase by between 2.5°C and 3.2°C, while rainfall is expected to decline by 9 to 27% by the end of the century. This scenario is consistent with observations that rainfall has generally declined over the last 50 years in West Africa due to the long-term general southward shift of the migration of the ITCZ (Dickinson et al., 2017).

Changes in rainfall translate into food and water security challenges. In Ghana's semiarid region, there is growing evidence that the impacts of climate change will significantly alter the water security cycle with debilitating consequences on food security and poverty reduction and undermine adaptive capacity (Dinko et al., 2019; Nyantakyi-Frimpong & Bezner-Kerr, 2015; Yaro, 2013). According to Ghana's *Third National Communication Report to the UNFCCC*, observed historical minimum temperatures have increased by 2% in the south (rainforest, coastal agroecological, deciduous, and transition zones) and 37% in the north (Guinea and Sudan savannah zones) (Amlalo & Oppong-Boadi, 2015). When taken together as a geospatial unit, the average rate of climate change may present modest changes in Ghana. However, this picture is misleading as it masks wide spatial variation of observed and projected climatic changes.

Like observed and projected temperature changes, rainfall decline is greater in the Sudan Savannah than in any other agroecological zone. Because agriculture is almost exclusively rainfed coupled with limited diversification of livelihood options, the decline in rainfall has the potential to offset large-scale multiple shocks to the Ghanaian economy. The combined ramifications for national security could be dire.

Linking climate change with ongoing demographic and agricultural land expansion in semiarid Ghana highlights the scope and nature of future vulnerability to climatic shocks and stress. Grazing land and livestock production (which is predominant in semiarid Ghana) are vulnerable to climate change for three plausible reasons. First, decreasing precipitation and increasing evaporation due to rising temperatures in semiarid regions could potentially reduce the primary productivity of grazing land and accompanying livestock carrying capacity. Second, prolonged droughts could directly lead to the loss of herds. The third reason is a loss of biomass. Repeated and prolonged drought could decimate the capacity of soil to regenerate sufficient biomass to sustain growing livestock. This may leave the soil unable to recover even during wetter periods.

Beyond climate impact on agriculture, the effect of a changing climate on water bodies in semiarid areas presents a significant threat to livelihood security. Studies by Alcamo et al. (2003), Ojo et al. (2004), and Riede et al. (2016) forecast that by the year 2050, rainfall in West Africa will decline by 10%, prompting major water shortages. They further reason that the 10% decrease in precipitation would translate into a 17%–20% reduction in runoff, while semiarid regions such as semiarid Ghana may experience a reduction of 50%–30%, respectively, in the surface drainage. With a population growth above 2.7% (Bongaarts & Casterline, 2013; Yansaneh, 2005), competition and pressure on water resources could double within this same period in the Sudan Savannah. This could lead to a decline in agricultural production and significantly affect food inflation, thus affecting food availability, access, and stability. The northern savannah belt faces an even more serious dilemma. The region is already experiencing a decline in soil fertility, declining yields, and environmental desertification. Declining precipitation could exacerbate these stresses and throw poverty reduction efforts out of gear.

Comparative Analysis of the Three Countries and Key Takeaways

This literature review examined the intersections of climate change and water insecurity in semiarid Africa using Kenya, Malawi, and Ghana as case studies. In three cases, there is growing evidence that climate change has negatively impacted water security, and the trend is projected to continue. The predominance of rainfed agriculture coupled with the fact that agriculture remains the largest single employer in all three countries particularly make them sensitive to climate change and variability. The sector accounts for roughly 40% of employment in Kenya and Ghana and about 80% of employment in Malawi (Wankuru et al., 2019). Intersecting with high dependence on rainfed agriculture is low human development, which explains the low autonomous and institutional adaptive capacities.

While the above shows similarities among the three cases, there exist some differences that must be highlighted. Generally, while Kenya and Ghana are expected to endure increasing temperatures and a simultaneous decline in rainfall, Malawi is expected to receive a modest increase in rainfall overall with associated floods. Malawi, however, is expected to endure the greatest temperature increase of all three cases, as Table 2 shows.

Table 2 shows both the observed and projected changes of climate change in Kenya, Malawi, and Ghana from the likelihood of turning into extreme events and the most likely impact it will cause on water security and livelihoods. In all three countries, we observe that there has been an increase in temperatures by 1°C from the 1980s to the late 2000s. However, by the end of the century, there is a projected increase in temperature of 3.2°C for Ghana, 4.5°C for Kenya, and 6°C for Malawi, leaving Kenya and Malawi more susceptible to intense droughts and floods, heatwaves, and severe droughts than Ghana. Also, Kenya and Malawi will experience more water stress in terms of evaporation losses and unpredictable rainfalls, aggravating food production and livelihoods more than Ghana. The FAO AQUASTAT (2022) data in Figure 2 further shows that from 1995 to 2019, the percent of people in Kenya who have become water stressed has increased from 14.8% to 33.2%, followed by Malawi (12.7% to 17.5%) and Ghana, which has moved from 3.7% to 6.3% of people who are water stressed.

In semiarid Kenya, climate-induced water insecurity has led to violent armed conflicts over water resources. Prolonged droughts have plunged millions of people into hunger necessitating a declaration of a humanitarian crisis over the Horn of Africa[1]. Violent

---

[1] The Horn of Africa consists of Somalia, Djibouti, Ethiopia, Eritrea, and Kenya. Eastern Uganda is sometimes added.

Table 2. Summary of the Nature of Climatic Changes in the Three Case Studies and Implications on Water Security

Country	Observed Changes in Climate	Projected Changes in Climate	Likelihood of Extreme Events	Impact on Water and Related Issues
Kenya	Mean temperature increased by 1°C from 1960 to 2009 and coincides with an increased frequency of extreme droughts and floods since the mid-1970s (Nicholson, 2014; Opere, 2013).	A projected increase of 4.5°C in average temperature by the end of the century (Gebrechorkos et al., 2019; Nicholson, 2014; Otieno & Anyah, 2013).	There will be an increase in the frequency and intensity of droughts and floods (Barrios et al., 2010; Hope et al., 2012; Mogaka et al., 2006; Sutherland et al., 1991).	Rising temperatures and associated evapotranspiration rates will negatively impact water availability (Barrios et al., 2010; Nicholson, 2014; Otieno & Anyah, 2013).
Malawi	The observed increase in temperatures of 0.9°C between 1960 and 2006 led to a decrease in the freshwater runoff to Lake Malawi and the Zambezi River Basin over the period 1971–2000 (Msowoya et al., 2016; Vizy et al., 2015).	It is projected that by the end of the century, the average temperature will rise between 5°C and 6°C (Ngongondo et al., 2011).	Increased heat waves, droughts, and heavy rains are becoming more common (Joshua et al., 2016; Mariotti et al., 2013; Mughogho, 2014).	Rising temperatures, evaporation losses, and changes in rainfall are increasingly leading to water stress (Asfaw et al., 2015; de Wit & Stankiewicz, 2006; Kumambala, 2010).
Ghana	Ghana has experienced about a 1°C rise in temperature and a 20% overall reduction in rainfall since 1980 (EPA, 2000; Nicholson et al., 2000).	Projected increase of average temperature to be between 2.5°C and 3.2°C by the end of the century (Amadou et al., 2018; Dickinson et al., 2017).	Increased frequency and length of drought are expected (Owusu & Waylen, 2009; Antwi-Agyei et al., 2017; Appiah, 2019).	Water scarcity issues that will compromise food and livestock production (Bongaarts & Casterline, 2013; Yansaneh, 2005).

conflicts over water resources in semiarid Kenya have thrust to the fore the role of water insecurity in exacerbating existing societal tensions. It also shows how already fragile societies can further disintegrate under the threat of climate-induced water insecurity. In comparison to Ghana and Malawi, climate-induced water insecurity has not led to violent

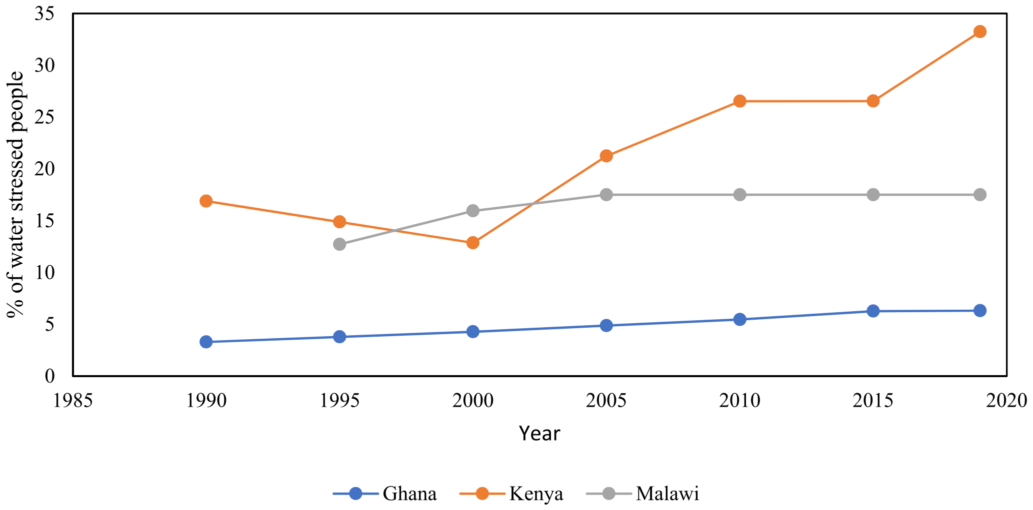

Figure 2. Percentage of water-stressed people in Ghana, Kenya, and Malawi from 1990 to 2019. Compiled from FAO AQUASTAT (2022).

armed conflicts, albeit anecdotal evidence suggests there are growing contestations in semiarid Ghana for access to and control over water for dry season farming and rearing of animals.

CONCLUSION AND RECOMMENDATIONS

This article reviewed the literature on the nexus of climate change and water security in semiarid Africa, focusing on three cases from Kenya, Malawi, and Ghana. It has highlighted the nature and extent of climatic changes and how these changes intersect with water security in semiarid Africa. Generally, while climate change is driving water insecurity in semiarid Africa, the literature confirms that the preexisting socioeconomic conditions have exacerbated their vulnerability. Through a comparative analysis of the three countries, the review of the literature shows that there are synergies between climate change and social, ecological, political, and economic factors that have often been ignored in the water insecurity and climate change discourse in semiarid areas. There is an urgent need to examine the contestations arising from multiple and competing uses of surface water and how policy engagements can bring fair regulation of access outcomes. Again, with climate-induced water insecurity likely to increase, sufficient knowledge is needed to understand how internal functions of language, culture, and politics continue to determine who gets access rights to water. Sufficient knowledge is also necessary to understand how differences in social inequalities are reproduced and the ways societies are coping in times of water insecurity crises.

This review of the literature highlights the need for capacity building to achieve adaptation and mitigation processes that equip different stakeholders (including nation-states, businesses, and local people) in building sustainable and climate-resilient water systems. Smallholder farmers should be empowered to anticipate and respond robustly to climate change–induced water insecurity without losing their basic access to water for household and agricultural needs (Adger, 2006; Cutter et al., 2003; Dixon & Stringer, 2015). This can be achieved through agroecology (Woodgate, 2016) and a participatory approach where key issues of land rights, labor, gender, and food security are part of the programming (Bahati et al., 2022) as agrarian change ensues in larger parts of semiarid Africa.

Finally, while climate change may be increasing the severity of natural hazards, the impact is exacerbated by social, ecological, political, and economic factors (Yaro et al., 2015). The vulnerability of the three countries as shown in this article is simultaneously embedded in the broader socioeconomic challenges that are faced. Climatic changes will increasingly lead to more water stress and an increase in temperature. This means that the ability of people in the three countries to adapt and respond robustly to climate extremes such as droughts and floods is a function of idiosyncratic and wider forces, including the state of the national economy and the nature of economic activities. Thus, the vulnerability of the three countries should not just be viewed from the changes in the climatic variables (i.e., temperature and precipitation) but from the fact that they are largely rainfed agrarian economies, albeit with growing diversification in the case of Ghana and Kenya. In essence, the impact of climate-induced water insecurity is filtered through other nonclimatic factors, including demographic dynamics, the nature of livelihood pursuits, water policies, and other pertinent socioeconomic drivers. Building resilient local systems that use both Indigenous and modern methods of farming, water preservation, and conservation to combat climate-induced water insecurity should be given priority since water insecurity can easily accelerate social conflict in semiarid areas.

REFERENCES

About 3.5 million Kenyans Facing Food Insecurity—WHO. (2022, June 27). *The Star*. https://www.the-star.co.ke/news/2022-06-27-about-35-million-kenyans-facing-food-insecurity-who/

Abubakari, S., Dong, X., Su, B., Hu, X., Liu, J., Li, Y., Peng, T., Ma, H., Wang, K., & Xu, S. (2017). Modelling the spatial variation of hydrology in the Volta River basin of West Africa under climate change. *Nature Environment and Pollution Technology*, *16*(4), 1095–1105.

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

African Development Bank. (2018). *2018 African economic outlook country note: Malawi*. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/country_notes/Malawi_country_note.pdf

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., & Siebert, S. (2003). Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences Journal*, *48*(3), 317–337. https://doi.org/10.1623/hysj.48.3.317.45290

Amadou, M. L., Villamor, G. B., & Kyei-Baffour, N. (2018). Simulating agricultural land-use adaptation decisions to climate change: An empirical agent-based modelling in northern Ghana. *Agricultural Systems*, *166*, 196–209. https://doi.org/10.1016/j.agsy.2017.10.015

Amlalo, D. S., & Oppong-Boadi, K. Y. (2015). *Ghana's third national communication report to the UNFCCC: 2015 climate change report*. Ministry of Environment, Science and Technology.

Antwi-Agyei, P., Quinn, C. H., Adiku, S. G. K., Codjoe, S. N. A., Dougill, A. J., Lamboll, R., & Dovie, D. B. K. (2017). Perceived stressors of climate vulnerability across scales in the Savannah zone of Ghana: A participatory approach. *Regional Environmental Change*, *17*(1), 213–227. https://doi.org/10.1007/s10113-016-0993-4

Appiah, D. O. (2019). Climate policy research uptake dynamics for sustainable agricultural development in Sub-Saharan Africa. *GeoJournal*, *85*(2), 579–591. https://doi.org/10.1007/s10708-019-09976-2

Arnall, A., Kothari, U., & Kelman, I. (2014). Introduction to politics of climate change: Discourses of policy and practice in developing countries. *The Geographical Journal*, *180*(2), 98–101. https://doi.org/10.1111/geoj.12054

Armah, F. A., Yawson, D. O., Yengoh, G. T., Odoi, J. O., & Afrifa, E. K. A. (2010). Impact of floods on livelihoods and vulnerability of natural resource dependent communities in northern Ghana. *Water*, *2*(2), 120–139. https://doi.org/10.3390/w2020120

Arndt, C., Chinowsky, P., Fant, C., Paltsev, S., Schlosser, C. A., Strzepek, K., Tarp, F., & Thurlow, J. (2019). Climate change and developing country growth: The cases of Malawi, Mozambique, and Zambia. *Climatic Change*, *154*(3–4), 335–349. https://doi.org/10.1007/s10584-019-02428-3

Armstrong, A. K., Krasny, M. E., & Schuldt, J. P. (2018). Framing climate change. In A. K. Armstrong, M. E. Krasny, & J. P. Schuldt (Eds.), *Communicating climate change: A guide for educators* (pp. 59–69). Cornell University Press. https://www.jstor.org/stable/10.7591/j.ctv941wjn.14

Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M. (2015). *Climate variability, adaptation strategies and food security in Malawi* (ESA Working Paper No. 14-08). FAO. https://doi.org/10.22004/ag.econ.210961

Bahati, I., Martiniello, G., & Abebe, G. K. (2022). The implications of sugarcane contract farming on land rights, labor, and food security in Bunyoro sub-region, Uganda. *Land Use Policy*, *122*, Article 106326. https://doi.org/10.1016/j.landusepol.2022.106326

Barrios, S., Bertinelli, L., & Strobl, E. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the african growth tragedy. *Review of Economics and Statistics*, *92*(2), 350–366. https://doi.org/10.1162/rest.2010.11212

Barron, J., Kemp-Benedict, E., Morris, J., de Bruin, A., Wang, G., & Fencl, A. (2015). Mapping the potential success of agricultural water management interventions for smallholders: Where are the best opportunities? *Water Resources and Rural Development*, *6*, 24–49. https://doi.org/10.1016/j.wrr.2015.06.001

Beall, J. (2022). *Beall's list of potential predatory journals and publishers*. https://beallslist.net/

Barry, A. A., Caesar, J., Tank, A. M. G. K., Aguilar, E., McSweeney, C., Cyrille, A. M., Nikiema, M. P., Narcisse, K. B., Sima, F., Stafford, G., Touray, L. M., Ayilari-Naa, J. A., Mendes, C. L., Tounkara, M., Gar-Glahn, E. V. S., Coulibaly, M. S., Dieh, M. F., Mouhaimouni, M., Oyegade, J. A., ... Laogbessi, E. T. (2018). West Africa climate extremes and climate change indices. *International Journal of Climatology*, *38*(Suppl. 1), e921–e938. https://doi.org/10.1002/joc.5420

Bongaarts, J., & Casterline, J. (2013). Fertility transition: Is sub-Saharan Africa different? *Population and Development Review*, *38*(Suppl. 1), 153–168. https://doi.org/10.1111/j.1728-4457.2013.00557.x, PubMed: 24812439

Callo-Concha, D., Gaiser, T., Webber, H., Tischbein, B., Müller, M., & Ewert, F. (2013). Farming in the West African Sudan Savanna: Insights in the context of climate change. *African Journal of Agricultural Research*, *8*(38), 4693–4705. https://doi.org/10.5897/AJAR2013.7153

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, *84*(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

de Wit, M. D., & Stankiewicz, J. (2006). Changes in surface water supply across Africa with predicted climate change. *Science*, *311*(5769), 1917–1921. https://doi.org/10.1126/science.1119929, PubMed: 16513946

Dickinson, K. L., Monaghan, A. J., Rivera, I. J., Hu, L., Kanyomse, E., Alirigia, R., Adoctor, J., Kaspar, R. E., Oduro, A. R., & Wiedinmyer, C. (2017). Changing weather and climate in northern Ghana: Comparison of local perceptions with meteorological and land cover data. *Regional Environmental Change*, *17*(3), 915–928. https://doi.org/10.1007/s10113-016-1082-4

Dinko, D. H. (2022). Scale matters: A spatiotemporal analysis of freshwater conflicts from 1900–2019. *Water Resources Management*, *36*, 219–233. https://doi.org/10.1007/s11269-021-03023-x

Dinko, D. H., Yaro, J., & Kusimi, J. (2019). Political ecology and contours of vulnerability to water insecurity in semiarid north-eastern Ghana. *Journal of Asian and African Studies*, *54*(2), 82–299. https://doi.org/10.1177/0021909618811838

Dixon, J. L., & Stringer, L. C. (2015). Towards a theoretical grounding of climate resilience assessments for smallholder farming systems in Sub-Saharan Africa, *Resources*, *4*(1), 128–154. https://doi.org/10.3390/resources4010128

Douxchamps, S., Ayantunde, A., Panyan, E. K., Ouattara, K., Kaboré, A., Karbo, N., & Sawadogo, B. (2014). Agricultural water management and livelihoods in the crop–livestock systems of the Volta Basin. *Water Resources and Rural Development*, *6*, 92–104. https://doi.org/10.1016/j.wrr.2014.10.001

Dunning, C. M., Black, E., & Allan, R. P. (2018). Later wet seasons with more intense rainfall over Africa under future climate change. *Journal of Climate*, *31*(23), 9719–9738. https://doi.org/10.1175/JCLI-D-18-0102.1

FAO AQUASTAT. (2022). *Percentage of water-stressed people in Ghana, Kenya, and Malawi from 1990–2019*. https://tableau.apps.fao.org/views/ReviewDashboard-v1/result_country?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

Faramarzi, M., Abbaspour, K. C., Vaghefi, S. A., Farzaneh, M. R., Zehnder, A. J. B., Srinivasan, R., & Yang, H. (2013). Modeling impacts of climate change on freshwater availability in Africa. *Journal of Hydrology*, *480*, 85–101. https://doi.org/10.1016/j.jhydrol.2012.12.016

Fritz, M., Koch, M., Johansson, H., Emilsson, K., Hildingsson, R., & Khan, J. (2021). Habitus and climate change: Exploring support and resistance to sustainable welfare and social–ecological transformations in Sweden. *The British Journal of Sociology*, *72*(4), 874–890. https://doi.org/10.1111/1468-4446.12887, PubMed: 34405888

Gebrechorkos, S. H., Bernhofer, C., & Hülsmann, S. (2019). Impacts of projected change in climate on water balance in basins of East Africa. *Science of the Total Environment*, *682*, 160–170. https://doi.org/10.1016/j.scitotenv.2019.05.053, PubMed: 31112817

GoK. (2013). *Kenya National Climate Change Action Plan*. Nairobi.

Groenfeldt, D. (2019). *Water ethics: A values approach to solving the water crisis* (2nd ed.). Routledge. https://doi.org/10.4324/9781351200196

Hellberg, S. (2018). *The biopolitics of water: Governance, scarcity and populations*. Routledge. https://doi.org/10.4324/9781315183251

Hope, R., Foster, T., & Thomson, P. (2012). Reducing risks to rural water security in Africa. *Ambio*, *41*(7), 773–776. https://doi.org/10.1007/s13280-012-0337-7, PubMed: 22821145

Intergovernmental Panel on Climate Change. (2013). Summary for policymakers. In *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–30). Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.004

Joshua, M. K., Ngongondo, C., Chipungu, F., Monjerezi, M., Liwenga, E., Majule, A., Stathers, T., & Lamboll, R. (2016). Climate change in semi-arid Malawi: Perceptions, adaptation strategies and water governance. *Jàmbá: Journal of Disaster Risk Studies*, *8*(3), 1–10. https://doi.org/10.4102/jamba.v8i3.255, PubMed: 29955323

Kahn, M. E. (2009). Urban growth and climate change. *Annual Review of Resource Economics*, *1*, 333–349. https://www.jstor.org/stable/43202497. https://doi.org/10.1146/annurev.resource.050708.144249

Kankam-Yeboah, K., Obuobie, E., Amisigo, B., & Opoku-Ankomah, Y. (2013). Impact of climate change on streamflow in selected river basins in Ghana. *Hydrological Sciences Journal*, *58*(4), 773–778. https://doi.org/10.1080/02626667.2013.782101

Karekezi, S., Kimani, J., Onguru, O., & Kithyoma, W. (2009). *Large scale hydropower, renewable energy and adaptation to climate change: Climate change and energy security in East and Horn of Africa*. Occasional Paper No. 33, Energy, Environment and Development Network for Africa/Heinrich Böll Stiftung.

Kerr, R. B., Liebert, J., Kansanga, M., & Kpienbaareh, D. (2022). Human and social values in agroecology: A review. *Elementa*, *10*(1), Article 00090. https://doi.org/10.1525/elementa.2021.00090

Khangura, S., Konnyu, K., Cushman, R., Grimshaw, J., & Moher, D. (2012). Evidence summaries: The evolution of a rapid review approach. *Systematic Reviews*, *1*, Article 10. https://doi.org/10.1186/2046-4053-1-10, PubMed: 22587960

Kumambala, P. G. (2010). *Sustainability of water resources development for Malawi with particular emphasis on North and Central Malawi* (PhD thesis, University of Glasgow). https://theses.gla.ac.uk/1801/

Mahe, G., Lienou, G., Descroix, L., Bamba, F., Paturel, J. E., Laraque, A., Meddi, M., Habaieb, H., Adeaga, O., Dieulin, C., Kotti, F. C., & Khomsi, K. (2013). The rivers of Africa: Witness of climate change and human impact on the environment. *Hydrological Processes*, *27*(15), 2105–2114. https://doi.org/10.1002/hyp.9813

Mariotti, A., Schubert, S., Mo, K., Peters-Lidard, C., Wood, A., Pulwarty, R., Huang, J., & Barrie, D. (2013). Advancing drought understanding, monitoring, and prediction. *Bulletin of the American Meteorological Society*, *94*(12), 186–188. https://doi.org/10.1175/BAMS-D-12-00248.1

Matchawe, C., Bonny, P., Yandang, G., Mafo, H. C. Y., & Nsawir, B. J. (2022). Water shortages: Cause of water safety in sub-Saharan Africa. In M. Eyvaz, A. Albahnasawi, M. Tekbaş, & E. Gürbulak (Eds.), *Drought - Impacts and management*. IntechOpen. https://doi.org/10.5772/intechopen.103927

Mogaka, H., Gichere, S., Davis, R., & Hirji, R. (2006). *Climate variability and water resources degradation in Kenya: Improving water resources development and management*. World Bank Working Paper No. 69. World Bank. https://doi.org/10.1596/978-0-8213-6517-5

Msowoya, K., Madani, K., Davtalab, R., Mirchi, A., & Lund, J. R. (2016). Climate change impacts on maize production in the warm heart of Africa. *Water Resources Management*, *30*(14), 5299–5312. https://doi.org/10.1007/s11269-016-1487-3

Mughogho, P. (2014). *Assessing the spatial and temporal characteristics of rainfall over the southern region of Malawi* (Thesis, University of Nairobi). UoN Digital Repository. https://erepository.uonbi.ac.ke/handle/11295/95427

Muller, C. (2009). *Climate change impact on sub-Saharan Africa? An overview and analysis of scenarios and models*. DIE Discussion Paper, 3/2009. SSOAR. https://nbn-resolving.org/urn:nbn:de:0168-ssoar-193970

Newell, P., & Mulvaney, D. (2013). The political economy of the "just transition." *The Geographical Journal*, *179*(2), 132–140. https://www.jstor.org/stable/43868543. https://doi.org/10.1111/geoj.12008

Ngongondo, C. S., Xu, C.-Y., Tallaksen, L. M., Alemaw, B., & Chirwa, T. (2011). Regional frequency analysis of rainfall extremes in Southern Malawi using the index rainfall and L-moments approaches. *Stochastic Environmental Research and Risk Assessment*, *25*(7), 939–955. https://doi.org/10.1007/s00477-011-0480-x

Niasse, M. (2005, June 21–23). Climate-induced water conflict risks in West Africa: Recognizing and coping with increasing climate impacts on shared watercourses (Paper presentation). *Human Security and Climate Change International Workshop*, Oslo, Norway.

Nicholson, S. E. (2014). A detailed look at the recent drought situation in the Greater Horn of Africa. *Journal of Arid Environments*, *103*, 71–79. https://doi.org/10.1016/j.jaridenv.2013.12.003

Nicholson, S. E. (2016). An analysis of recent rainfall conditions in eastern Africa. *International Journal of Climatology*, *36*(1), 526–532. https://doi.org/10.1002/joc.4358

Nicholson, S. E., Klotter, D., & Chavula, G. (2014). A detailed rainfall climatology for Malawi, Southern Africa. *International Journal of Climatology*, *34*(2), 315–325. https://doi.org/10.1002/joc.3687

Nicholson, S. E., Some, B., & Kone, B. (2000). An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Nino and the 1998 La Nina years. *Journal of Climate*, *13*(14), 2628–2640. https://doi.org/10.1175/1520-0442(2000)013<2628:AAORRC>2.0.CO;2

Nyadzi, E., Nyamekye, A. B., Werners, S. E., Biesbroek, R. G., Dewulf, A., Slobbe, E. V., Long, H. P., Termeer, C. J. A. M., & Ludwig, F. (2018). Diagnosing the potential of hydro-climatic information services to support rice farming in northern Ghana. *NJAS: Wageningen Journal of Life Sciences*, *86–87*(1), 51–63. https://doi.org/10.1016/j.njas.2018.07.002

Nyantakyi-Frimpong, H., & Bezner-Kerr, R. (2015). The relative importance of climate change in the context of multiple stressors in semi-arid Ghana. *Global Environmental Change*, *32*, 40–56. https://doi.org/10.1016/j.gloenvcha.2015.03.003

Ojo, O., Gbuyiro, S. O., & Okoloye, C. U. (2004). Implications of climatic variability and climate change for water resources availability and management in West Africa. Source: GeoJournal *GeoJournal*, *61*(1), 111–119. https://doi.org/10.1007/s10708-004-2863-8

Opere, A. (2013). Floods in Kenya. In P. Paron, D. Ochieng Olago, & C. Thine Omuto (Eds.), *Developments in Earth surface processes* (Vol. 16, pp. 315–330). Elsevier B.V. https://doi.org/10.1016/B978-0-444-59559-1.00021-9

Otieno, V. O., & Anyah, R. O. (2013). CMIP5 simulated climate conditions of the Greater Horn of Africa (GHA). Part 1: Contemporary climate. *Climate Dynamics*, *41*(7–8), 2081–2097. https://doi.org/10.1007/s00382-012-1549-z

Owusu, K., & Waylen, P. (2009). Trends in spatio-temporal variability in annual rainfall in Ghana (1951–2000). *Weather*, *64*(5), 115–120. https://doi.org/10.1002/wea.255

Oyebande, L. (2013). Climate change impact on water resources at the transboundary level in West Africa: The cases of the Senegal, Niger and Volta Basins. *The Open Hydrology Journal*, *4*(1), 163–172. https://doi.org/10.2174/1874378101004010163

Paeth, H., Capo-Chichi, A., & Endlicher, W. (2008). Climate change and food security in tropical West Africa—A dynamic-statistical modelling approach. *Erkunde*, *2*, 101–115. https://doi.org/10.3112/erdkunde.2008.02.01

Poussin, J.-C., Renaudin, L., Adogoba, D., Sanon, A., Tazen, F., Dogbe, W., Fusillier, J.-L., Barbier, B., & Cecchi, P. (2015). Performance of small reservoir irrigated schemes in the Upper Volta basin: Case studies in Burkina Faso and Ghana. *Water Resources and Rural Development*, *6*, 50–65. https://doi.org/10.1016/j.wrr.2015.05.001

Riede, J. O., Posada, R., Fink, A. H., & Kaspar, F. (2016). What's on the 5th IPCC Report for West Africa? In J. Yaro & J. Hesselberg (Eds.), *Adaptation to climate change and variability in rural West Africa* (pp. 7–23). Springer. https://doi.org/10.1007/978-3-319-31499-0_2

Roudier, P., Ducharne, A., & Feyen, L. (2014). Climate change impacts on runoff in West Africa: A review. *Hydrology and Earth System Sciences*, *18*(7), 2789–2801. https://doi.org/10.5194/hess-18-2789-2014

Sharpe, E. E., Karasouli, E., & Meyer, C. (2017). Examining factors of engagement with digital interventions for weight management: Rapid review. *JMIR Research Protocols*, *6*(10), Article e205. https://doi.org/10.2196/resprot.6059, PubMed: 29061557

Sovacool B. K., & Linnér, B.-O. (2016). *The political economy of climate change adaptation*. Palgrave Macmillan. https://doi.org/10.1057/9781137496737

Sutherland, R. A., Bryan, R. B., & Wijendes, D. O. (1991). Analysis of the monthly and annual rainfall climate in a semi-arid environment, Kenya. *Journal of Arid Environments*, *20*(3), 257–275. https://doi.org/10.1016/S0140-1963(18)30688-8

Thomas, N., & Nigam, S. (2018). Twentieth-century climate change over Africa: Seasonal hydroclimate trends and Sahara Desert expansion. *Journal of Climate*, *31*(9), 3349–3370. https://doi.org/10.1175/JCLI-D-17-0187.1

United Nations Development Programme. (2021). *Malawi national human development report 2021*. https://www.undp.org/sites/g/files/zskgke326/files/migration/mw/Malawi-National-Human-Development-Report-2021---SUMMARY-REPORT.pdf

UN-Water. (2013). *Water security & the global water agenda: A UN-water analytical brief*. United Nations University.

U.S. Environmental Protection Agency. (2000). *Climate change vulnerability and adaptation assessment of the agricultural sector of Ghana*. Ministry of Environment Science and Technology.

Vizy, E. K., Cook, K. H., Chimphamba, J., & McCusker, B. (2015). Projected changes in Malawi's growing season. *Climate Dynamics*, *45*(5–6), 1673–1698. https://doi.org/10.1007/s00382-014-2424-x

Wakeford, J. J. (2017). *The water-energy-food nexus in a climate-vulnerable, frontier economy: The case of Kenya*. GOV.UK. https://assets.publishing.service.gov.uk/media/58e27db9ed915d06ac0000b2/Water-energy-food_nexus_in_Kenya_2017.pdf

Wankuru, P. C., Dennis, A. C., Angelique, U., Chege, P. N., Mutie, C. K., Sanya, S. O., Chengula, L. K., Njagi, T., Pape, U. J., & Haynes, A. (2019). *Kenya economic update: Unbundling the slack in private sector investment – Transforming agriculture sector productivity and linkages to poverty reduction* (Kenya economic update, no. 19). World Bank Group. https://documents.worldbank.org/curated/en/820861554470832579/Kenya-Economic-Update-Unbundling-the-Slack-in-Private-Sector-Investment-Transforming-Agriculture-Sector-Productivity-and-Linkages-to-Poverty-Reduction

Witsenburg, K. M., & Adano, W. R. (2009). Of rain and raids: Violent livestock raiding in northern Kenya. *Civil Wars*, *11*(4), 514–538. https://doi.org/10.1080/13698240903403915

Woodgate, G. (2016). Agri-cultural practice and agroecological discourse in the Anthropocene: Confronting environmental change and food insecurity in Latin America and the Caribbean. In M. Coletta & M. Raftopoulos (Eds.), *Provincialising nature: Multidisciplinary approaches to the politics of the environment in Latin America* (pp. 65–88). University of London Press. https://www.jstor.org/stable/j.ctv13nb6g6.11

World Bank. (2022, March 17). *Bold action needed for a water-secure Africa*. World Bank Blogs. https://blogs.worldbank.org/water/bold-action-needed-water-secure-africa

Xie, F., & Cheng, H. (2021). The political economy of climate change: The impasse and way out. *Economic and Political Studies*, *9*(3), 315–335. https://doi.org/10.1080/20954816.2021.1885780

Yansaneh, I. S. (2005). *An analysis of cost issues for surveys in developing countries*. Household Sample Surveys in Developing and Transition Countries. United Nations.

Yaro, J. A. (2013). The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. *Regional Environmental Change*, *13*(6), 1259–1272. https://doi.org/10.1007/s10113-013-0443-5

Yaro, J. A., & Hesselberg, J. (2016). *Adaptation to climate change and variability in rural West Africa*. Springer International. https://doi.org/10.1007/978-3-319-31499-0

Yaro, J. A., Teye, J., & Bawakyillenuo, S. (2015). Local institutions and adaptive capacity to climate change/variability in the northern savannah of Ghana. *Climate and Development*, *7*(3), 235–245. https://doi.org/10.1080/17565529.2014.951018