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Weather and Climate Extremes

journal homepage: www.elsevier.com/locate/wace

Extreme events as sources of health vulnerability: Drought as an example



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ARTICLE INFO

Article history:

Received 24 July 2015

Received in revised form

30 September 2015

Accepted 6 October 2015

Available online 8 October 2015

Keywords:

Climate change

Health

Extreme events

Drought

Flood

Vulnerability

ABSTRACT

The health risks of climate change arise from the interactions of the hazards associated with a changing climate (e.g. increases in the frequency and intensity of extreme weather and climate events, such as drought), the communities exposed to those hazards, the susceptibility of communities to adverse health impacts when exposed, and the capacity to prepare for and cope with the hazard. However, there is a very limited understanding of how extreme weather and climate events could themselves be sources of vulnerability. Drought is used as an example of an extreme event that can simultaneously be a current hazard and can directly and indirectly influence future vulnerability. A better understanding of droughts and other extreme events as sources of vulnerability is needed, including (i) the patterns of risks and how these could change over time, (ii) the reasons for any changes, (iii) how these risks could affect human health and well-being, and (iv) the longer-term consequences of extreme events for vulnerability. This knowledge will become increasingly important for managing risks to health as the frequency and intensity of extreme weather and climate events increase with climate change.

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1. Introduction

In vulnerable regions, extreme weather and climate events³ can lead to disasters with significant impacts on human and natural systems. Historically, extreme events were generally rare in any one location, with time between events when human and natural systems could recover from the impacts experienced. However, as climate change increases the frequency, intensity, and duration of some extreme weather and climate events (IPCC, 2012; IPCC, 2013), the time between extreme events will shorten across this century. Further, the type and pattern of extreme events may shift, with alternating floods and droughts in many locations, leading to communities and nations requiring more integrated preparedness

to extreme events. As extreme events become more common and more intense, these events themselves will be one factor determining vulnerability to subsequent events. Given the importance of these extreme events, it is surprising that there has been limited attention to this issue in the scientific literature.

The paper first reviews a framework for evaluating the risks of extreme weather and climate events; review trends in these events; and then focuses on drought as an example of an extreme event that could affect the vulnerability of individuals, communities, and health systems to future events.

2. Framework of the risks of extreme weather and climate events

The magnitude and pattern of impacts from extreme weather and climate events are due to the characteristics of the extreme event, the extent of exposure of human and natural systems to the event, the susceptibility of those systems to harm, and their ability to cope with and recover from the event (IPCC, 2012; NRC, 2013). An extreme event can alter vulnerability to future events by changing the extent of exposure (e.g. reducing the presence or effectiveness of coastal barriers), the susceptibility of exposed human and natural systems (e.g. making individuals and communities more or less susceptible by affecting access to and/or

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³ The definition of extreme weather and climate events used is the one used in IPCC 2012: The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable.

effective functioning of healthcare facilities or the proportion of the population vulnerable to an event), or the ability of organizations and institutions to effectively and efficiently prepare for and manage events. Understanding the magnitude and pattern of impacts and of the factors increasing (or decreasing) susceptibility and coping abilities is vital to modifying current policies and to implementing new policies and programs to increase resilience to extreme events.

There is abundant literature on factors that increase vulnerability to extreme weather and climate events (e.g. IPCC, 2012), with less emphasis on how extreme events themselves alter the sensitivity and coping capacity of human systems to future events. The wide range of factors that describe vulnerability can be divided into environmental, social, and economic dimensions (Cardona et al. 2012). Environmental dimensions include physical variables (e.g. location-specific context for human-environment interactions); geography, location, and place; and settlement patterns and development trajectories. Social dimensions include demographic variables (education, human health and well-being); cultural variables; and institutions and governance. Crosscutting factors include relevant and accessible science and technology. In the health sector, important factors include the health of the population and the status of health systems (e.g. ability of healthcare facilities, laboratories, and other parts of the health system to manage an extreme event)

From the perspective of the health sector, vulnerability is viewed as the summation of all risk and protective factors that determine whether an individual or subpopulation experiences adverse health outcomes from exposure, in this case, to an extreme event (Balbus and Malina 2009). Sensitivity to an event is viewed as an individual or subpopulation's increased responsiveness, often for biological reasons such as the presence of a chronic disease. There is a rich literature describing particular factors that increase human health vulnerability to particular extreme events. The poor, pregnant women, children, individuals with chronic medical conditions, and individuals with mobility and/or cognitive constraints are at increased risk of adverse health outcomes during an extreme event (Balbus and Malina 2009). In addition, the social determinants of health influence vulnerability. These include access to health care services, access to and quality of education, availability of resources, transport options, social capacity, and social norms and culture.

Fig. 1 shows the framework used to explore the key drivers of vulnerability in the health sector to extreme weather and climate events. Impacts can be categorized into those that affect environmental services, social and economic factors, or health status and health systems. Impacts on environmental services that could

affect future vulnerability to extreme events include availability of safe water (including quality and quantity), food security, and consequences of extreme events that affect ecosystem services such as wildfires, coastal erosion, and saltwater intrusion into freshwater sources. Impacts on community services, livelihoods, and social capital include economic resources, infrastructure, access to services, and social capital. Impacts on health status and health systems include stress, mental illness as a consequence of the event or recovery, worsening chronic diseases, and undernutrition.

2.1. Trends in extreme weather and climate events

The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; IPCC, 2012) and the IPCC Working Group II contribution to the 5th Assessment Report (IPCC, 2013) assessed to what extent current and projected climate change is affecting or could affect the magnitude and pattern of extreme weather and climate events. Overall, Seneviratne et al. (2012) concluded that *a changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes*. Conclusions include that there is *medium confidence that since the 1950s, some world regions experienced a trend to more intense and longer droughts, particularly in southern Europe and West Africa. Droughts became less frequent, less intense, or shorter in central North America and northwestern Australia*. For precipitation and flooding, Seneviratne et al. (2012) concluded it is *likely that the number of heavy precipitation events increased significantly in more regions than there were decreases, with strong regional and sub-regional variations. There is limited to medium evidence to assess whether there have been climate-driven changes in the magnitude and frequency of floods*

Projections for how climate change could affect the magnitude and pattern of future extreme events varies by event, with confidence in projections driven by robustness in understanding the drivers and processes leading to particular events and the underlying evidence base. Natural climate variability is one of the key sources of uncertainty in projections over coming decades because the extent of climate change over this period is expected to be small compared with natural variability (Seneviratne et al. 2012). For some extremes, such as precipitation-related extremes, uncertainties in climate models are key. For other extremes, such as temperature extremes, future greenhouse gas emissions and the sensitivity of the climate system to those emissions are key drivers of uncertainty. Given the complex nature of the climate system, the authors concluded that low probability, high impact changes

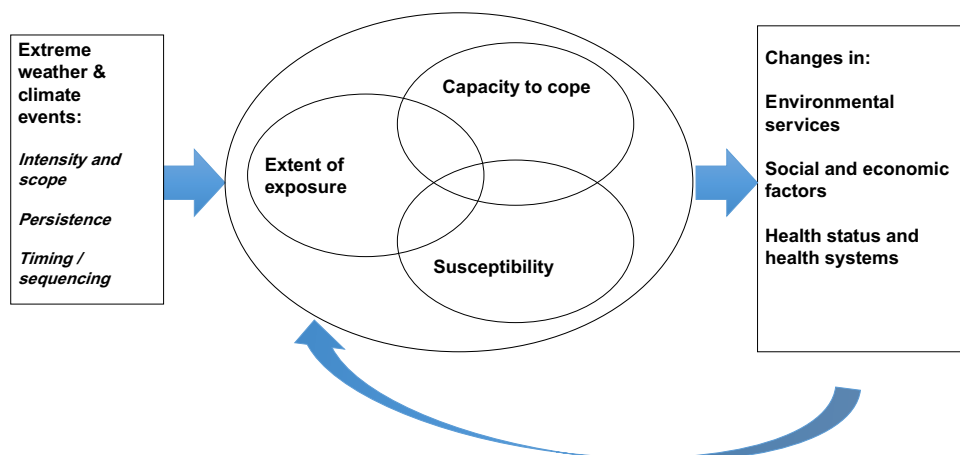


Fig. 1. Key drivers of health vulnerability to extreme weather and climate events.

in extremes associated with crossing poorly understood climate thresholds cannot be excluded.

Projected changes in extreme weather and climate events in the 21st century include that *there is medium confidence that droughts will intensify in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration, including in southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa (Seneviratne et al. 2012).* For precipitation and flooding, the authors concluded *it is likely the frequency of heavy precipitation or the proportion of total rainfall from heavy rainfall will increase over many parts of the globe, particularly in high latitudes and tropical regions. It is likely that heavy rainfall associated with tropical cyclones will increase. There is medium confidence that some regions will see such an increase despite projected decreases in total precipitation. For a range of greenhouse gas emission scenarios, a 1-in-20 year annual maximum 24-hour precipitation is likely to become a 1-in 5 to a 1-in 15-year event in many regions, with higher emission scenarios leading to greater decreases in the return period. And, there is medium confidence that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions.*

Christenson et al. (2014) estimated population exposure to cyclones, droughts, and floods, and ranked country-level population exposure to the individual extreme events and to all hazards combined. This analysis provides useful information on the likelihood that a location was exposed to a given hazard. Exposures for approximately 1980–2000 were calculated based on gridded datasets of population density and the relative frequency of climate-related hazards events, differentiated between urban and rural populations. A drought event was defined as when the magnitude of monthly precipitation was less than or equal to 50% of its long-term median value for three or more consecutive months. Drought exposure was more broadly distributed than cyclone exposure. During 1980–2009, populations with high drought exposure included residents of countries in South Asia, Southeast Asia, and Western Asia through to the Mediterranean. The ten countries with the greatest population exposure to drought were Gibraltar, Lebanon, Malta, Nauru, Swaziland, Saint Kitts and Nevis, Djibouti,

Jordan, Myanmar, and Guatemala. Drought exposure increased as the Human Development Index class decreased.

Adding the scores for each extreme event type resulted in a multi-country hazard ranking (Table 1). Countries in the top quintile are from all major world regions except Australia, and from low-, middle-, and high-income countries with varying degrees of baseline vulnerability. These analyses highlight countries at higher risk of experiencing an extreme weather and climate event that could affect resilience to subsequent events, and regions that are more likely to have multiple events. For example, Saint Kitts and Nevis and the British Virgin Islands are ranked fairly high for cyclones and droughts, and Guatemala, Bangladesh, and Nepal are ranked fairly high for drought and flood. Climate change is reducing the return period of many extreme events, which means the magnitude and pattern of risks these countries face could increase (IPCC, 2012; IPCC, 2013).

The Human Development Index (HDI) was used to categorize countries into four equally-spaced development classes (Low, Medium, High and Very High) based on the country's level of education, gross national income per capita, and life expectancy at birth (Christenson et al., 2014). The results illustrate the importance of poverty to vulnerability. Very high HDI countries are the most developed and generally the wealthiest. Countries with medium HDI had multi-hazard exposure 17% greater than the global mean; countries with high HDI had the lowest multi-hazard exposure (32% less exposure than the global mean). Not surprisingly, a low HDI was generally associated with greater exposure to droughts and floods. Exposures in urban populations were 40% higher than for rural populations for cyclones and 34% lower for droughts. There was no difference for floods.

2.2. Extreme weather and climate events as sources of future vulnerability

The extent to which the impacts of an extreme event(s) could affect future vulnerability is determined by the characteristics of the events (e.g. magnitude and duration), the timing and sequence of events, and whether individuals, communities, and health systems fully recover from an event before the next occurs. The focus of research has been on identifying factors that increase individual vulnerability, with less attention to the possible impacts of extreme events on healthcare facilities and public health services.

Recovery from significant extreme events can take decades (UNESCAP, 2015). Further, cyclones, floods, or droughts can have long-term effects on communities and healthcare services. However, studies have typically viewed the relationship between extreme events, vulnerability, and impacts from the perspective of identifying factors that increase individual vulnerability to events, and the impacts resulting from events. Studies rarely identify which environmental, social, and economic factors increase individual vulnerability at a particular point in time (before, during, or after an extreme event). This is important because the timing of exposure to an event will interact with characteristics of the physical environment, social factors and livelihoods, and health status and health systems in ways that can increase or decrease vulnerability. Also, this information is needed for developing and deploying effective policies and programs to increase resilience throughout an event. There has been less attention paid to factors affecting the vulnerability of healthcare facilities and public health services to extreme events, other than obvious factors such as location.

One exception is Lowe et al. (2013), who systematically reviewed factors increasing vulnerability to health effects before, during, and after floods. Limited research identified pre-flood vulnerability factors; these included existing gastrointestinal conditions. Factors increasing during-flood vulnerability included

Table 1
Countries with the greatest multi-hazard population exposure, with country rankings for cyclones, drought, and floods. Source: Christenson et al. (2014).

Country	Cyclone rank	Drought rank	Flood rank	Multi-hazard exposure rank
Hong Kong	5	139	3	1
Philippines	11	74	22	2
Macao	10	132	1	3
Guatemala	63	10	5	4
South Korea	22	118	15	5
Bangladesh	53	29	2	6
Vietnam	36	80	12	7
Saint Kitts and Nevis	20	6	181	8
Guadeloupe	17	65	83	9
Guam	1	68	132	10
Lebanon	93	2	42	11
Ecuador	93	27	17	12
Nepal	93	44	6	13
Japan	7	182	64	14
British Virgin Islands	8	45	181	15
Thailand	73	35	20	16
Puerto Rico	14	193	48	17
Antigua and Barbuda	9	70	134	18
New Caledonia	6	66	166	19
Mozambique	40	31	73	20

gastrointestinal illnesses, psychological distress, and respiratory diseases. One of the few studies examining risk factors for gastrointestinal illness (GI) up to three months post-flood found that the risk of GI among children whose home or property was flooded was 1.9 times higher than the risk among children without those experiences (Wade et al. 2004). Adults over the age of 50 years also were at increased risk of gastrointestinal illness if their homes or yards were flooded (IRR 6.20, 95% CI: 3.34, 11.51). Persistence of these factors after a flooding event would clearly increase vulnerability to a subsequent flood or drought.

It also may be possible to infer from other research that extreme events increase vulnerability to subsequent events. For example, Sena et al. (2014) reviewed the health impacts of drought in Brazil, concluding that although there has been great progress in reducing social and economic vulnerability, many health and well-being indicators are worse in semi-arid regions that experience drought more regularly than the rest of the country, implying that drought may have played a role.

2.3. Displacement as a source of vulnerability

Extreme weather and climate events, particularly storms, floods, and droughts, can lead to short- and long-term displacement that often has negative consequences for health, social capital, and productivity. A review of disasters and displacement found that since 2008, an average of 26.4 million people have been displaced annually by disasters due to natural hazards, or one person displaced every second (IDMC, 2015). Drought and its impacts on water- and food-security is one driver of displacement. The likelihood of being displaced by a disaster today is 60% higher than it was four decades ago, even after adjusting for population growth. The peak year of displacement was 1998, when the strongest El Niño on record occurred. The review included an evaluation of protracted displacement, concluding there is a common assumption that displacement following disasters is short-term and temporary, which is not true in some situations. There is relatively little known about such displacements, requiring increased research on the impacts and how they could be managed. A review of 34 case studies identified people who have been living in protracted displacement for up to 26 years (IDMC, 2015). Those displaced the longest from extreme weather and climate events or their consequences were in Bangladesh (cyclone Alia) and Columbia (Gramalote landslide). Individuals and families in these types of events often are left behind in long-term recovery. The hazards leading to long-term displacement include those that persist for long periods and frequent short-lived events.

3. Drought as an example of an extreme weather and climate event that can increase vulnerability

Drought is a relative term for a period of abnormally dry weather that persists long enough to cause a serious hydrological imbalance (IPCC, 2012). Arid regions and areas experiencing desertification can be considered as permanently experiencing various degrees of drought. Humid and semi-arid regions can experience drought during specific seasons or over prolonged period of time. Drought can be categorized into the following based on how it is measured:

- Meteorological drought is based on the degree and duration of dryness.
- Hydrological drought is based on the impacts of precipitation shortages on surface or groundwater water supplies.
- Agricultural drought is based on soil moisture deficiencies from either meteorological or hydrological drought resulting in

insufficient moisture to meet the needs of a particular crop.

- Socioeconomic drought occurs when the demand for a particular economic good exceeds supply because of weather-related shortfalls in water supply or when water or agricultural shortages begin affecting communities.

Droughts are fundamentally related to water sources, with the typical categorization reflected in which sectors impacts occur, and indicated by the speed, scale, and complexity of the event. Meteorological drought particularly affects rain-dependent areas; agricultural drought can impact plant development; hydrological drought can affect freshwater ecosystems; and groundwater drought can affect pumped water supply (Stanke et al., 2013). A long-standing drought could be categorized as more than one of these.

3.1. Health impacts of droughts

From 2003–2012, 15 major droughts affected nearly 36.5 million people worldwide; there were nearly 8 million people affected in 2013 alone (EM-DAT, 2014). In Asia and the Pacific, drought affected 1.62 billion people between 1970 and 2014, and was associated with about USD53 billion in economic losses (UNESCAP, 2015). Evidence of the magnitude and pattern of impacts of a drought is difficult to document because the onset and ending of a drought are ill defined, and because droughts can last for years with accumulating effects. Socioeconomic choices, population growth and movement, infrastructure, land use change, the underlying population vulnerability, and other factors affect the severity of droughts. Poor health, poverty, and conflict contribute to the impacts of a drought (Stanke et al., 2013).

Recent comprehensive reviews of the health risks of droughts, one international, one for Canada based on national and international literature, and one for Brazil (Yusa et al., 2015; Sena et al., 2014; Stanke et al., 2013) highlight the potentially significant consequences of long-term drought. Most of the health impacts of droughts are indirect: food and water insecurity; loss of livelihoods; population displacement; and other mediating circumstances, with the impacts largest on low-income countries (Stanke et al., 2013). Conclusions include that drought can affect health effects associated with inadequate nutrition (including under-nutrition, micronutrient deficiencies, and mortality), food- and waterborne diseases, airborne and dust-related diseases, vector-borne infectious diseases, illnesses related to exposure to toxins, mental health effects (including distress and other emotional consequences), and other health effects (including wildfire, effects of migration, and damage to infrastructure) (Sena et al., 2014; Stanke et al., 2013; Yusa et al., 2015). Droughts could also exacerbate chronic diseases that leave individuals less able to cope with and recover from another event.

The probability of a drought-related health effect depends on drought severity, baseline susceptibility, access to adequate health and sanitation infrastructure, and socioeconomic conditions of the individual and community in which the drought occurs. The greater the impact of the drought, the more likely the drought will increase vulnerability to the next extreme event, particularly another drought or flood in low-resource settings if there is not adequate time for the individual and community to recover. Factors that could reduce longer-term resilience would likely include poor food and water security, mental health issues, and displacement.

Sena et al. (2014) reviewed the consequences of drought for human health in Brazil, showing semi-arid regions making slower gains in population health than the rest of Brazil. Between 1991 and 2010, there were close to 17,000 drought events recorded in the 2944 municipalities in the country; it was the leading type of

disaster with over 50% of total disaster events reported. Of the 96 million affected persons in these 20 years, 48 million (50%) were affected by drought. Trends for the 1133 municipalities in the semi-arid region of Brazil, compared with the rest of Brazil (4432 municipalities), for the years 1991, 2000, and 2010 showed that although health improved over the nearly twenty-year time period, the semi-arid region remained worse off in terms of health and well-being, as measured by infant mortality rate, poverty, illiteracy, and municipal human development index. There also were differences in life expectancy by average income, with people living in semi-arid regions having lower life expectancy and income. These differences between the regions would tend to make the semi-arid regions more vulnerable to concurrent or subsequent extreme events.

3.1.1. Drought effects on water security

Drought is a key but not the sole driver of water security; mismanagement of resources can exacerbate or ameliorate the impacts of a drought. Drought can negatively impact the quality and quantity of safe water (Berry et al., 2014; Lemmen et al., 2014) by increasing temperatures facilitating the growth of pathogens; by reducing water levels and stream flows that lead to stagnation; by increasing the concentration of contaminants in ground and surface water; and through contamination of drinking water sources with salt water in coastal areas. Droughts also can damage water-related infrastructure, with the recovery timeline important for determining vulnerability to subsequent events. A wide range of adverse health consequences are associated with insufficient safe water, including infectious diseases, diseases associated with chemicals and pollutants found in water sources, skin diseases, and algae-related diseases (Stanke et al., 2013; Yusa et al., 2015). The extent to which a community or region fully recovers access to safe water will determine the sensitivity to and capacity to cope with a subsequent event. The challenges are much larger in low- and middle-income country settings without adequate quality and quantity of safe water before a drought.

The future vulnerability baseline for water stress on which extreme events will interact is worrying. The number of people affected by flooding and water stress is projected to increase with climate change over at least the course of this century. Under a middle of the road socioeconomic scenario, Arnell and Lloyd-Hughes (2014) projected that climate change by 2050 would increase exposure to water resources stress for between approximately 920 and 3400 million people under the highest greenhouse gas emission scenario, and increase exposure to river flood risk for between 100 and 580 million people. Uncertainty in projected future impacts is dominated by uncertainty in the projected spatial and seasonal pattern of change in climate, particularly precipitation. Using a different definition of water stress and different assumptions and scenarios, Hanasaki et al. (2013) projected higher population exposure to water resources stress in 2050 – between 7.1 and 7.9 billion people living in grid cells with withdrawals greater than 40% of runoff.

3.1.2. Drought effects on food security

Extreme weather and climate events significantly affect food security. A review of 78 post-disaster needs assessments between 2003–2013 in 48 low- and middle-income countries found that 22% of the total economic impact of USD 140 billion was in agriculture, with 42% of all damage and losses in crops and 36% in livestock (FAO, 2015a). In total, 44% of crop and livestock production losses were caused by droughts and 39% by floods, with the livestock sub-sector particularly affected by droughts (86% of the impact due to droughts). This has important implications for human health and well-being and for future productivity through direct and indirect pathways.

Food security exists when all people at all times in a community or other spatial unit have physical and economic access to safe and nutritious food (and food preferences) that is sufficient to meet their dietary needs for an active and healthy life, and is obtained in a socially acceptable and ecologically sustainable manner (WFS, 1996). The four dimensions of food security are (1) food availability (i.e. production and trade); (2) stability of food supplies; (3) access to food; and (4) food utilization. Food security is often used interchangeably with malnutrition. However, malnutrition indicates various forms of undernutrition that are caused by many factors, including dietary inadequacy, infections, and socio-cultural factors. Undernutrition includes stunting, wasting, and deficiencies of essential vitamins and minerals, as well as obesity or over-consumption of specific nutrients (Ebi et al., 2010). Drought can directly affect food availability and stability through impacts on production, can affect food access, and can affect food utilization indirectly by affecting water quality and quantity in ways that could alter the burden of diarrheal diseases.

About 795 million people are below the minimum calorie threshold (FAO et al., 2015b). Being underweight is the number-one contributor to the burden of disease in Africa south of the Sahara and number four in South Asia (Lim et al., 2012). Undernutrition during pregnancy and the first two years of life is a major determinant of stunting of linear growth and subsequent obesity and non-communicable diseases in adulthood (Black et al., 2013). Nutritional deficiencies are responsible for over 50% of years lived with disability in children age four and under (Vos et al., 2012). Prevention of undernutrition in early childhood leads to hourly earnings that are 20% higher, wage rates that are 48% higher, and individuals who are 33% more likely to escape poverty (Hoddinott et al., 2013). Asia and Africa lose 11% of GNP every year due to poor nutrition (Horton and Steckel, 2013).

Through impacts on crops and subsequent changes in diet, drought can also affect micronutrient deficiencies, including reductions in concentrations of iron, zinc, vitamin A, and vitamin C (Stanke et al., 2013; Yusa et al., 2015). Dietary deficiencies of zinc and iron are a substantial global public health problem, with an estimated two billion people suffering these deficiencies (Myers et al., 2014). Micronutrient deficiencies not only increase mortality, but can also contribute to children not reaching their development potential (Black et al., 2013). Any reductions in micronutrients could have important health consequences, particularly in regions with high levels of micronutrient deficiencies before the onset of drought.

The burdens of undernutrition and micronutrient deficiencies are high. Estimates of the total burden of undernutrition in low- and middle-income countries, including fetal growth restriction, stunting, wasting, and vitamin A and zinc deficiencies combined with suboptimum breastfeeding, are 3.1 million child deaths in 2011, or 45% of all child deaths (Black et al., 2013). Optimum fetal and child nutrition and development increase cognitive, motor, and socio-emotional development; school performance and learning capacity; and work capacity and productivity. The extent to which the severity and/or persistence of drought directly or indirectly affects nutrition would determine its potential impact on future vulnerability.

Although undernutrition and excess morbidity and mortality are directly and causally related, it is difficult to attribute adverse health outcomes to a drought event because multiple other factors influence the severity of impacts (Stanke et al., 2013). Further, the impacts of drought on some of these other factors, such as socioeconomic status, can alter the susceptibility of communities to subsequent extreme events.

An important further consideration of the interaction between food security and extreme weather and climate events is that many countries have failed to reach international hunger targets

because of natural and human-induced disasters or political instability (FAO, 2015b). These protracted crises increased vulnerability and food insecurity for large parts of the population. Over the past 30 years, crises shifted from catastrophic short-term events to more structural and protracted situations, with natural disasters and conflicts increasingly frequent among the exacerbating factors. In 1990, 12 countries in Africa faced food crises, of which four were in protracted crisis. Twenty years later, 24 countries were experiencing food crises, with 19 in crisis for eight or more of the previous ten years. In 2012, approximately 366 million people lived in protracted crisis situations, of whom approximately 129 million were undernourished; this was about 19% of the global total of food-insecure people. Food security can be a cause and an effect of protracted crises, and can help trigger or deepen conflict and civil strife. Protracted crises are the new norm, with significant implications for vulnerability to extreme weather and climate events.

Without explicitly considering extreme weather and climate events, climate change is projected to increase all aspects of food security (Porter et al., 2014). In tropical and temperate regions, climate change without adaptation is projected to negatively impact production of the major crops (wheat, rice, and maize) for local temperature increases of 2 °C or more above late-20th-century levels, although individual locations may benefit. Projected impacts vary across crops and regions and adaptation scenarios. The impacts increase after 2050, with projections showing consistent and negative effects of climate change, particularly in low-latitude countries. Considering the impacts of changes in mean climate along with changes in extreme events could lead to higher projected impacts, likely increasing baseline vulnerability in many regions.

In summary, there are direct and indirect pathways by which drought can affect human health and nutrition. Continued concerns over the health burdens of undernutrition and micronutrient deficiencies are reflected in having hunger, food security, and nutrition as key elements of the second of the seventeen proposed Sustainable Development Goal (<https://sustainabledevelopment.un.org/?page=view&nr=164&type=230&menu=2059>). However, this goal does not consider what additional efforts may be needed to address the future risks of climate change, including droughts and other extreme events, to achieving the targets and goals.

3.2. *Social capital as a determinant of susceptibility to drought and other extreme weather and climate events*

Social capital can be considered as the capacity of a population to work harmoniously as a self-organizing unit, in which many individuals co-operate, but in which no single person or group controls all activities. Social capital is broadly understood as the social bonds and norms that contribute to social cohesion (Pretty, 2003). Four central aspects of social capital are: relations of trust; reciprocity and exchanges; shared rules, norms and sanctions; and connectedness, networks and groups.

There is a growing interest in the ways by which social capital can influence collective action, particularly in relation to adapting to environmental changes (including climate change). Securing livelihoods and maintaining well-being (at least partly) results from levels of social capital that enhance shared access to resources (Bebbington and Perreault, 1999) and it has been argued that community-based adaptation has social capital at its core (Ebi and Semenza, 2008). Where social capital is well-developed, local groups with locally developed rules and sanctions are able to make more of existing resources than individuals working alone or in competition (Pretty and Ward, 2001). In addition, benefits may accrue out of building trust and cooperation between government

and wider society when addressing the issue of climate change adaptation. Such benefits may take the form of (i) greater synergism from community involvement with decision-making while promoting the legitimacy and sustainability of adaptation strategies, as well as (ii) the potential to shift the perception of climate change from being an insoluble global problem to that of a local problem that may be at least partially solvable with the inclusion of community-initiated processes and projects (Adger, 2003).

Drought is an example of a natural hazard that can alter human and social capital in ways that could increase vulnerability to the next extreme event. For example, in communities where livelihoods are heavily dependent on agricultural production, a stressor such as drought and the subsequent decline of agricultural commodities has the very real potential to result in economic pressure that is associated, possible causally, with mental health and well-being (De Silva et al., 2005; Sartorius, 2003; Whitley and McKenzie, 2005). Further, increased workloads in alternative sectors (if available; this will require migration in some cases) as individuals compensate for loss of income from drought-affected agricultural activities, lack of time and money keep people from social activities, particularly from the vital informal social connections that are important for mental health (Berry et al., 2007). In addition, where pressure is placed on important relationships, mental health problems are likely to increase (Berry et al., 2010).

4. Discussion

Many extreme weather and climate events are projected to increase in frequency, intensity, and duration over the coming decades with climate change. With such changes, it is apparent the events themselves could potentially increase the vulnerability of individuals, communities, and regions to subsequent extreme weather and climate events. Long recovery times from an extreme event, particularly in low- and middle-income countries, may mean the community, sector, or country is less resilient when the next event occurs. Drought is one example of these events and is associated with a myriad of health outcomes, including undernutrition, mental illness, and the exacerbation of underlying chronic diseases. The paucity of literature on extreme events as sources of health and health system vulnerability to subsequent events is of concern, given that (i) the magnitude of impacts will increase the severity of consequences following events and (ii) return periods will decrease in a changing climate. When recovery time from disasters takes years or displacement occurs, and when food security is compromised, there can be consequences for the future health of children raised during this period. Better understanding is needed of the shape and drivers of recovery curves over time, to identify opportunities for targeted interventions.

Development choices will be major determinants of the extent to which repeated extreme events will become sources of vulnerability. The development level of a country and community is a key determinant of vulnerability to extreme events. Extreme events also affect development levels; a disaster can push those just above to below the poverty line, increasing longer-term vulnerability. Protracted and/or repeated cycles of extreme events have the potential to increase the numbers of vulnerable individuals in a population.

Strengthening community adaptive capacity is one mechanism by which individuals and their communities can build and sustain the multiple resources that can increase resilience during times of stress, such as recurring disasters associated with extreme events. Determinants of coping capacity include access to education, economic wealth, a healthy population, good governance, and high levels of human and social capital. Strengthening these determinants can enable individuals and communities to appropriately

prepare for and respond to the changing nature of extreme weather events. Also important is prioritizing investments in the health aspects of disaster risk management, from research to implementation. Rapidly reducing greenhouse gas emissions is equally critical to protect future generations from ever more, and more severe, extreme weather and climate events.

5. Conclusion

Understanding of the potential impacts of recurring extreme weather and climate events on health vulnerability is limited. This paper used drought as an example of an extreme event that—especially when recurring or when followed by an extreme event such as a flood—can itself increase vulnerability, with risks posed to human health and wellbeing. Drought can affect health in a variety of ways, including through threats to food and water security. However, we do not yet know how these impacts may be magnified if we consider droughts themselves as a source of vulnerability. To address this gap, greater emphasis is needed on understanding and supporting countries and communities to effectively prepare for, respond to, and recover from the impacts of recurring extreme events. Such strategies include assessing vulnerabilities and developing adaptation strategies, capacity development of health professionals, and appropriate disaster risk reduction/management programs and support. Without this targeted focus, communities will continue to experience the substantial losses and risks to health arising from extreme weather and climate events, and our responses will continue to be reactive, rather than necessarily proactive.

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