International Journal of Agriculture, Environment and Biotechnology
Citation: *IJAEB*: **17**(04): 749-763, December 2024
DOI: 10.30954/0974-1712.04.2024.14

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

REVIEW PAPER

Impact of Climate Change on Drought: A Comprehensive Review

Jyotsana Pandit[1*] and Anish Kumar Sharma[2]

[1]Department of Environmental Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, India
[2]Department of Biotechnology, School of Sciences, P.P. Savani University, Surat, India

*Corresponding author: jyotsanapandit@gmail.com (**ORCID ID:** 0000-0001-9205-6666)

Paper No. 1194 **Received:** 22-08-2024 **Revised:** 24-11-2024 **Accepted:** 07-12-2024

ABSTRACT

This paper investigates the influence of climate change on drought events, with a particular emphasis on the global implications, severity, and frequency of droughts that are intensified by evolving climatic conditions. The interplay of high temperatures and low precipitation has resulted in intensified droughts, particularly flash droughts, as climate change accelerates atmospheric water demand. The study examines a variety of droughts, including meteorological, agricultural, hydrological, and socioeconomic, and emphasizes their cascading effects on human health, water resources, ecosystems, and agriculture. Additionally, the investigation explores the mitigation strategies necessary to mitigate drought risks and provides policymakers with suggestions for the development of sustainable water management practices and the improvement of resilience in vulnerable regions. This article emphasizes the pressing necessity of a proactive strategy for drought preparedness in light of the ongoing evolution of climate variability.

HIGHLIGHTS

- Droughts are becoming more severe around the world as a result of climate change, with serious consequences for water supplies, ecosystems, agriculture and human health.
- Flash droughts, caused by high temperatures and low precipitation, are becoming more often and severe as a result of atmospheric feedback mechanisms.
- Droughts lower agricultural production, impair water quality, endanger biodiversity, and worsen food and water scarcity.
- Building resilience requires sustainable practices such as drought-resistant crops, efficient irrigation systems, and the integration of indigenous knowledge.
- Future research should concentrate on high-resolution regional models and cross-sectoral approaches to better anticipate and mitigate drought effects.

Keywords: Climate Change, Drought, Water Scarcity, Flash Droughts, Agricultural Impact, Water Resources Management, Ecosystem Vulnerability, Climate Adaptation

The term "climate change" refers to the long-term fluctuations in temperatures and weather patterns. Significant worldwide changes, including actual and expected climate alterations and global warming, happened within the past 65 years. Climate change is a global issue that has a multifaceted impact on various domains, including ecological, environmental, socio-political, and socio-economic (Feliciano *et al.* 2022; Abbass *et al.* 2022). Since the 1800s, human activities have been the primary cause of climate change (Murshed *et al.* 2022). This is primarily due to the combustion of fossil fuels, including coal, oil, and gas. Human activities are responsible for nearly all of the global warming that has occurred in the past two centuries, as evidenced

How to cite this article: Pandit, J. and Sharma, A.K. (2024). Impact of Climate Change on Drought: A Comprehensive Review. *Int. J. Ag. Env. Biotech.*, **17**(04): 749-763.

Source of Support: None; **Conflict of Interest:** None

by climate scientists. At present, the Earth's surface is approximately 1.2°C warmer than it was in the late 1800s, prior to the industrial revolution. Each of the last four decades has been warmer than any previous decade since 1850, and the most recent decade (2011-2020) was the warmest on record. There is more to climate change than just increasing temperatures; it affects the interconnected systems of the planet. Water shortages, wildfires, inundation, rising sea levels, biodiversity loss, and intense droughts are among the consequences. The rate of these changes is increasing at a rate that has not been observed in the past two millennia. A recurring extreme climate event that occurs over land and is defined by below-average precipitation is known as a drought. It is frequently accompanied by high temperatures for a period of months to years (Wilhite, 2000; Dai *et al.* 2018). Droughts are among the most costly natural calamities in the world resulting in substantial expenses for human societies (Gautier *et al.* 2016), agriculture (Madadgar *et al.* 2017), and ecosystems (Breshears *et al*. 2005). It is anticipated that drought frequency and severity will increase across a significant portion of the world (Cook *et al*. 2014), particularly in semi-arid regions that are already experiencing significant water stress (Seager *et al*. 2014). Consequently, it is essential that we enhance our comprehension of the dynamics and consequences of droughts in the context of climate change (Cook *et al.* 2018). Droughts are classified into four categories: meteorological, hydrological, agricultural, and socioeconomic. An imbalance between precipitation and evaporation is the primary cause of meteorological droughts, with precipitation being the most frequently employed indicator for analysis (Chang 1991). Agricultural droughts can result from these droughts, which can reduce soil moisture and negatively impact agricultural productivity. Hydrological droughts arise when the demands of a particular water resource management system are not met by the available surface and subsurface water resources. These droughts are typically analysed using stream-flow data (Dracup *et al.* 1980). The assessment of socioeconomic droughts is based on reservoir activities, which are crucial in the management of water supply during extreme climate events. These droughts have a substantial impact on rural economies, notably on farmers, resulting in economic hardship, social disruption, and population decline. Nevertheless, the emotional impact of witnessing damage to agriculture, livestock, and vegetation, which are more broadly societal effects, receives less attention (Bogale and Erena, 2022).

Fig. 1 elucidates the relationship between the different categories of drought and the duration of the occurrence. A complex, progressive phenomenon, drought is initiated by natural climate variability. The onset of the phenomenon is meteorological drought, which is defined by a reduction in precipitation and an increase in evaporation, resulting in a deficiency of soil water. As drought continues, it transforms into agricultural drought, which is characterized by plant water stress and effects crop growth and yield. A hydrological drought is the consequence of prolonged conditions, which affects ecosystems and wildlife habitats by reducing stream-flow and reservoir levels. The cumulative effects of the drought result in a broad range of economic, social, and environmental consequences, including food insecurity, water scarcity, and ecosystem degradation, which intensify as the drought continues. The hydrological cycle is anticipated to be "accelerated" as a result of climate change, with increasing or decreasing total annual precipitation in various regions of the world. This is due to the fact that a warmed atmosphere may hold more water, which in turn causes more precipitation (IPCC, 2021). Nevertheless, a warmer atmosphere could ultimately lead to a decrease in water availability, even in areas with increasing total precipitation, as a result of increased evaporation rates and arid periods (Oguntunde *et al.* 2020). Examining the effects of climate change on drought is essential for comprehending the rising frequency and intensity of these occurrences, which can disturb ecosystems and endanger biodiversity (Parker *et al.* 2023). Droughts substantially impact agricultural output, resulting in economic vulnerabilities, especially in poorer regions where food security is already compromised (Dai *et al*. 2024). The health consequences are significant, since water shortage can result in hunger and heightened conflict over resources (Bevacqua *et al.* 2022). This research provides policymakers with essential adaptive solutions for water management and catastrophe preparedness. By thoroughly addressing these challenges, we may improve resilience to future climate impacts and safeguard vulnerable people.

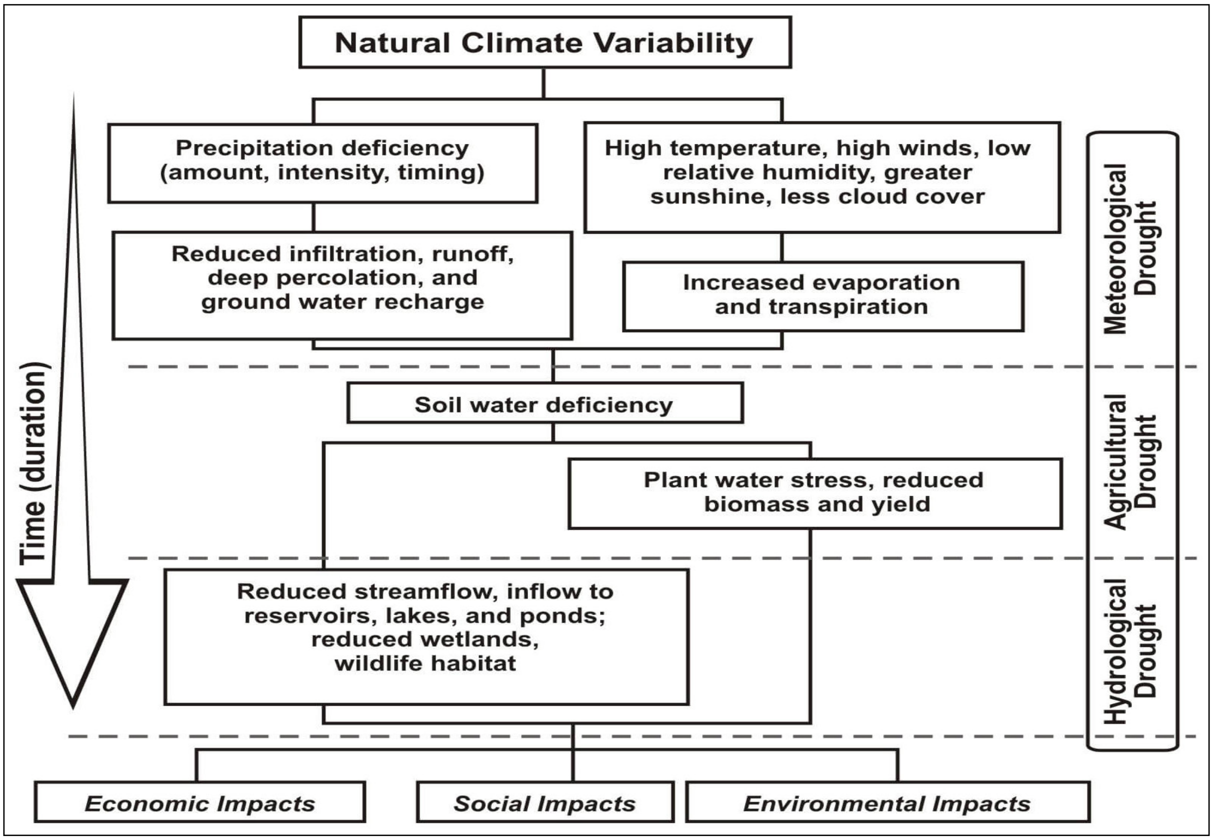

Fig. 1: Duration of drought events and the relationship between distinct forms of drought (Wilhite, 2000)

Comprehending the relationship between climate change and drought is essential for sustainable development and environmental preservation. The main objective of this paper is to investigate the effects of climate change on drought events in a variety of sectors, such as agriculture, water resources, and ecosystems. It aims to evaluate the impact of these changes on both natural systems and human societies by identifying the drivers and dynamics of drought in a warming climate. The study endeavours to offer policymakers precious insights for the development of effective mitigation strategies by conducting a comprehensive analysis of various types of drought and their socio-economic repercussions. The research encompasses a variety of critical areas, such as the examination of the ways in which intensified drought conditions are influenced by atmospheric feedback loops, diminished precipitation, and rising temperatures. It also investigates the sectoral effects of drought on human health, ecosystems, water quality, and agriculture. Furthermore, the investigation suggests sustainable agricultural practices, policy interventions, and water management strategies to improve resilience to future droughts. Additionally, it identifies research gaps and future orientations, emphasizing the necessity of comprehensive socio-economic assessments and high-resolution regional models.

Drivers of Drought in a Warming Climate

The dynamics of drought have been significantly altered by climate change, which has resulted in an increase in atmospheric water demand due to elevated temperatures and vapor pressure deficits. This increases evapotranspiration and intensifies soil moisture depletion, resulting in more frequent and severe droughts, particularly flash droughts. These flash droughts are distinguished by their rapid onset and are driven by positive temperature anomalies, which are frequently exacerbated by reduced precipitation. As a result, acute water stress can occur within days to weeks. Land-atmosphere feedback mechanisms further exacerbate these conditions by reducing evapotranspiration and increasing sensible heat flux, which in turn raises temperatures and perpetuates drought severity as a result of declining soil moisture. The escalating prevalence of concurrent heatwaves and precipitation deficiencies has resulted in a transition from precipitation-deficit droughts to compound hot-dry events since 2000 (Zeng *et al.* 2023). The frequency of soil moisture–atmosphere feedbacks has increased globally from 1980 to 2020, and they are key in the transition from drought to pluvial (intense rainfall) conditions. Low soil moisture in humid regions increases latent heat flux, which in turn enhances atmospheric moisture and results in rainfall. Conversely, in arid regions, reduced soil moisture promotes moisture convergence, which in turn triggers post-drought precipitation. Improved climate forecasting and hazard preparedness strategies are imperative due to the amplification of extreme weather variability by this dynamic coupling (Qing *et al.* 2023). In their 2018 study, Naumann *et al*. (2018) examine the extent to which drought conditions will be exacerbated globally as a result of increasing global temperatures. As the temperature rises by 1.5°C, 2°C, and 3°C, the demand for water in the atmosphere increases due to heightened evapotranspiration, resulting in more severe and prolonged droughts. Intensified droughts are anticipated in dry regions such as Africa, Australia, the Mediterranean, and parts of the Americas, while high-latitude regions may experience minor improvements. Droughts become more frequent and protracted at temperatures beyond 2°C, diminishing the capacity of groundwater and reservoirs to recover. Under a 3°C scenario, 100-year drought events could occur every 5 to 10 years, underscoring the socio-economic risks of climate change if mitigation strategies are not implemented. Masroor *et al.* (2020) investigated the influence of climate variability on drought occurrence in the Godavari Middle sub-basin of India. Their study, conducted using 35 years of meteorological data, found that decreased precipitation and increased temperatures in specific watersheds have amplified drought conditions. The analysis also showed that meteorological variables, including temperature, solar radiation, and wind speed, play a more significant role in short-term droughts. A critical mechanism connecting climate change and drought is snow drought, which disrupts the natural cycle of water storage and availability. Climate change leads to earlier snowmelt and reduced snow accumulation, causing water deficits during critical growing seasons. Research conducted in the Upper Mississippi River Basin by Yeşilkoy *et al.* (2024) demonstrates how snow droughts limit soil moisture and streamflow, inducing agricultural droughts. The interaction between snow droughts and climatic patterns, such as La Niña, further exacerbates these droughts, underscoring the importance of monitoring snow dynamics to improve agricultural drought forecasts. The dynamics of snowpack and glacier systems, essential for seasonal water availability, have been significantly impacted by climate change. Warming temperatures lead to earlier snowmelt and reduced glacier volume, causing irregular water flows and seasonal shortages, especially in regions dependent on glacial discharge. These disruptions exacerbate water stress by impairing agricultural activities and hydropower generation during critical growing seasons (Huss and Hock, 2018). Droughts are exacerbated by climate change through increased temperatures that accelerate evapotranspiration and soil moisture depletion. The projected poleward expansion of subtropical dry zones will make wet regions wetter and dry regions drier. Natural variability, such as the El Niño-Southern Oscillation (ENSO), further complicates the identification of long-term drought trends. While climate change may not directly cause droughts, it intensifies their frequency, severity, and duration (Trenberth *et al.* 2013).

IMPACTS OF DROUGHT

Agriculture

Crop growth and yields are significantly impacted by climate variables, including temperature and precipitation, which have a profound impact on agricultural production. Crop production is anticipated to be adversely affected by the predicted increase in the frequency of extreme weather events, such as droughts, across a variety of geographic scales (Howden *et al.* 2007; Kang *et al.* 2009). Droughts impede crop growth and productivity, particularly for water-intensive crops like corn, by reducing soil moisture and water availability. Conversely, drought-tolerant crops, such as sorghum and cotton, perform better in water-limited conditions (Gurian-Sherman, 2012; Almas *et al.* 2007). Agricultural productivity is substantially impacted by drought stress, which is a critical factor that limits crop yield, quality, and plant growth (Battaglia *et al.* 2019). Metabolic modifications, enhanced root growth, and stomatal regulation are implemented by plants to mitigate water loss in response to water scarcity (Mostofa *et al.* 2018). Nevertheless, water deficits impede growth and development by impairing nutrient absorption, cell enlargement, and turgor pressure (Elemike *et al.* 2019). The intensity and frequency of droughts are further exacerbated by climate change, which poses a threat to agricultural output, particularly in arid and semi-arid regions (Sobhanian *et al.* 2020). Leaf rolling, yellowing, withering, and stunted growth are among the most common drought symptoms, and severe cases can result in necrosis and plant mortality (Corso *et al*. 2020). Excessive water can also impede plant health, resulting in mold, decay, and fungal infections, in addition to reducing yields as a result of drought stress (Zargar *et al.* 2017). In order to enhance crop resilience in response to evolving climate conditions, future research must investigate the combined impacts of thermal stress and drought (Seleiman *et al.* 2018). The productivity of livestock in arid and semi-arid regions has been considerably impacted by an increasing number of droughts, the unpredictable patterns of rainfall, and the rise in temperatures (Ulrichs *et al.* 2019). This has resulted in a hazard to both food security and livelihoods. Recurrent droughts, floods, heatwaves, and unpredictable precipitation are all manifestations of climate variability, which is further exacerbated by events such as El Niño and La Niña (Melkamu, 2017). These climatic shifts necessitate the implementation of new sustainable development strategies, as they reduce cereal and pasture yields, abbreviate growing seasons, and adversely impact livestock production (Anita *et al.* 2010). Livestock species exhibit varying responses to climate variability. During droughts, cattle and sheep exhibit increased mortality rates, while goats and camels exhibit greater resilience (Wako *et al*. 2017). Reduced forage availability and degraded rangelands result in an increase in physiological stress for livestock. The composition of grasslands is also influenced by climate change, which frequently results in a decrease in grass productivity and an increase in the abundance of specific browse species. This further strains feed resources (Thornton *et al.* 2011). Furthermore, the distribution of pathogens and vectors is influenced by climate change, which in turn facilitates the transmission of livestock diseases, for example, through wind patterns. These modifications exacerbate the hazard to species diversity by increasing the susceptibility of livestock to diseases and thermal stress (Lubroth, 2012; Habte *et al*. 2022). Food prices worldwide increased due to severe droughts, including the 2012 drought in the United States, which resulted in a decrease in cereal supply and an increase in the cost of essential products like animal forage (Dunn and Bórawski, 2012).

In 2011, a comparable incident occurred in China, resulting in a surge in wheat prices. This, in turn, contributed to political and social instability in Egypt as a result of the elevated bread prices (Sternberg, 2012). According to a study on global agricultural production, the yields of wheat, maize, rice, and soybeans are exceedingly susceptible to droughts, with the severity of production losses increasing as the intensity of the drought increases (Leng and Hall, 2019). The global food markets, notably in Asia, were impacted by the drought-driven decrease in agricultural exports from Australia, which resulted in an increase in food prices and a hazard to food security (Qureshi *et al.* 2013). Drought and other crises, such as the COVID-19 pandemic, aggravate disruptions to food supply chains, thereby increasing food insecurity in vulnerable regions (Mishra *et al.* 2020). Water availability is restricted and soil moisture deficits are aggravated by droughts, which dramatically reduce crop productivity.

In China, this has resulted in substantial decreases in the yields of critical commodities, including soybeans and maize, during droughts (Wang *et al*. 2020). Droughts necessitate that producers relocate their agricultural production. The regional disparities in agricultural output are a result of the increasing dearth in southern regions of Europe, which is causing crop suitability to migrate northward (Falloon and Betts, 2010). The security of food is further impacted by drought, which results in a decrease in agricultural productivity and an increase in food prices. In California, the economic challenges faced by farmers have been exacerbated by the dwindling water resources as a result of the drought (Medellín-Azuara *et al*. 2011).

Water Resources

The frequency and intensity of droughts are increasing due to climate change, which is resulting in a decrease in the availability of water for critical purposes, including irrigation, consumption, and industrial processes. The dilution of pollutants in water is affected by drought, which also impacts crop productivity due to poor water quality resulting from the contamination of water with organic pollutants and heavy metals (Amanullah *et al.* 2020). The availability of water for irrigation is also reduced. In numerous regions, the demand for crop water and the dependence on irrigation have been accelerated by a combination of declining precipitation and rising temperatures. This leads to a decrease in groundwater levels and an increase in the burden on water resources (Nunes *et al.* 2017). Pokhrel *et al.* (2021) anticipate that future scenarios will result in additional reductions in water storage and availability, which will increase the likelihood of drought-related impacts on agricultural and potable water supplies. In rural areas, groundwater resources are particularly susceptible to degradation, as minor aquifers are essential for the production of potable water. Local water shortages and contamination are exacerbated by droughts, particularly in regions with inadequate recharge capacity (MacDonald *et al.* 2009). Additionally, droughts result in diminished water availability for industries. The environmental degradation and pollution levels are exacerbated by the increase in industrial discharges into surface waters, which is a consequence of the limited water supply (Bhat, 2020). The competition for water resources is exacerbated by the drought caused by climate change, which presents substantial obstacles to the sustainable administration of water in various sectors. The demand for water from agriculture, industry, urban populations, and ecosystems increases as water availability decreases. Research suggests that competition becomes greater in drought-prone regions, such as Southeastern Spain, by the increasing exploitation of water and the necessity of environmental protection (Kahil *et al.* 2015). It is anticipated that climate change will result in an increase in the frequency and severity of droughts, which will result in a greater competition for water. This will have a significant impact on agriculture and ecosystems (Dessai and Sims, 2010). Forest dynamics are altered by drought events, which result in mortality and changes in forest structure as a result of the increased competition for water among plant species (Carnicer *et al.* 2011). Hydropower generation is substantially affected by climate change, which results in heightened droughts and altered hydrological cycles. This, in turn, affects energy security and redirects energy production toward alternatives that are more reliant on fossil fuels. During drought years, the global utilization of hydropower was reduced by 5.2%, and thermoelectric power was also constrained by the scarcity of cooling water (Vliet *et al.* 2016). In regions that are heavily reliant on hydropower, such as Finland, severe droughts pose a threat to energy security by reducing hydropower output and requiring the importation of electricity (Jaaskelainen *et al.* 2018).

In California, climate-induced droughts resulted in a decrease in hydropower generation, a decrease in spinning reserves, and a greater dependence on fossil fuels to ensure grid stability (Forrest *et al.* 2018). Severe reductions in reservoir inflows were observed in Southeast Brazil, as droughts hindered the availability of water for significant hydropower facilities, thereby raising concerns regarding the stability of long-term energy production (Mello *et al.* 2021). In the western United States, higher greenhouse gas emissions and worsened air quality were the result of increased fossil fuel utilization during droughts, demonstrating the cascading environmental and economic effects of reduced hydropower output (Qiu *et al.* 2023). Water quality is significantly affected by droughts caused by climate change.

This is the result of decreased water volumes, altered nutrient dynamics, increased pollutant concentrations, and environmental stress on aquatic ecosystems. During droughts, the dilution capacity is reduced due to reduced river flows and lower water volumes, resulting in elevated concentrations of pollutants such as nutrients, minerals, and heavy metals (Vliet and Zwolsman, 2008). High water temperatures and extended water residence periods are frequently the consequence of drought conditions, which create an environment that is conducive to algal blooms, including toxic cyanobacteria (Mosley, 2015). The depletion of oxygen levels by these outbreaks has a detrimental effect on aquatic ecosystems. The nutrient cycling in watersheds is influenced by drought, and excessive rainfall following a drought can mobilize accumulated nutrients, thereby exacerbating eutrophication and the degradation of water quality (Wright *et al*. 2014). Reduced oxygen levels and fluctuations in turbidity are frequent during droughts, which can both impede water treatment processes and deteriorate water quality (Ahmadi and Moradkhani, 2019). The deterioration of water quality during droughts has an impact on drinking water supplies by increasing the concentrations of disinfection by-products and altering the flavor and odor. This presents difficulties for water treatment facilities (Delpla *et al.* 2009). The mobilization of non-point source pollutants, such as nitrogen, by alternating cycles of drought and flooding further stresses water systems, resulting in sudden increases in contamination (Huang *et al*. 2015).

Ecosystem

Drought results in decreased tree growth, decreased water consumption, and increased mortality of lesser trees. Although mature trees are initially more resilient, their susceptibility to pests and diseases is exacerbated by protracted droughts (Hanson and Weltzin, 2000). Furthermore, the composition of the ecosystem and the likelihood of wildfires are both increased by drought-induced vegetation die-offs, particularly those that affect overstory species (Breshears *et al*. 2005). Drought disrupts carbon and nitrogen cycles by decreasing litter decomposition and microbial respiration, which impacts nutrient availability and CO_2 emissions in ecosystems such as forests and grasslands (Deng *et al*. 2021). Ecosystem services, such as biodiversity conservation and water purification, are diminished by fluctuations in water quality and availability during droughts. The California drought serves as an example of the cascading effects on hydropower generation, recreation, and stream health (Chang and Bonnette, 2016). Forests demonstrate multi-year growth reductions in response to severe droughts, which restricts their capacity to function as carbon sinks and diminishes the resilience of ecosystems to subsequent droughts (Anderegg *et al.* 2015). Climate change-induced droughts are contributing to biodiversity loss by disrupting ecosystems and limiting species' ability to live and reproduce. This phenomenon has a significant impact on the function and services of a variety of ecosystems, including forests and grasslands. Reduced tree growth and elevated mortality rates result in biodiversity loss, as forests are exceedingly susceptible to drought stress. This vulnerability is linked to hydraulic failure in plants, which reduces their ability to transport water during droughts (Choat *et al.* 2012). Phylogenetic diversity has decreased in grasslands that are experiencing severe drought, particularly in species that possess drought-sensitive characteristics. The adaptive capacity of such ecosystems is restricted by the loss of diversity, rendering them more susceptible to additional environmental stress (Li *et al.* 2019). The Amazon rainforest is a prime example of vulnerability to drought, as moisture stress leads to biomass loss and carbon emissions, thereby weakening its capacity to serve as a global carbon sink (Phillips *et al.* 2009). Ecosystems are substantially impacted by droughts caused by climate change, as they disrupt natural feedback loops that involve interactions between soil, water, vegetation, and the atmosphere. These feedback cycles are intricate, frequently exacerbating the effects of drought and leading to additional environmental challenges. By altering soil microbial communities, droughts have long-term effects on plant-soil feedbacks, which can affect future plant growth and competition. These changes have long-term repercussions on soil function and ecosystem recovery (Kaisermann *et al*. 2017). Droughts and heat-waves are interconnected through feedback mechanisms. Evapotranspiration becomes reduced by soil moisture deficits, which results in elevated atmospheric temperatures and the reinforcement of drought conditions that can be disseminated across regions (Miralles *et al.* 2018).

The carbon sequestration capacity of forest ecosystems is diminished for several years as a result of the reduced growth that occurs during and after droughts. The carbon sink capacity of forests can be weakened by this "legacy effect" of drought, which can exacerbate climate change (Anderegg *et al*. 2015). The dynamics of the land-atmosphere are altered by the shifts in vegetation that are a result of drought, which intensify the drought by altering energy fluxes and transpiration. These feedbacks are significantly influenced by specific plant characteristics, including water transport efficiency (Anderegg *et al*. 2019). The water cycle is disrupted by drought events, which in turn initiate feedback loops that alter precipitation patterns. For instance, the Amazon Basin's drought further diminishes rainfall by disrupting water recycling processes, which results in forest dieback and exacerbates arid conditions (Bayer *et al*. 2012).

Human Health

Climate change-induced droughts have a substantial impact on human populations, affecting both health and livelihoods in a variety of regions. These effects can be either direct (through water scarcity) or indirect (through economic and social disruptions). Malnutrition and micronutrient deficiencies are more prevalent among vulnerable populations, such as women and children, as a result of droughts that diminish food production (Algur *et al.* 2021). Poor water quality and increased exposure to vectors frequently result in the outbreak of diseases such as malaria, cholera, and diarrhoea (Stanke *et al*. 2013). Psychological stress and mental health disorders are exacerbated in communities that have been impacted by drought-induced displacement and economic instability (Rosen *et al.* 2021).

In Brazil's Amazon region, the incidence of respiratory diseases is higher in regions that are experiencing droughts as a result of the increased aerosol emissions from fires (Smith *et al*. 2014). Droughts are particularly detrimental to rural communities that depend on agriculture, as they result in decreased agricultural yields and income. Families frequently abandon farming as a result of livelihood insecurity in regions such as Iran and Zambia (Keshavarz *et al*. 2017). The adoption of costly water-saving measures by households is compelled by the decline in access to pure water that occurs during droughts, which impact sanitation. In Bangladesh, droughts restrict access to freshwater, which has a direct impact on household routines and health (Rabbani *et al.* 2012). The workload and health hazards for women are exacerbated by droughts, particularly in regions such as India.

In addition, children in these regions are subjected to forced labour to support family income, increased school dropouts, and inadequate nutrition (Algur *et al*. 2021). Vulnerable communities are unable to effectively adapt to droughts due to a dearth of resources, which exacerbates inequalities. For example, drought-induced income losses have a profound impact on populations in West Africa, which are largely dependent on subsistence farming (Gautier *et al*. 2016). Climate change contributes to drought, which is a significant factor in the displacement and migration of vulnerable populations worldwide. Complex social, economic, and health consequences are the result of pressured movement within and across borders, which is a consequence of this phenomenon. As a result of drought, populations have been displaced both domestically and internationally. In an effort to secure food security and livelihood opportunities, individuals frequently relocate from rural areas to urban centres (Koubi *et al.* 2016). Internal displacement and civil unrest were the consequences of long-lasting droughts in severe cases, such as Syria (Gerrard, 2016). This ultimately led to further migration to Europe. A common survival strategy for families that are experiencing the scarcity of water and the decline in agricultural productivity as a result of drought is migration. Due to food shortages and failed crops, numerous individuals migrate in regions like the Sahel and Horn of Africa (Warner *et al*. 2010). Drought also induces socio-economic changes, compelling individuals, particularly in Africa and Asia, to relocate to cities where resources are already constrained. Poverty, resource competition, and social instability are all exacerbated by this urban influx (Schutte *et al.* 2018).

Mitigation Strategies

Mitigation strategies are designed to mitigate the fundamental causes of climate change by reducing greenhouse gas emissions and fostering sustainable practices. These endeavours are indispensable for mitigating the risks of future droughts and reducing the acceleration of climate change. The implementation of integrated solutions that balance environmental and economic objectives, the adoption of water-efficient technologies, and the transformation of agricultural practices are all essential components of successful mitigation. Resilience is enhanced by transitioning from monoculture systems to diverse cultivation patterns, such as alternating between cereals and fruit crops. For instance, in response to diminished precipitation, producers in China implemented apple-corn systems (Lei *et al.* 2014). The introduction of drought-resistant varieties that are genetically modified or locally adapted guarantees consistent yields in the face of water scarcity, as demonstrated in South Africa (Elum *et al*. 2016). It is crucial to assure a consistent supply, particularly during droughts, by coordinating the use of surface and groundwater. In the Yakima River Basin of Washington, managed aquifer recharge has been demonstrated to be a cost-effective solution (Zhao and Boll, 2022).

In arid regions, half-moon structures are a particularly effective method for reducing discharge and increasing water retention (Tamagnone *et al*. 2020). These assist farmers in making well-informed judgments regarding irrigation and planting schedules. In Bangladesh, the utilization of mobile-based advisory services for weather forecasts has demonstrated advantages (Anik *et al.* 2021). In order to more effectively manage water supply under variable conditions, reservoir operations can be optimized through the use of algorithms (Elgendy *et al*. 2024). Adaptive capacity is enhanced by engaging local stakeholders in drought preparedness and water management. The significance of decentralization is further illustrated by the Sahel region's effectiveness in managing climate variability through indigenous knowledge (Nyong *et al.* 2007). Adaptive behaviour is promoted by providing producers with insurance against crop failure and drought-resistant seeds. By employing soil management techniques such as cover cultivation and reducing fertilizer usage, emissions from agricultural operations can be mitigated (Iglesias and Garrote, 2015).

In addition to reducing water consumption, technologies such as trickle and sprinkler irrigation systems also reduce energy consumption, thereby reducing emissions (Salinas and Mendieta, 2013). By encouraging the efficient utilization of water, stormwater management systems that concentrate on groundwater recharge reduce the effects of both droughts and floods. Carbon sequestration is facilitated by forest conservation, which also creates buffer zones against drought. Adaptive resilience and mitigation are both enhanced by sustainable forestry practices (Ravindranath, 2007). Proactive policy interventions are essential to address the rising risks of climate-change-induced droughts. Shifting from reactive crisis management to proactive risk management is critical. Implementing drought monitoring and early warning systems will help communities respond more effectively to water shortages. Investing in community-based preparedness, combined with forecasting technologies, will build resilience and reduce dependence on costly emergency measures (Gana and Sa'id, 2022). A key policy goal is to enhance the adaptive capacity of water administrators and farmers through targeted training and capacity-building programs. Educating farmers about drought-resistant crops, efficient irrigation, and ICT-based planning improves their ability to manage drought impacts. Policymakers should support these practices with financial aid, such as insurance products and subsidies. Expanding affordable crop insurance and awareness programs will encourage farmers to adopt these strategies, protecting their livelihoods from drought risks (Elum *et al*. 2016). Water management policies should integrate surface and groundwater resources using technologies like managed aquifer recharge and improved irrigation. Policymakers must promote low-emission agricultural practices, such as trickle irrigation and crop rotation, to reduce greenhouse gas emissions and water use. Adopting modern water policies that address both short-term drought risks and long-term scarcity will enhance the resilience of agricultural and water systems (Zhao and Boll, 2022).

A comprehensive strategy integrating both adaptation and mitigation is essential for national and regional climate policies to maximize co-benefits. Policies should promote practices like sustainable agriculture, reforestation, and agroforestry that reduce emissions while enhancing resilience. Strengthening the synergy between adaptation and mitigation ensures climate policies effectively address both immediate and long-term drought impacts, improving overall efficiency (Nyong *et al*. 2007). Policymakers must adopt context-specific and adaptable strategies that account for regional differences in drought impacts. For instance, northern regions with greater water availability may prioritize water management optimization, while arid southern regions may prioritize drought-tolerant crops and enhanced irrigation infrastructure

(Falloon and Betts, 2010). Integrating indigenous knowledge and engaging local communities ensures culturally appropriate and effective solutions. Long-term resilience and reduced vulnerability to future droughts require well-coordinated adaptation and mitigation efforts as climate change intensifies.

Research Gaps and Future Directions

A variety of socio-economic, environmental, and climatic factors contribute to the complex and ever-changing nature of drought. The understanding of the regional variability of drought is becoming increasingly critical in the development of effective mitigation strategies and the prediction of future risks as global temperatures increase. Nevertheless, the precise prediction of drought patterns continues to be a difficult task as a result of the disparities in regional climates, topography, and socio-economic conditions. Moreover, the separation of meteorological, agricultural, and hydrological drought studies and the constraints of current climate models further confound endeavours to offer comprehensive insights. In order to more effectively evaluate the effects of drought and develop adaptation strategies that are equitable and tailored to the specific requirements of the region, future research must prioritize the integration of climate and ecological models, as well as the consideration of socio-economic factors.

The climate patterns, topography, and socio-economic contexts of different regions result in substantial variations in drought projections. For example, while certain regions, such as the Mediterranean or East Africa, are at a higher risk of drought, Northern Europe may experience fewer droughts (Haile *et al.* 2020). It is difficult to develop adaptation strategies that are customized due to the absence of high-resolution regional models, which restricts the accuracy of projections. Studies that employ multiple climate models (e.g., CMIP5 and IPCC models) exhibit substantial variability in projections, which complicates the prediction of drought frequency, duration, and intensity under alternative emissions scenarios (Sheffield and Wood, 2008).

This variability complicates the evaluation of regional impacts and the formulation of effective mitigation policies. Agricultural, meteorological, and hydrological droughts are frequently separated in existing research. Integrated models that account for interactions between sectors (e.g., agriculture, water resources, and human demand) are essential for predicting the comprehensive impact of climate-induced droughts on various systems (Wanders and Wada, 2015). The incorporation of climate, hydrological, and ecological models in future research is necessary to more effectively convey the intricacies of drought. By taking into account the interactions between temperature, precipitation, soil moisture, vegetation health, and river movements, these models can enhance their predictions (Wan *et al.* 2018). Key feedback mechanisms, including changes in vegetation cover or water management policies, are frequently oversimplified in contemporary models. Robust feedback mechanisms between atmospheric conditions and land use changes are absent in numerous current models. The integration of vegetation response, soil moisture dynamics, and ecosystem processes will improve predictions, particularly in agricultural regions that have been impacted by protracted drought (Cook *et al.* 2018). Enhanced models will facilitate the evaluation of the extent to which these feedbacks affect the severity of droughts over time.

In order to identify populations that are most susceptible to drought, research should concentrate on territories that are prone to drought. Studies can develop resilient adaptation strategies for impacted communities by integrating climate data with social and economic indicators (e.g., income, agricultural reliance, infrastructure) (Lehner *et al.* 2017). There is a requirement for socio-economic modeling that assesses the influence of water policies, migration trends, and disaster relief initiatives on drought mitigation. This form of research has the potential to offer valuable insights to governments and NGOs that are striving to improve drought preparedness (Smirnov *et al.* 2016). Income, infrastructure, and social resilience are the primary factors that determine the effects of drought on different regions and populations. Research that prioritizes social justice and equity will guarantee that drought adaptation strategies are inclusive, thereby benefiting the most vulnerable populations (Nam *et al.* 2015).

CONCLUSION

The frequency and severity of droughts have been amplified by climate change, which has had a significant impact on human livelihoods, agriculture, water resources, and ecosystems. There are numerous interconnected forms of drought, including meteorological, agricultural, hydrological, and socioeconomic, which result in compounding challenges. The availability of water is diminished, precipitation patterns are disrupted, and evapotranspiration is accelerated by increasing temperatures. Agricultural productivity and water systems are further compromised by flash droughts, which exacerbates economic instability and food insecurity. Ecosystems are also compromised by water scarcity, which results in the degradation of forests, the loss of biodiversity, and the degradation of water quality. Malnutrition, disease outbreaks, and displacement as a result of livelihood losses all have an impact on human health. In order to mitigate future drought risks, it is imperative to implement effective mitigation strategies, such as sustainable agriculture, water-efficient technologies, and policy interventions. The integration of indigenous knowledge and proactive water management can enhance the resilience of communities. It is imperative that policymakers prioritize comprehensive solutions that optimize local adaptive capacities and mitigate greenhouse gas emissions. Future research should resolve gaps by establishing cross-sectoral strategies and high-resolution regional climate models. In order to mitigate climate risks and guarantee long-term environmental sustainability and socio-economic stability, it is imperative to implement coordinated global initiatives.

REFERENCES

Abbass, K., Qasim, M.Z., Song, H., Murshed, M., Mahmood, H. and Younis, I. 2022. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research,* **29**: 42539-42559.

Ahmadi, B. and Moradkhani, H. 2019. Revisiting hydrological drought propagation and recovery considering water quantity and quality. *Hydrological Processes,* **33**: 1492-1505.

Algur, K., Patel, S. and Chauhan, S. 2021. The impact of drought on the health and livelihoods of women and children in India: A systematic review. *Children and Youth Services Review,* **122**: 105909.

Almas, L.K., Colette, W.A. and Warminski, P.L. 2007. Reducing irrigation water demand with cotton production in West Texas. Paper presented at: Southern Agricultural Economics Association Annual Meeting, Mobile, AL, 4–7 Feb.

Amanullah, N., Khalid, S., Imran, N., Khan, H.A., Arif, M., Altawaha, A.R., Adnan, M., Fahad, S., Shah, A. and Parmar, B. 2020. Effects of Climate Change on Irrigation Water Quality. In Springer e-Books, pp. 123-132. https://doi.org/10.1007/978-3-030-49732-3_6

Anderegg, W., Anderegg, W., Schwalm, C., Biondi, F., Camarero, J., Koch, G., Litvak, M., Ogle, K., Shaw, J., Shevliakova, E., Williams, A., Wolf, A., Ziaco, E. and Pacala, S. 2015. Pervasive drought legacies in forest ecosystems and their implications for carbon cycle models. *Science*, **349**: 528-532.

Anderegg, W., Trugman, A., Bowling, D., Salvucci, G., and Tuttle, S. 2019. Plant functional traits and climate influence drought intensification and land–atmosphere feedbacks. *Proceedings of the National Academy of Sciences of the United States of America,* **116**: 14071-14076.

Anik, A., Rahman, S., Sarker, J. and Hasan, M. 2021. Farmers' adaptation strategies to combat climate change in drought-prone areas in Bangladesh. *International Journal of Disaster Risk Reduction.* https://doi.org/10.1016/j.ijdrr.2021.102562

Anita, W., Dominic, M. and Neil, A. 2010. Climate change and agriculture impacts, adaptation and mitigation: Impacts, adaptation and mitigation: OECD Publishing.

Battaglia, M., Lee, C., Thomason, W., Fike, J. and Sadeghpour, A. 2019. Hail damage impacts on corn productivity: A review. *Crop Science,* **59**: 1-14.

Bayer, L., Hurk, B., Strengers, B. and Minnen, J. 2012. Regional feedbacks under changing climate and land-use conditions. *Earth System Dynamics Discussions,* **3**: 201-234.

Bevacqua, E., Rakovec, O., Schumacher, D.L. *et al.* 2024. Direct and lagged climate change effects intensified the 2022 European drought. Nature Geoscience. https://doi.org/10.1038/s41561-024-01559-2

Bhat, V. 2020. Impact of droughts on industrial emissions into surface waters. *Environmental Science and Pollution Research,* **27**: 42806-42814.

Bogale, G.A. and Erena, Z.B. 2022. Drought vulnerability and impacts of climate change on livestock production and productivity in different agro-ecological zones of Ethiopia. *Journal of Applied Animal Research,* **50**: 471-489.

Breshears, D.D., Cobb, N.S., Rich, P.M., Price, K.P., Allen, C.D., Balice, R.G., Romme, W.H., Kastens, J.H., Floyd, M.L., Belnap, J., Anderson, J.J., Myers, O.B. and Meyer, C.W. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America, 102:15144-15148. https://doi.org/10.1073/pnas.0505734102

Carnicer, J., Coll, M., Ninyerola, M., Pons, X., Sánchez, G. and Peñuelas, J. 2011. Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. *Proceedings of the National Academy of Sciences,* **108**: 1474-1478.

Chang, T.J. 1991. Investigation of precipitation droughts by use of kriging method. *Journal of Irrigation and Drainage Engineering,* **117**: 935-943.

Chang, H. and Bonnette, M.R. 2016. Climate change and water-related ecosystem services: impacts of drought in California, SA. *Ecosystem Health and Sustainability,* **2**: 12.

Choat, B., Jansen, S., Brodribb, T., Cochard, H., Delzon, S., Bhaskar, R., Bucci, S., Feild, T., Gleason, S., Hacke, U., Jacobsen, A., Lens, F., Maherali, H., Martínez-Vilalta, J., Mayr, S., Mencuccini, M., Mitchell, P., Nardini, A., Pittermann, J., Pratt, R., Sperry, J., Westoby, M., Wright, I. and Zanne, A. 2012. Global convergence in the vulnerability of forests to drought. *Nature,* **491**: 752-755.

Cook, B.I., Smerdon, J.E., Seager, R. and Coats, S. 2014. Global warming and 21st-century drying. *Climate Dynamics,* **43**: 2607-2627.

Cook, B.I., Mankin, J.S. and Anchukaitis, K.J. 2018. Climate change and drought: From past to future. *Current Climate Change Reports,* **4**: 164-17.

Corso, D., Delzon, S., Lamarque, L.J., Cochard, H., Torres-Ruiz, J.M., King, A. and Brodribb, T. 2020. Neither xylem collapse, cavitation, nor changing leaf conductance drive stomatal closure in wheat. *Plant Cell and Environment,* **43**: 854-865.

Dai, R., Huang, J., Chen, Z., Zhou, J. and Havea, P.H. 2024. Impacts of anthropogenic climate change on meteorological drought in China. *Frontiers in Earth Science,* **12**: 1369523.

Dai, A., Zhao, T. and Chen, J. 2018. Climate change and drought: A precipitation and evaporation perspective. *Current Climate Change Reports,* **4**: 301-312.

Delpla, I., Jung, A., Baurès, E., Clément, M. and Thomas, O. 2009. Impacts of climate change on surface water quality in relation to drinking water production. *Environment International,* **35**: 1225-1233.

Deng, L., Peng, C., Kim, D., Li, J., Liu, Y., Hai, X., Liu, Q., Huang, C., Shangguan, Z. and Kuzyakov, Y. 2021. Drought effects on soil carbon and nitrogen dynamics in global natural ecosystems. *Earth-Science Reviews,* **214**: 103501.

Dessai, S. and Sims, C. 2010. Public perception of drought and climate change in Southeast England. *Environmental Hazards,* **9**: 340-357.

Dracup, J.A., Lee, K.S. and Paulson, E.G. 1980. On the statistical characteristics of drought events. *Water Resources Research,* **16**: 289-296.

Dunn, J. and Bórawski, P. 2012. The effect of the 2012 U.S. drought on global grain markets: A measure of globalization. *SJ-Economics Scientific Journal.* https://doi.org/10.58246/sjeconomics.v10i.453

Elemike, E.E., Uzoh, I.M., Onwudiwe, D.C. and Babalola, O.O. 2019. The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. *Applied Sciences,* **9**: 499.

Elgendy, M., Hassini, S. and Coulibaly, P. 2024. Review of climate change adaptation strategies in water management. *Journal of Hydrologic Engineering.* https://doi.org/10.1061/jhyeff.heeng-6014

Elum, Z., Modise, D. and Marr, A. 2016. Farmers' perception of climate change and responsive strategies in three selected provinces of South Africa. *Climate Risk Management,* **16**: 246-257.

Falloon, P. and Betts, R. 2010. Climate impacts on European agriculture and water management in the context of adaptation and mitigation: The importance of an integrated approach. *Science of the Total Environment,* **408**: 5667-5687.

Feliciano, D., Recha, J., Ambaw, G., MacSween, K., Solomon, D. and Wollenberg, E. 2022. Assessment of agricultural emissions, climate change mitigation, and adaptation practices in Ethiopia. *Climate Policy,* 1-18. https://doi.org/10.1080/14693062.2022.2028910

Forrest, K., Tarroja, B., Chiang, F., Aghakouchak, A. and Samuelsen, S. 2018. Assessing climate change impacts on California hydropower generation and ancillary services provision. *Climatic Change,* **151**: 395-412.

Gana, A.H. and Sa'id, A.I. 2022. Importance of climate change adaptation in drought mitigation: A review. *UMYU Journal of Microbiology Research (UJMR).* https://doi.org/10.47430/ujmr.2272.006

Gautier, D., Denis, D. and Locatelli, B. 2016. Impacts of drought and responses of rural populations in West Africa: A systematic review. *Wiley Interdisciplinary Reviews Climate Change,* **7**: 666-681.

Gerrard, M. 2016. Climate change and human trafficking after the Paris Climate Agreement. *Human Rights & the Global Economy e-Journal*. https://doi.org/10.7916/D8T43T72

Gurian-Sherman, D. 2012. High and dry: Why genetic engineering is not solving agriculture's drought problem in a thirsty world. UCS Publications, Cambridge, MA.

Habte, M., Eshetu, M., Maryo, M., Andualem, D. and Legesse, A. 2022. Effects of climate variability on livestock productivity and pastoralists' perception: The case of drought resilience in Southeastern Ethiopia. *Veterinary and Animal Science,* **16**: 100240.

Haile, G., Tang, Q., Hosseini-Moghari, S., Liu, X., Gebremicael, T., Leng, G., Kebede, A., Xu, X. and Yun, X. 2020. Projected impacts of climate change on drought patterns over East Africa. *Earth's Future,* **8**.

Hanson, P. and Weltzin, J. 2000. Drought disturbance from climate change: Response of United States forests. *Science of the Total Environment,* **262**: 205-220.

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M. and Meinke, H. 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences USA,* **104**: 19691-19696.

Huang, B., Yan, D., Wang, H., Cheng, B. and Cui, X. 2015. Effects of water quality of the basin caused by nitrogen loss from soil in drought. *Natural Hazards,* **75**: 2357-2368.

Huss, M. and Hock, R. 2018. Global-scale hydrological response to future glacier mass loss. *Nature Climate Change,* **8**: 135-140.

Iglesias, A. and Garrote, L. 2015. Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, **155**: 113-124.

IPCC. 2021. Climate change. In *The Physical Science Basis***.** Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, eds. V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, et al. Cambridge: Cambridge University Press.

Jaaskelainen, J., Veijalainen, N., Syri, S., Marttunen, M. and Zakeri, B. 2018. Energy security impacts of a severe drought on the future Finnish energy system. *Journal of Environmental Management*, **217**: 542-554.

Kahil, M., Dinar, A. and Albiac, J. 2015. Modeling water scarcity and droughts for policy adaptation to climate change in arid and semi-arid regions. *Journal of Hydrology*, **522**: 95-109.

Kaisermann, A., de Vries, F., Griffiths, R. and Bardgett, R. 2017. Legacy effects of drought on plant-soil feedbacks and plant-plant interactions. *New Phytologist*, **215**: 1413-1424.

Kang, Y., Khan, S. and Ma, X. 2009. Climate change impacts on crop yield, crop water productivity, and food security: A review. *Progress in Natural Science*, **19**: 1665-1674.

Keshavarz, M., Maleksaeidi, H. and Karami, E. 2017. Livelihood vulnerability to drought: A case of rural Iran. *International Journal of Disaster Risk Reduction*, **21**: 223-230.

Koubi, V., Stoll, S. and Spilker, G. 2016. Perceptions of environmental change and migration decisions. *Climatic Change*, **138**: 439-451.

Lehner, F., Coats, S., Stocker, T.F., Pendergrass, A.G., Sanderson, B.M., Raible, C.C. and Smerdon, J.E. 2017. Projected drought risk in 1.5°C and 2°C warmer climates. *Geophysical Research Letters*, **44**: 7419-7428.

Lei, Y., Wang, J., Yue, Y., Yin, Y. and Sheng, Z. 2014. How adjustments in land use patterns contribute to drought risk adaptation in a changing climate: A case study in China. *Land Use Policy*, **36**: 577-584.

Leng, G. and Hall, J. 2019. Crop yield sensitivity of global major agricultural countries to droughts and the projected changes in the future. *Science of the Total Environment*, **654**: 811-821.

Li, D., Miller, J. and Harrison, S. 2019. Climate drives loss of phylogenetic diversity in a grassland community. *Proceedings of the National Academy of Sciences*, **116**: 19989-19994.

MacDonald, A., Calow, R., Macdonald, D., Darling, W. and Dochartaigh, B. 2009. What impact will climate change have on rural groundwater supplies in Africa? *Hydrological Sciences Journal*, **54**: 690-703.

Madadgar, S., Agha Kouchak, A., Farahmand, A. and Davis, S.J. 2017. Probabilistic estimates of drought impacts on agricultural production. *Geophysical Research Letters*, **44**: 7799-7807.

Masroor, M., Rehman, S., Avtar, R., Sahana, M., Ahmed, R.U. and Sajjad, H. 2020. Exploring climate variability and its impact on drought occurrence: Evidence from Godavari Middle sub-basin, India. *Weather and Climate Extremes*, **30**: 100277.

Medellín-Azuara, J., Howitt, R., MacEwan, D. and Lund, J. 2011. Economic impacts of climate-related changes to California agriculture. *Climatic Change*, **109**: 387-405.

Melkamu, B.N. 2017. The effects of El Niño on agricultural GDP of Ethiopia. *American Journal of Water Science and Engineering*, **3**: 45-49.

Mello, C., Vieira, N., Guzman, J., Viola, M., Beskow, S. and Alvarenga, L. 2021. Climate change impacts on water resources of the largest hydropower plant reservoir in southeast Brazil. *Water*, **13**: 1560.

Miralles, D., Gentine, P., Seneviratne, S. and Teuling, A. 2018. Land-atmospheric feedbacks during droughts and heatwaves: State of the science and current challenges. *Annals of the New York Academy of Sciences*, **1436**: 19-35.

Mishra, A., Bruno, E. and Zilberman, D. 2020. Compound natural and human disasters: Managing drought and COVID-19 to sustain global agriculture and food sectors. *Science of the Total Environment*, **754**: 142210.

Mosley, L. 2015. Drought impacts on the water quality of freshwater systems: Review and integration. *Earth-Science Reviews*, **140**: 203-214.

Mostofa, M.G., Ghosh, A., Li, Z.G., Siddiqui, M.N., Fujita, M. and Tran, L.S.P. 2018. Methylglyoxal—a signaling molecule in plant abiotic stress responses. *Free Radical Biology and Medicine*, **122**: 96-109.

Murshed, M., Nurmakhanova, M., Al-Tal, R., Mahmood, H., Elheddad, M. and Ahmed, R. 2022. Can intra-regional trade, renewable energy use, foreign direct investments, and economic growth reduce ecological footprints in South Asia? Energy Sources, Part B: Economics, Planning, and Policy. https://doi.org/10.1080/15567249.2022.2038730

Nam, W., Hayes, M., Svoboda, M., Tadesse, T. and Wilhite, D. 2015. Drought hazard assessment in the context of climate change for South Korea. *Agricultural Water Management*, **160**: 106-117.

Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R.A., Carrao, H. *et al.* 2018. Global changes in drought conditions under different levels of warming. *Geophysical Research Letters*, **45**: 3285-3296.

Nunes, J., Jacinto, R. and Keizer, J. 2017. Combined impacts of climate and socio-economic scenarios on irrigation water availability for a dry Mediterranean reservoir. *Science of the Total Environment*, **584-585**: 219-233.

Nyong, A., Adesina, F. and Elasha, B. 2007. The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change*, **12**: 787-797.

Oguntunde, P.G., Abiodun, B.J., Lischeid, G. and Abatan, A.A. 2020. Droughts projection over the Niger and Volta River basins of West Africa at specific global warming levels. *International Journal of Climatology*, **40**: 5688-5699.

Parker, B.A., Lisonbee, J., Ossowski, E., Prendeville, H.R. and Todey, D. 2023. Drought assessment in a changing climate:

Priority actions and research needs. NOAA Technical Memorandum OAR CPO-002.

Phillips, O.L., Aragão, L.E.O.C., Lewis, S.L., Fisher, J.B., Lloyd, J., Lopez-Gonzalez, G. *et al.* 2009. Drought sensitivity of the Amazon rainforest. *Science,* **323**: 1344-1347.

Pokhrel, Y., Felfelani, F., Satoh, Y., Boulange, J., Burek, P., Gädeke, A. *et al.* 2021. Global terrestrial water storage and drought severity under climate change. *Nature Climate Change,* **11**: 226-233.

Qing, Y., Wang, S., Yang, Z. and Gentine, P. 2023. Soil moisture-atmosphere feedbacks have triggered the shifts from drought to pluvial conditions since 1980. *Communications Earth & Environment,* **4**(1): Article 9.

Qiu, M., Ratledge, N., Azevedo, I., Diffenbaugh, N. and Burke, M. 2023. Drought impacts on the electricity system, emissions, and air quality in the western United States. *Proceedings of the National Academy of Sciences,* **120**(28): e2300395120.

Qureshi, M.E., Hanjra, M.A. and Ward, J. 2013. Impact of water scarcity in Australia on global food security in an era of climate change. *Food Policy,* **38**: 136-145.

Rabbani, G., Huq, S. and Rahman, S. 2012. Impacts of climate change on water resources and human health: Empirical evidences from a coastal district (Satkhira) in Bangladesh. In *Climate Change and Food Security in South Asia*, pp. 272-285. https://doi.org/10.1201/B14323-18

Ravindranath, N. 2007. Mitigation and adaptation synergy in the forest sector. *Mitigation and Adaptation Strategies for Global Change,* **12**: 843-853.

Rosen, J., Mulenga, D., Phiri, L., Okpara, N., Brander, C., Chelwa, N. and Mbizvo, M. 2021. "Burnt by the scorching sun": Climate-induced livelihood transformations, reproductive health, and fertility trajectories in drought-affected communities of Zambia. BMC Public Health, 21: Article 11560. https://doi.org/10.1186/s12889-021-11560-8

Salinas, C. and Mendieta, J. 2013. Effectiveness of the strategies to combat land degradation and drought. *Mitigation and Adaptation Strategies for Global Change,* **18**: 1269-1281.

Schutte, S., Gemenne, F., Zaman, M.H., Flahault, A. and Depoux, A. 2018. Connecting planetary health, climate change, and migration. *The Lancet Planetary Health,* **2**(2): e58-e59.

Seager, R., Liu, H., Henderson, N., Simpson, I., Kelley, C., Shaw, T., Kushnir, Y. and Ting, M. 2014. Causes of increasing aridification of the Mediterranean region in response to rising greenhouse gases. *J. Climate.*, **27**(12): 4655-4676.

Seleiman, M.F. Kheir, A.M. 2018. Saline soil properties, quality and productivity of wheat grown with bagasse ash and thiourea in different climatic zones. *Chemosphere,* **193**: 538–546.

Sheffield, J. and Wood, E. 2008. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. *Clim. Dyn.,* **31**: 79-105.

Smirnov, O., Zhang, M., Xiao, T., Orbell, J., Lobben, A. and Gordon, J. 2016. The relative importance of climate change and population growth for exposure to future extreme droughts. *Clim. Change,* **138**: 41-53.

Smith, L., Aragão, L., Sabel, C. and Nakaya, T. 2014. Drought impacts on children's respiratory health in the Brazilian Amazon. *Sci. Rep.,* **4**.

Sobhanian, H., Pahlavan, S. and Meyfour, A. 2020. How does proteomics target plant environmental stresses in a semi-arid area? *Mol. Biol. Rep.,* **47**: 3181–3194.

Stanke, C., Kerac, M., Prudhomme, C., Medlock, J. and Murray, V. 2013. Health effects of drought: A systematic review of the evidence. *PLoS Curr.,* **5**.

Sternberg, T. 2012. Chinese drought, bread and the Arab Spring. *Appl. Geogr.,* **34**: 519-524.

Tamagnone, P., Comino, E. and Rosso, M. 2020. Rainwater harvesting techniques as an adaptation strategy for flood mitigation. *J. Hydrol.,* **586**: 124880.

Thornton, P.K., Herrero, M.T. and Ericksen, P.J. 2011. Livestock and climate change. Livestock Thematic Papers Tools for project design (pp. 20): International Fund for Agricultural Development (IFAD).

Trenberth, K.E., Dai, A., Van Der Schrier, G., Jones, P.D., Barichivich, J., Briffa, K.R. and Sheffield, J. 2013. Global warming and changes in drought. *Nat. Clim. Change,* **4**(1): 17–22.

Ulrichs, M., Slater, R. and Costella, C. 2019. Building resilience to climate risks through social protection: From individualised models to systemic transformation. *Disasters,* **43**: S368-S387.

Vliet, M. and Zwolsman, J. 2008. Impact of summer droughts on the water quality of the Meuse river. *J. Hydrol.,* **353**: 1-17.

Vliet, M., Sheffield, J., Wiberg, D. and Wood, E. 2016. Impacts of recent drought and warm years on water resources and electricity supply worldwide. *Environ. Res. Lett.,* **11**.

Wako, G., Tadesse, M. and Angassa, A. 2017. Camel management as an adaptive strategy to climate change by pastoralists in southern Ethiopia. *Ecol. Process.,* **6**(1): 1–12.

Wan, W., Zhao, J., Li, H., Mishra, A., Hejazi, M., Lu, H., Demissie, Y. and Wang, H. 2018. A holistic view of water management impacts on future droughts: A global multimodel analysis. *J. Geophys. Res.: Atmos.,* **123**: 5947 - 5972.

Wanders, N. and Wada, Y. 2015. Human and climate impacts on the 21st century hydrological drought. *J. Hydrol.,* **526**: 208-220.

Wilhite, D.A. 2000. Drought as a natural hazard: Concepts and definitions. *In:* Droughts: A global assessment, Wilhite, D.A. (Ed.), Routledge, pp. 3–18.

Wright, B., Stanford, B., Reinert, A., Routt, J., Khan, S. and Debroux, J. 2014. Managing water quality impacts from drought on drinking water supplies. *J. Water Supply Res. Technol.-Aqua,* **63**: 179-188.

Yeşilkoy, S., Baydaroglu, O. and Demir, I. 2024. Is snow drought a messenger for the upcoming severe drought period? A case study in the Upper Mississippi River Basin. *Atmos. Res.*, **309**: 107553.

Zargar, S.M., Gupta, N., Nazir, M., Mahajan, R., Malik, F.A., Sofi, N.R., Shikari, A.B. and Salgotra, R.K. 2017. Impact of drought on photosynthesis: Molecular perspective. *Plant Gene*, **11**: 154–159.

Zeng, Z., Wu, W., Peñuelas, J. *et al.* 2023. Increased risk of flash droughts with raised concurrent hot and dry extremes under global warming. *npj Clim. Atmos. Sci.*, **6**: 134.

Zhao, M. and Boll, J. 2022. Adaptation of water resources management under climate change. *Front. Water*, **4**.