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Public Health Implications of Drought in a Climate Change Context: A Critical Review

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Keywords

climate change, drought trends, human health, vulnerability, drought risk management

Abstract

Extreme weather events are expected to increase due to climate change, which could pose an additional burden of morbidity and mortality. In recent decades, drought severity has increased in several regions around the world, affecting health by increasing the risk of water-, food-, and vector-borne diseases, malnutrition, cardiovascular and respiratory illness, mental health disorders, and mortality. Drought frequency and severity are expected to worsen across large regions as a result of a decrease in precipitation and an increase in temperature and atmospheric evaporative demand, posing a pressing challenge for public health. Variation in impacts among countries and communities is due to multiple factors, such as aging, socioeconomic status, access to health care, and gender, affecting population resilience. Integrative proactive action plans focused on risk management are required, and resources should be transferred to developing countries to reduce their vulnerability and risk.

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1. INTRODUCTION

Climate change is currently considered one of the greatest threats to human health. According to the recent Intergovernmental Panel on Climate Change (IPCC) report, climate hazards increasingly contribute to a growing number of adverse health outcomes in multiple geographical areas (59). In the absence of additional actions, climate change will exacerbate the current health burden and alter the geographic range of climate-sensitive health outcomes and functioning of public health and health care systems (53).

Climate change, through increases in the frequency and intensity of extreme weather events, affects health through multiple pathways, leading to short-term shocks or changes in temporal patterns of climate-sensitive diseases (37, 97). Extreme weather events, such as heat waves, droughts, and floods, are associated with an increased risk of hospitalizations and mortality due to various diseases, including cardiovascular, respiratory, mental health, and renal diseases (48, 52, 87). In addition, climate alters environmental risk factors, such as pollen and air pollution, leading to an increased risk of cardiovascular and respiratory outcomes, including death (9, 88, 126). The incidence and geographical spread of vector-borne, waterborne, and foodborne infectious diseases, such as dengue, malaria, and diarrheal diseases, have changed during the last several decades, driven mostly by changes in climate extremes, climate variability, and geographic environmental conditions (97). Furthermore, climate change could drive multifaceted influences on food production systems and water resources, which would lead to increased undernutrition, poverty, conflicts, and migration. Several of these mechanisms can happen simultaneously in time and space, resulting in compounding or cascading impacts, which, when coupled with higher vulnerability, would translate into magnified health effects (59).

In addition to the progressive warming and changing patterns in climate-related hazards, existing societal challenges, such as social inequality, progressive urbanization, and aging populations, will likely amplify the health burden attributed to climate change (22, 151). For instance, vulnerable and marginalized populations are and will continue to be disproportionately impacted by climate change, including impoverished and undernourished communities, those in poor housing, people with chronic conditions, and elderly populations. Therefore, future climate change trends will likely exacerbate existing health and social inequalities, enhancing vulnerability to climate-related hazards (59, 97).

Drought is one of the climate hazards with the most far-reaching effects and impacts a multitude of sectors, such as agriculture, water availability, livestock breeding, ecosystems, and food supply (144). Compound and cascading impacts that are often associated with droughts, such as intensification of heat waves and a higher risk of wildfires and sandstorms, as well as the interaction between these events and emerging threats, such as the COVID-19 pandemic, can amplify morbidity and mortality risks, particularly in vulnerable populations (59, 119). For instance, more than 50 million people were simultaneously affected by climate-related hazards and COVID-19 in 2020, leading to escalating threats and new challenges in responding to health and economic emergencies (97, 145). Moreover, these situations may occur with a lag in time and space, complicating their identification and evaluation. An estimated 1.43 billion people were severely affected by droughts between 2019 and 2020, and the damages associated with drought and floods reached US$764 billion (27). However, these figures may be underestimated due to deficiencies in the drought monitoring systems of poor countries, and these countries are usually the ones most affected; knowledge of costs of indirect and long-term impacts is limited (45).

This article analyzes the observed and projected trends in drought occurrence, assesses the main impacts of drought on health, and provides an overview of prevention and adaptation policies, providing recommendations to address future threats of climate change and to enhance resilience. **Figure 1** summarizes the conceptualization of drought, the mechanisms through which this

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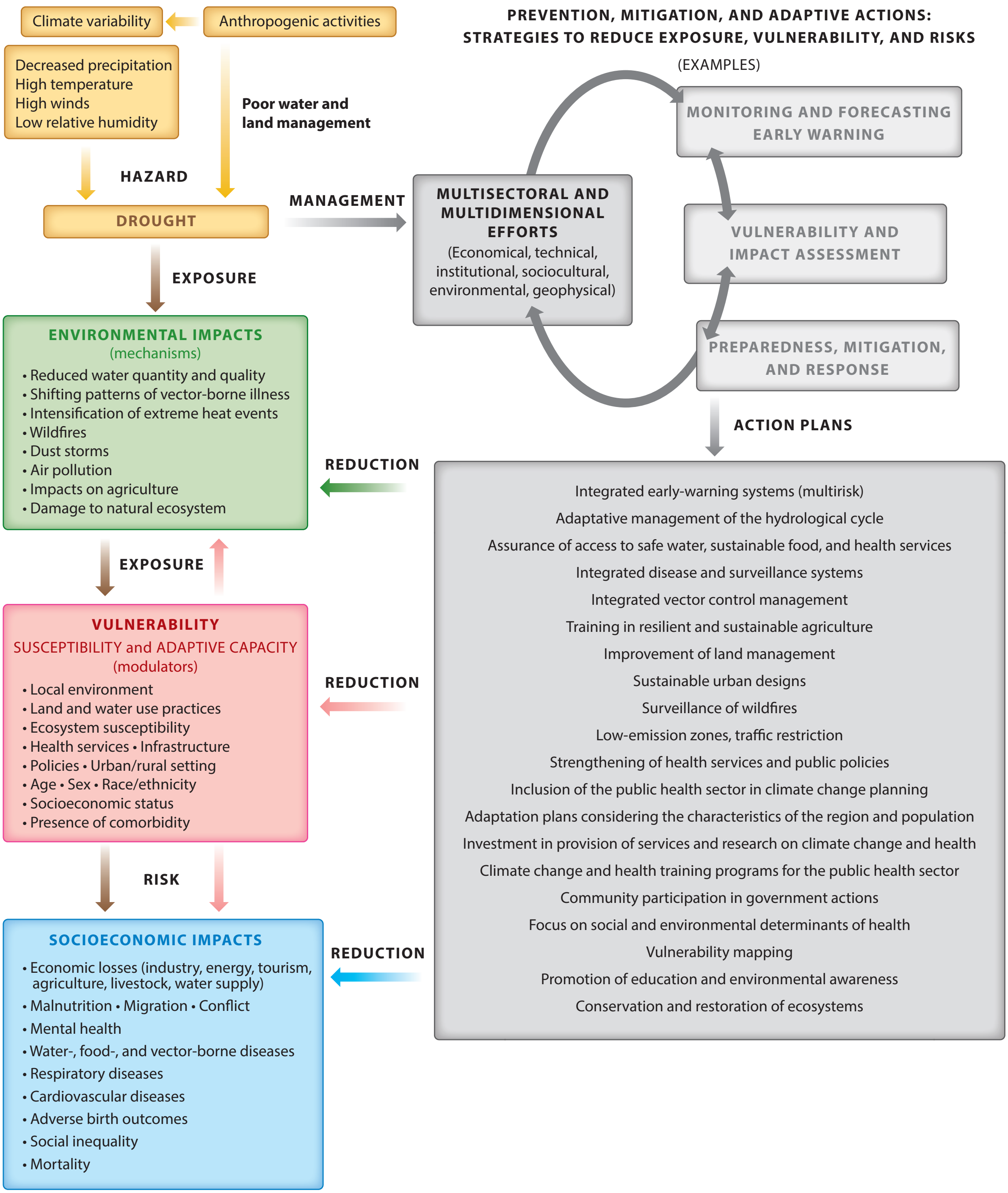

(*Caption appears on following page*)

Figure 1 (*Figure appears on preceding page*)

Conceptual diagram on the main mechanisms through which drought impacts human health under a climate change context, vulnerability factors (social, economic, and environmental), and strategies to manage drought risks. Drought-related health risks are the result of the interaction of the hazard (e.g., the severity of the drought event), the extent of exposure, and vulnerability (susceptibility to impacts, adaptive capacity, and ability to cope with drought).

phenomenon impacts human health, the potential effect modifiers, and strategies to manage drought from an integrative approach, which is addressed in depth in the following sections.

2. DROUGHT EVENTS IN A CHANGING CLIMATE

Whether drought has increased in recent decades is unclear because the assessment of recent drought trends is complex (30, 117). Paradoxically, the availability of generalized meteorological, hydrological, and environmental observations in the last century did not produce robust assessments of drought trends due to highly complex and imprecise definitions of droughts (66) and the variety of drought types. Drought is impact dependent and may refer to damages to agriculture (e.g., crop yield failure) and ecosystems (e.g., tree mortality); the hydrological dimension, including reductions in streamflow and reservoir or groundwater storage; and socioeconomic implications. Common classification distinguishes between meteorological, agricultural, hydrological, socioeconomic, and ecological (or environmental) droughts, preventing a straightforward drought assessment (144). Moreover, drought cannot be directly measured, and a unique variable to provide an absolute assessment of drought severity is lacking. Thus, various direct (e.g., precipitation, streamflow) or indirect drought metrics (e.g., vegetation measurements) may provide different temporal anomalies and trends.

Drought quantification is usually based on climate data, as most events have a climatic origin, and drought trends have usually been analyzed with climate drought indices (79). Precipitation is the main variable controlling variability and trends; however, precipitation shows strong temporal variability related to the influence of large-scale circulation mechanisms, such as El Niño–Southern Oscillation, which mask the identification of trends associated with climate change (30, 117). Global studies based on precipitation do not show trends in drought severity in recent decades (30, 84, 107, 111).

Nevertheless, other variables trigger or exacerbate drought. The most important variable during climate change is temperature increase, which has increased atmospheric evaporative demand (AED) in recent decades (131). This increased demand has reinforced drought severity (*a*) by increasing actual evapotranspiration (E_t) in land areas and reducing soil moisture (115), water storages (42), and streamflow (129, 132), and (*b*) by enhancing plant stress in ecosystems and agricultural lands (6, 16). AED influence on drought severity has been particularly relevant during the warm season in periods of precipitation deficits, when the effects of AED on water resources and plants would be multiplicative (116). Global studies based on climate drought indices suggest an increase in drought severity associated with higher AED (29, 31, 32, 109, 111), particularly in subtropical and semiarid regions, such as West, Central, and Southern Africa, the Mediterranean, Western North America, and regions of Australia, East Asia, and South America (**Figure 2*a***).

Changes in drought severity have reinforced some drought impacts; however, few studies have analyzed the influence of recent trends on changes in impacts. Nevertheless, studies on environmental systems have stressed that stronger megafires (2) and more frequent forest mortality episodes (7, 41) are consequences of drought events characterized by warmer conditions. These findings are consistent with increased stress in agricultural systems, in which higher AED has reduced crop yields during periods of precipitation deficits (67). Agricultural and ecological drought

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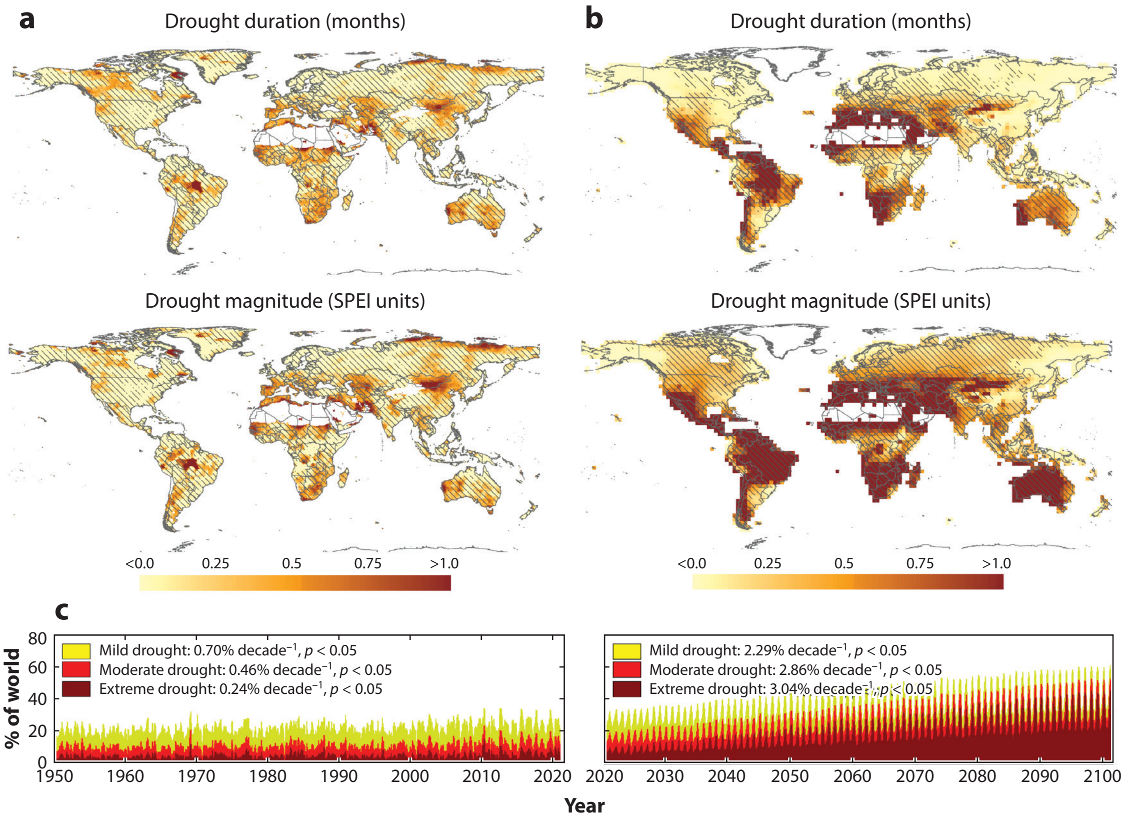

Figure 2

(*a*) Trends in the drought duration and magnitude based on the 12-month SPEIbase (**https://spei.csic.es/spei_database**) calculated with data from the CRU from 1950 to 2020 based on the SSP5–8.5 scenario. Striping represents areas characterized by nonstatistically significant changes ($p > 0.05$, based on the Mann-Kendall test). (*b*) Trends in drought duration and magnitude based on the SPEI calculated with data from 18 CMIP6 models between 2020 and 2100 for the SSP5–8.5 scenario. Striping represents areas in which 70% of the models show a statistically significant trend ($p < 0.05$). (*c*) The evolution of the percentage of the world affected by mild, moderate, and extreme drought conditions from 1950 to 2020 (*left*) and from 2020 to 2100 (*right*). Abbreviations: CMIP, Coupled Model Intercomparison Project; CRU, Climate Research Unit; SPEI, Standardised Precipitation Evapotranspiration Index; SSP, shared socioeconomic pathway.

severity has increased in recent decades (107), causing a cascade of socioeconomic effects in regions that strongly depend on agriculture and livestock (46).

The assessment of future drought projections is uncertain given the complexity of the processes involved, which include radiative and physiological effects of atmospheric CO_2 concentrations and uncertainties in precipitation projections by Earth system models (59). Projections show a reinforcement of meteorological droughts in some regions, such as the Mediterranean, South, North, and Central America, southern Africa, and southern Australia (73, 107), due to projected precipitation decrease (34). These projections would exacerbate soil moisture and hydrological deficits (26, 153). The current scientific debate focuses on increased AED projected in scenarios of high greenhouse gas emissions (130), which expands the areas affected by drought trends beyond regions where precipitation deficits are projected (13).

Consensus finds that increased AED would increase the evapotranspiration deficit (i.e., the difference between land evapotranspiration and AED) and increase plant water stress. Therefore, the

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limited increase in drought severity beyond areas of precipitation decrease, which is suggested by projections of streamflow and soil moisture (26), seems to contradict impact model results, which suggests a reinforcement of drought severity with strong agricultural and ecological implications (6, 47, 147). Thus, reinforcement of drought severity is likely in areas that project a precipitation increase. Precipitation projections for future climate scenarios show increased decadal and interannual precipitation variability (90, 114); therefore, periods of precipitation deficits are also expected in areas where precipitation is projected to increase. During these periods, higher AED would exacerbate agricultural/ecological and hydrological drought severity. This pattern has been observed in regions that showed precipitation increase in recent decades, such as the British Isles and Scandinavia, which have been affected by extreme droughts associated with precipitation deficits and increased AED (65, 91, 118).

Projections based on the Palmer Drought Severity Index (PDSI) (32, 152, 153) and Standardised Precipitation Evapotranspiration Index (SPEI) (23, 110, 138, 150) suggest greater drought severity in future climate scenarios in more areas than indicated by projections of soil moisture and streamflow in the Coupled Model Intercomparison Project (CMIP). In the worst future climate scenario, the main increase in drought severity is projected by these metrics in large areas, including most of Europe, North and Central America, the Amazon basin, North Africa, the Middle East, South Africa, Australia, and Southeast Asia (81, 107, 153) (**Figure 2*b***).

The effects of this projected increase could go beyond the effects described above, affecting the CO_2 emissions from land areas (49), soil carbon storage (28), and air quality. Thus, Wang et al. (139) estimated that the concentrations of O_3 and $PM_{2.5}$ would increase due to drought by 1.6% and 1.16%, respectively, in the United States by 2100. These projected changes could be influenced by the combined effects of drought on natural emissions (e.g., increased frequency and severity of wildfires, dust intrusions, volatile organic compounds), deposition (e.g., reduction of dry ozone deposition to vegetation), and atmospheric chemistry (e.g., reduction of wet scavenging of pollutants; changes in the production, loss, or lifetime of pollutants in the atmosphere) (139). In addition, drought is often accompanied by high temperature events, which have substantial effects on some pollutants such as tropospheric ozone (92). Furthermore, the frequency of hydrological droughts and wildfires is projected to increase (59, 95) and periods of water scarcity are projected to dramatically increase (135), with serious socioeconomic consequences.

3. DROUGHT IMPACTS ON HEALTH AND HUMAN WELL-BEING: A COMPREHENSIVE APPROACH

While there is substantive literature on the impact of drought on agriculture and the environment, studies on the effect of drought on human health are limited in part because drought-related health impacts are essentially indirect, accumulative, and cascading and include various mechanisms, all of which make assessment difficult (51, 103). Drought constitutes a significant concern for humankind, as it has been associated with health problems such as water- and vector-borne diseases, cardiovascular and respiratory conditions, injuries, kidney conditions, esophageal cancer, food insecurity and malnutrition, mental health disorders, and mortality (11, 12, 36, 93, 112, 119, 134, 149). In particular, drought was one of the deadliest climate-related phenomena between 1970 and 2019, mostly in Africa (146).

Drought impacts on public health are unevenly distributed across countries, across territories within countries, and within population groups, exacerbating existing social inequalities and influencing future vulnerability (59). Higher exposure and vulnerability (increased susceptibility and/or reduced adaptive capacity) lead to higher risks related to drought (60). Differences in vulnerability and exposure usually arise from nonclimatic factors, such as socioeconomic status and

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inequalities based on social constructs. Harmful effects of drought on health often fall disproportionately on children, the older population, pregnant women, chronic patients, outdoors workers, marginalized individuals, and impoverished people or who are affected by other social determinants of health (59, 62, 77, 105, 106, 119, 140). Evidence indicates that drought exposure during pregnancy can affect a child's health by reducing height and weight, especially among children born to low-educated, poor, and rural mothers (62). Several studies indicate that older populations are often more at risk of drought-related mortality than are younger adults due to their higher vulnerability (77, 101, 105); however, there can be some regional exceptions, as shown in a recent study conducted in Nebraska, United States, where authors speculate that different outdoor exposure levels could have influenced differences in drought risks on mortality by age (1). On the other hand, drought can have different effects on women and men; women are especially vulnerable in developing countries because they often face discrimination, as reflected in lower salaries, limited education opportunities, and exclusion from political and decision-making processes (33, 119). In these countries, there are unequal power relationships between men and women, such that women often have lower access to and control of resources to cope with extreme weather hazards such as drought, a higher likelihood of lower health literacy, and lower socioeconomic positions, all of which make them more vulnerable to drought events (119). Moreover, women often suffer a higher work burden during drought events and harmful consequences linked to traveling long distances in search of water for domestic uses (5, 140). However, current studies of drought effects on mortality show inconsistent patterns, with larger mortality risks among women in Brazil (105) and Nebraska (1) and among men in Lisbon (101). Lynch et al. (71) did not observe differences in the association between drought and all causes of death between adult women and men across the whole United States. Lynch et al. (71) and Abadi et al. (1) also suggest that race may be an important predictor of social and environmental inequalities and a modifier of the effect.

3.1. Waterborne Diseases and Water-Related Effects

Drought influences the risk of waterborne diseases through its impact on water availability and quality (11, 37, 100, 112). Drought effects on water quality are complex and depend on watershed characteristics and climate and environmental conditions (75, 78, 131). The reduction of streamflow and groundwater levels during drought events favors stagnant water conditions and pollution, such as chemicals, metals, and solid particles (21, 37, 112, 149). For instance, a recent study in the United States predicted an increase in arsenic exposure in domestic wells that is associated with drought (68). Nutrients and turbidity often decrease during droughts due to a lack of catchment runoff, increase in sedimentation, and the influence of internal processes (e.g., biological uptake of nutrients, denitrification due to longer water residence times); however, changes are dependent on land-use settings and types of source pollution (75, 78, 119, 131). Drought can impact fecal coliform levels in streams, but studies show inconsistent effects; some results suggest an increase due to higher stock use of waterways and lack of flushing flows, whereas others reveal a reduction (20, 78). However, drought events followed by intense rainfall conditions can lead to peaks in diseases caused by pathogens, such as species of the genus *Cryptosporidium*, *Campylobacter*, or *Escherichia coli* (43, 82, 149). Also, warmer and more stratified water often associated with drought events promotes the growth of microorganisms, including an increase in toxic cyanobacterial blooms, such as species of *Anabaena* and *Microcystis*, and a reduction in dissolved oxygen. Furthermore, drought events have been associated with an increase in salt levels due to lower dilution and to the intrusion of seawater into freshwater aquifers, compromising water security (75, 78, 100, 119, 149). Climate change is expected to increase future health risks associated with waterborne diseases and cause the expansion of pathogens such as *Vibrio* sp. due to warmer and saltier water as a result of increased temperatures and reduced precipitation (59).

A decreased water supply during drought combined with an increase in water demand for various uses, such as residential, agricultural, and commercial uses as well as for energy and sanitation, can lead to or exacerbate water scarcity (100, 119). Limited water resources during drought events force people to use unsafe water for domestic uses or for irrigating fields and can lead to reduced hygiene practices, increasing the risk of water- and foodborne diseases and skin and eye infections (5, 8, 10, 21, 43, 54, 112). Populations with low socioeconomic status and limited access to basic services such as water and sanitation, as in Africa and Asia, are particularly vulnerable (5, 59, 119). A recent study showed a substantial effect of long-term drought exposure on the incidence of diarrhea among children under age 5 in low- and middle-income countries (LMICs), which was mediated in part by water, sanitation, and hygiene practices. Moreover, the climate zone, the round-trip time to collect water, and the availability of water or soap/detergent for handwashing were relevant risk modifier factors (137). Currently, 2.2 billion people lack access to safe drinking water and ~4.2 billion people have no access to safe sanitation services, with most of these populations living in the least developed countries (125). Vulnerability in these regions is expected to increase due to the expected population growth and increasing drought severity (59). Furthermore, prolonged severe droughts can affect power production and disrupt health services, such as a break in the cold chain necessary to maintain medical supplies (50).

3.2. Food Insecurity, Malnutrition, and Other Health-Related Effects

Drought events have detrimental consequences for food security and nutrition, including increased risk of malnutrition (including undernutrition and micronutrient deficits) and starvation, which poses a significant threat to LMICs that have fewer resources to mitigate food scarcity, fewer livelihood alternatives, poor transportation networks, and limited access to markets (5, 8, 55, 59, 76, 83, 119). In 2020, ~1 in 3 people worldwide did not have access to adequate food, which was an increase of nearly 320 million people compared to 2019, and nearly 12% of the global population suffered from severe food insecurity, mostly in Africa, Latin America and the Caribbean, and Asia (40). Furthermore, future climate change is expected to increase the risk of food insecurity and malnutrition in 2050, exacerbating the existing scenario (59).

Drought events have been associated with a reduction in food supply, such as decreased crop yields, livestock, and fisheries production (119), and changes in the quantity and quality of household diets (19, 100). In India, drought conditions were associated with a less balanced diet, resulting in a lower consumption of fruits, vegetables, legumes, and animal-sourced foods and a lower caloric intake, including proteins and fats, mostly due to a reduction in household income (19). Drought often results in increased food prices, which can lead to lower dietary diversity and consumption levels (59, 119). Farmers, pregnant women, children under age five, older populations, people in shelters, and individuals with low socioeconomic status are often more affected (8, 119). Undernutrition leads to a higher risk of morbidity and mortality and is the leading cause of child mortality in sub-Saharan Africa (98). Children who survive undernutrition and those living in food-insecure households suffer cognitive damage; negative effects on physical development; increased risk of infections, such as malaria, pneumonia, and diarrheal diseases; and detrimental long-term consequences. In addition, nutritional deficiencies during pregnancy increase the risk of preterm birth and low birth weight (3, 98, 119).

Unavailability of food resources leads to an increased risk of mental health effects and declines in well-being (39). The impacts of droughts on economic sectors, such as agriculture, livestock, and other water-dependent sectors, and associated migration produce mental health effects, especially among vulnerable populations such as rural communities and farmers (119, 133). Socioeconomic impacts lead to higher levels of stress, anxiety, depression, and conflict situations

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due to an increase in workload, unemployment, loss of income, and additional financial pressure (15, 83, 100, 112, 119, 134). In extreme cases, drought can increase the risk of suicidal behaviors (56, 103). Drought-related socioeconomic effects have caused forced migrations in dryland rural areas of low-income regions, mainly in East Africa, followed by South Asia and West and South Africa (59). Children's education may be interrupted by parents who require their children to help at home or in business, increasing uncertainty about the future and contributing to an increased risk of negative mental health outcomes (15, 133). Differences in drought-related mental health impacts can occur between men and women; this variation is partly linked to differences in gender roles and responsibilities. A study in Northeast Brazil suggested that women suffered higher levels of anxiety, whereas men had higher levels of emotional distress in a drought-affected area compared to women and men, respectively, in another area unaffected by drought (25). However, some evidence indicates that drought principally influences suicide among men, with most studies conducted in Australia (56, 100, 119, 134, 140).

3.3. Vector-Borne Diseases

Drought affects transmission patterns of vector-borne diseases, such as dengue, chikungunya, malaria, West Nile Virus (WNV), and Rift Fever Virus, particularly in sensitive regions where vectors are endemic and control systems are weak (24, 59, 69, 89, 112, 134). The association between drought and an abundance of vectors is complex, as this phenomenon can either reduce the number of mosquito vectors by decreasing breeding habitats or increase its abundance (e.g., *Aedes* mosquitoes) by creating improvised breeding sites in water storage containers used to store limited water resources during the drought. Moreover, drought may reduce the number of predators and aquatic competitors of mosquito vectors, favoring the abundance of vectors under rewetting conditions (12, 18, 112, 119). The prevalence of mosquitoes such as the *Culex* species, which transmits WNV, may increase in drought conditions. Drought may lead to the aggregation of birds (reservoir host for WNV) in mosquito habitats and increase the risk of contact with humans (18, 89, 119). Lowe et al. (70) showed that drought effects on dengue risk lagged 3–5 months in Brazil and depended largely on climatic, social, and ecological conditions, such as the availability and quality of habitats for mosquitoes, household water supply, and water storage practices carried out by humans. Greater repercussions were observed in highly urbanized areas and regions with a higher frequency of water supply shortages (70). Drought has been described as a potential contributing factor for malaria mortality in developing countries, although its impact on malaria risk remains unclear (10, 54, 112). In contrast, other vector-borne diseases transmitted by ticks are likely to decrease under drought conditions, as ticks are highly dependent on wet conditions to survive (18, 100, 113).

Changing spatial patterns of drought frequency and intensity, described above, and trends such as population growth, migration, and urbanization are expected to redistribute the future burden of vector-borne diseases unless effective mitigation and adaptation policies are adopted. Climate change likely increases the risk of dengue and facilitates its global spread. In addition, the distribution and vectorial capacity of malaria vectors are expected to increase in parts of sub-Saharan Africa, Asia, and South America due to climate change (59).

3.4. Cardiovascular and Respiratory Diseases Associated with Drought-Related Hazards

Drought often exacerbates the occurrence of climate and environmental factors with detrimental effects on cardiorespiratory health (11, 59, 100). Drought is an important driver of air quality, increasing the concentration of pollutants in the atmosphere (e.g., increasing the frequency and

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severity of wildfires, dust intrusions) (131, 139), with larger mortality and morbidity impacts (8, 50, 99, 103). Drought events often result from persistent atmospheric blocking and high-pressure systems, which have been associated with the intensification of extreme temperatures and worsening of air quality (61, 86, 92, 131). Inhalation of air pollutants induces inflammatory and prothrombotic processes, increasing the risk of illness and death (85, 128).

Drought combined with high temperatures has been associated with an increased risk of wildfires due to decreased humidity and streamflow and dry vegetation (83). These dry compound hazards have been projected to increase in the Mediterranean and continental regions in Europe (38), and they were the fuel for the recent fire disasters in the Amazon and the Pantanal in Brazil (63, 80). Heat and wildfires are phenomena of great concern to public health and are associated with an increased risk of morbidity and mortality due to all/nonexternal causes and respiratory and cardiovascular diseases, mental health disorders, and adverse birth outcomes (44, 59, 108, 127, 148). Furthermore, urban environments are widely considered more at risk because they have additional sources of air pollution from road traffic and the urban heat island effect.

As soils become drier during drought, dust and other particles are more likely to circulate in the air, threatening respiratory and cardiovascular health (8, 11, 12). Droughts and high winds increase the risk of dust storms, which transport pathogenic microorganisms, allergens, fungi spores, and toxic substances that create and exacerbate respiratory problems due to the irritation of bronchial passages and lungs after inhalation, increasing the risk of meningococcal disease, allergies, and respiratory infections, such as bronchitis, pneumonia, and coccidioidomycosis (valley fever) (21, 37, 99, 119, 134, 149).

Recent studies have addressed mortality impacts associated with droughts in various parts of the world, such as the United States (1, 14, 71), Iberia (101, 104), Brazil (105), and Bangladesh (4). Most studies have found a positive association between drought events and all, nonexternal, respiratory and circulatory mortality, especially in vulnerable groups. However, the comparison between these studies is complex due to differences in study designs, data availability, modeling approaches, and the definition of the exposure variable, such as the drought index. Moreover, drought plays an important role in mortality risks associated with exposure (4, 102, 105). Some studies have addressed the association between drought exposure and cardiovascular and respiratory morbidity; however, evidence is limited (14, 72, 108, 136). Drought positively influenced respiratory hospital admissions in Brazil (72, 108) and China (mostly in children and adolescents) (136) but negatively influenced admissions among older adults in the western United States (14). Although drought effects on cardiovascular hospitalization were not significant among older adults in the western United States, the risk was higher in counties with less frequent drought. Moreover, higher mortality risk but lower cardiovascular hospitalization risk was found in rural counties compared to urban counties for high-severity worsening drought, although differences were not significant (14). There is a gap in the literature on differences in drought-related health outcomes between rural and urban environments (1).

4. PREVENTION AND ADAPTATION MEASURES TO FACE DROUGHT RISKS AND INCREASE POPULATION RESILIENCE

The most common policies to prevent negative drought effects are usually reactive measures, which have been termed the hydro-illogical response (17) and are characterized by short-term initiatives to address the crisis associated with droughts, providing additional resources to affected populations and territories. Once the crisis is over, the action ends and no further actions are taken to follow up on the underlying causes that transformed a natural hazard into a catastrophe. Without attention to preparedness, monitoring, early warning, water demand reduction policies, and other mitigation issues, the next drought is likely to be a new crisis (141, 142). Furthermore,

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decisions are left to a single agency, which is ineffective (45) because this approach does not account for the complex nature of drought and requires the involvement of many different actors. International organizations have provided guidelines and recommendations to move from these reactive approaches to proactive approaches. These organizations include the World Meteorological Organization (WMO), which hosts the Integrated Drought Management Programme (IDMP; **https://www.droughtmanagement.info/**), and the Associated Programme on Flood Management (APFM; **https://www.floodmanagement.info/**) with the support of the Global Water Partnership (**https://www.gwp.org/**). The IDMP is structured by three pillars: (*a*) drought monitoring and early warning, (*b*) vulnerability and impact assessment, and (*c*) drought preparedness, mitigation, and response (143). The APFM describes a cascade of actions for risk reduction, which includes watershed intervention, protection through infrastructure, land use regulation, emergency response preparedness for floods, and recovery. The EPIC Response (17) is based on five key elements: (*a*) enabling a setting of policies, laws, agencies, strategic plans, participation, and information; (*b*) planning at multiple and nested geographical levels to ensure that mitigation becomes a higher priority; (*c*) investing in healthy watersheds and water infrastructure; (*d*) controlling water use and flood plain development to reduce exposure; and (*e*) responding better to floods and droughts through more effective monitoring, response, and recovery. The 2021 Global Assessment Report on drought (119) describes the physical and societal context of drought, associated impacts, and methods for risk assessment. After analyzing in depth several case studies, this report provides guidelines for the transition from disaster compensation to more resilient policies.

Common features appear in these and other approaches (35, 64), including the need to combine short- and long-term policies to not only address the crisis but also strengthen structures responsible for drought prevention and management. Monitoring and early-warning systems, from satellite monitoring to local interactions, also require improvements. Improved land and water management is another key element to reduce population vulnerability to drought-related risks. This effort often involves the joint action of different government agencies working together at various levels, from national to local, the participation of private stakeholders, water companies, academics, organized associations, and individuals, such as farmers or ranchers. Furthermore, countries must move from short-term to more strategic planning, acting along the cycle that connects the drought as a natural hazard with the disaster. Doing so cannot be possible without institutional reinforcement of agencies involved in drought management, such as water agencies, land planners, and meteorological agencies, though the necessary resources and trained staff are currently lacking. The need for capacity building to adopt the multidisciplinary approach required for the new vision of drought management is not limited to government agencies, however, but includes all stakeholders.

In addition, this transformation requires adequate funding. More investment in services and research to strengthen general health systems, enhance protection against specific climate-sensitive exposure, and address the social and environmental determinants of health is essential to reduce vulnerability and the risks associated with extreme weather hazards associated with climate change (59). In particular, investigators must delve into the drought-specific health effects that require more attention (e.g., mental health disorders, infectious diseases, cardiovascular and respiratory morbidity, adverse birth outcomes) and consider different forms of drought and time periods in which these effects can occur. It is necessary to deepen the knowledge of what type of drought indices best reflect each of the health impacts and to learn how the environmental and social contexts and other individual characteristics interact with and intensify the health risks attributable to drought (103). Funding and investment opportunities pose a big problem in LMICs, which often lack the resources to maintain a reactive drought policy. Securing funding associated with climate

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change adaptation and mitigation could be a critical step toward helping these countries transition to new drought policies. However, the situation of resource mobilization seems optimistic after the United Nations Climate Change Conference (COP26) in Glasgow, which introduced a broad decision, the Glasgow Climate Pact (124), and called for renewed efforts to raise ambition on emission reduction, climate finance, adaptation, and loss and damage compensation (94). The document challenges countries to raise their climate ambition; creates the Glasgow Dialogue on funding for loss and damage, indicating climate change impacts that cannot be adapted and are unavoidable or already occurred; and asks for a doubling of adaptation finance. However, little progress was made along these lines. The finance target of transferring US$100 billion annually, which was set more than a decade ago, has not been met, and the COP declared the need urgent to meet by 2025, without giving further details (124). This lack of funding mobilization stands in contrast with the actual needs of LMICs to face climate change risks. A recent assessment by the United Nations Framework Convention on Climate Change (UNFCCC) Standing Committee on Finance (**https://unfccc.int/SCF**) concluded that these nations would require nearly US$6 trillion through 2030, including domestic funds, to support just half of the actions in their national determined contributions (NDCs) (123). The UN Environment Programme evaluated annual adaptation costs for developing countries at US$70 billion but estimated that this figure could quadruple by 2030 (120).

Moreover, it must be taken into account that the world is in the first phase of climate change, and the changes in the coming decades are expected to grow. Currently, the average global temperature, which is a measure of the energy available in the climate system, is around 1.1°C above preindustrial levels. The Paris Agreement sets 1.5° and 2° as targets to minimize global change impacts. However, the 1.5°C threshold is projected to be reached within the next decade (58, 122). In fact, governments plan to produce in 2030 more than twice the fossil fuels that would be consistent with limiting warming to 1.5° (121). The current production gap has remained unchanged since 2019. Global fossil fuel production would need to start declining rapidly to meet the target; however, most major oil, gas, and coal producers maintain their plans to continue or increase their production beyond 2030. The G20 countries have allocated more funds (US$300 billion) to fossil fuels than to clean energy. Current policies should lead to a warming between 2.6°C and 2.7°C (2°C–3.6°C) by the end of this century. If the countries meet their NDCs by 2030, warming should fall to 2.4°C (1.8°C–3.3°C), and if the long-term net zero carbon agreements are met, the reduction would be to 1.8°C (1.4°C–2.6°C) in 2100, with a peak of 1.9°C by mid-century (57). Due to a warmer and more energic climate, this scenario will not be stationary. This trend has severe implications, as the extreme intensity of events will continue to increase and the return periods of extreme events, including droughts, will shorten. These future projections may increase population vulnerability to subsequent extreme weather and climatic episodes linked to effects such as shorter times between events for the population and health systems to fully recover from previous episodes and less resilience (36). Thus, adaptation and mitigation policies will need to be revised frequently to adapt to the evolving nature of climate change. In other words, more robust and well-resourced management systems will be needed to cope with increasing risks.

Because droughts are often associated with other hazards, such as heat waves, wildfires, and pollution, and compound events are expected to increase due to climate change (37, 96), integrative drought risk management must account for potential synergies between drought and other climate-related events to better prepare for drought and effectively reduce major risks (64, 119). In addition, providing special attention to vulnerable individuals, including addressing social and environmental inequalities (e.g., gender inequalities) and supporting inclusive measures, is crucial to increase population resilience.

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5. CONCLUSIONS

Climate change has profound implications for public health, and drought is an extreme event with significant health impacts. Previous studies show that drought severity has increased in recent decades, which is mostly associated with changes in AED. The main increase has been observed in subtropical and semiarid regions of the world. Environmental and agricultural impact data support this observation, and the increase is predicted to continue in the coming decades. Climate change projections show a dominant increase in drought frequency and severity in large regions of the world. This increase will be associated with stronger precipitation variability worldwide, a decline in precipitation in some regions, a general increase in temperature and atmospheric demand, and loss of former agricultural land. Even in areas where precipitation is expected to increase, periods of precipitation deficits are expected. Therefore, impact models project that droughts will result in an increase in socioeconomic and environmental effects in future climate scenarios.

Drought exposure has far-reaching health impacts that affect millions of people around the world, regardless of a country's level of socioeconomic development, and includes various associated causes and consequences. Drought impacts can last for long periods of time, and health implications can lag. Drought's negative repercussions on health could be related to an increased risk of water-, food-, and vector-borne diseases and malnutrition as well as heat waves and higher atmospheric pollution, leading to cardiovascular and respiratory diseases and, ultimately, mortality. Drought has also been linked to mental health disorders associated with economic loss, migration, and social uprooting. Drought impacts are experienced unequally among communities and population groups: individuals with potentially higher vulnerability, such as children, older people, women, and people with low socioeconomic status, and those who suffer higher hazard exposures are often more affected. These impacts will be exacerbated with climate change.

Strategies to reduce drought-related health impacts are well defined and involve moving away from crisis management to risk management. Integrative action plans should be implemented to protect human health more effectively. Transferring resources to LMICs is crucial to reducing risk and vulnerability and ultimately to enhancing the resilience of populations as the climate changes.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

AUTHOR CONTRIBUTIONS

C.S., R.N., and L.G. conceived and planned the article; all authors contributed to the writing and editing of the manuscript and provided critical feedback and helped shape the paper. C.S. coordinated the manuscript.

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