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ORIGINAL ARTICLE

Social vulnerability to climate change: a review of concepts and evidence

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Abstract This article provides a review of recent scientific literature on social vulnerability to climate change, aiming to determine which social and demographic groups, across a wide range of geographical locations, are the most vulnerable to climate change impacts within four well-being dimensions: health, safety, food security, and displacement. We analyze how vulnerability changes over time and ask whether there is evidence of critical thresholds beyond which social vulnerability drastically changes. The review finds that climate change is expected to exacerbate current vulnerabilities and inequalities. The findings confirm concerns about climate justice, especially its intergenerational dimensions. For example, deficiencies in early childhood may limit future educational and income generation opportunities. Evidence of clear thresholds is rare and is mainly related to the vulnerability of different age groups, household income level, and the impacts of different degrees of global warming.

Keywords Climate change · Differential impacts · Social vulnerability · Thresholds

Introduction

The social dimensions of climate change go beyond biophysical impacts and relate to the social and structural factors underlying vulnerability (Kelly and Adger 2000). Social vulnerability is used, defined, and conceptualized in many different ways (Eakin and Luers 2006) and is often linked to associated concepts such as resilience, risk, exposure, sensitivity, and coping capacity (Füssel and Klein 2006). In this article, we first disentangle the existing

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concepts related to social vulnerability. Then we ask which social and demographic groups, across a large number of studies and geographical regions, are particularly vulnerable to climate change and why. We also ask whether there is evidence of thresholds in natural and social systems beyond which the vulnerability of specific social groups substantially increases. Revealing thresholds within socioecological systems is critical to understand the dynamic character of vulnerability and to make the case for mitigation and adaptation action (Cutter and Finch 2008). One such threshold at the Earth system level could be the 2 °C global warming target, exceeding which may lead to large-scale population migration and complete exodus from certain regions. At the household level, an example of a critical threshold could be a declining due to climate stress household subsistence to such low levels that the elevation out of poverty seems highly unlikely with individual means—a so-called *poverty trap* (e.g., Shepherd et al. 2013).

We draw on a review of the literature on social vulnerability to the effects of climate change, focusing on low and middle income countries. The review was primarily conducted between February and July 2014, with a limited number of references added after that date. The primary sources are papers published in peer reviewed scientific journals and other high-quality gray literature.

Conceptualizing social vulnerability to climate change

Research on vulnerability to climate change is highly interdisciplinary in nature with each research community bringing its own terminology into the field. The definitions currently used in the IPCC assessment reports have also evolved over time, based on research development and authorship. The first IPCC Assessment Report used the notion of vulnerability to refer to threats to human socioeconomic well-being that are primarily determined by health, safety, and food security (Tegat et al. 1990). A similar interpretation of vulnerability was used in the Second Assessment Report. Interestingly, the Third IPCC Assessment Report broadened the scope to include the vulnerability of natural systems (McCarthy et al. 2001). The focus on the human systems as the primary domain of vulnerability was brought in again by the Fifth Assessment Report that defines vulnerability as: "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to adapt. A broad set of factors such as wealth, social status, and gender determine vulnerability and exposure to climate-related risks" (Oppenheimer et al. 2014: 1048). As such, the current definition of vulnerability contains an active element—it is not just the physical exposure of people, assets, species or ecosystems in places and settings that could be adversely affected, but also the system's ability to respond. Vulnerability definitions also differ across research communities. As pointed out by Costa and Kropp (2013), risk hazard-oriented authors define vulnerability in terms of the external dimension and the exposure of a system to shocks from external stressors, threats or climate variation (e.g., Füssel and Klein 2006). Birkmann (2006) and other authors from the climate change community underline the capacity of the system to anticipate, cope with, and recover from an impact (Costa and Kropp 2013).

Although the human dimension of vulnerability is covered in the IPCC definitions, several authors use the term social vulnerability in order to separate the biophysical from the human dimension of natural hazards. For example, Cutter and Finch (2008: 2301) propose that "social vulnerability is a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards." Similarly, Füssel (2012) defines social vulnerability as the lack of capability of individuals, groups or communities to cope with and adapt to any external stress placed on their livelihoods and well-being. Furthermore, Schellnhuber et al. (2016) propose the term "differential social vulnerability," which they define as "the varying degree of adverse effects that different individuals and social groups in one location may suffer from the climate stressors they are exposed to." Social vulnerability can be differentiated along internal, person-specific and external, socioeconomic and locational factors. Among the internal factors, authors typically list race and ethnicity, sex, age, religion, disability, and health status. External factors include socioeconomic class, type of housing and assets (e.g., Cutter and Finch 2008; Cardona et al. 2012), but also access to social networks, education, cultural knowledge, and political power. These can be used to satisfy basic needs, i.e., water, food, shelter, clothing, or cultural values (Füssel 2012).

In addition, vulnerability of certain social individuals or communities might change over time along with changing environmental and social conditions (Cutter and Finch 2008). For example, Oppenheimer et al. (2014) differentiates vulnerability before a crisis or disaster (e.g., drought, flood), and subsequent vulnerability in the post-disaster and recovery processes. Other authors warn that critical thresholds may exist that result in cascading impacts and abrupt responses of human systems (Schellnhuber et al. 2016). Rather than exerting a gradual change, complex systems such as the Earth and social systems might undergo radical and abrupt shifts after crossing certain thresholds referred to as tipping points or catastrophic

bifurcations (Scheffer 2010; Lenton 2011). As a system gets closer to such a critical threshold, even small perturbations may trigger a massive shift causing the system to enter into a new state of equilibrium. For example, archeological studies show that climatic disasters can cause significant social and cultural shifts through mass migration and economic and social upheaval (Riede 2013). Understanding nonlinearities and cascading processes is therefore crucial for understanding complex socioecological systems (e.g., Young 2012) and social phenomena, including poverty traps, political riots, and economic crises (e.g., Squazzoni 2008).

In the next section, we review literature that provides the evidence of differential social vulnerability to climate change impacts. Following Tegat et al. (1990) the evidence is grouped according to threats to human socioeconomic well-being that are primarily determined by health, safety, and food security. We add one more category of well-being: displacement and migration (Fig. 1). This choice was motivated by the recent migration from the Middle East and North Africa and the scientific evidence linking the cases of war and social unrest with climate change impacts including droughts and desertification (Kelley et al. 2015; Sternberg 2012). When evident we discuss potential thresholds of deleterious climate change impacts on the well-being and vulnerability of different social groups.

Social vulnerability: summary of evidence

Food security

Climate change can affect food security either directly through food production losses and crop failures (e.g., Gupta 2013; Amarasinghe et al. 2005) or indirectly through increased food prices caused by decreased supply (e.g., Nelson et al. 2009; Wiggins and Slater 2011). Food availability and prices could be further affected by extreme weather-related disruptions to transport and food distribution infrastructure. The impacts of extreme weather on food distribution may be stronger than on food production (Carty and Magrath 2013; Ziervogel and Ericksen 2010).

Smallholder households situated on dryland areas of the lower latitudes are the most vulnerable to climate-induced food production losses (Gupta 2013). Amarasinghe et al. (2005) show that in Sri Lanka the poorest households are located in dryland areas where small-size agricultural holdings depend on rain-fed production, and where income diversification opportunities are scarce due to long distances from urban centers. Likewise, Shepherd et al. (2013) analyze data from rural Ethiopia and the Andhra Pradesh region in India and show that drought is the major and single most important factor of impoverishment in those areas. Case study evidence demonstrates that climate extremes can lead to a cycle of losses, contributing to poverty traps or very slow recovery. Repeated shocks and stresses can push affected groups into a permanent state of poverty (Ruth and Ibarran 2009). The inadequate capacity of households to recover from repeated climate shocks can lead to maladaptive strategies including divestment of productive assets such as livestock and land (UNDP 2007). These so-called fire sales have been observed among the poorest people selling-off the few assets they have. There is no clear critical income threshold that makes households resistant, but Shepherd et al. (2013) argue that above $4 per day the risk of falling into poverty is greatly reduced. Another study in drought-prone areas in Ethiopia and Hurricane-affected areas in Honduras also shows that

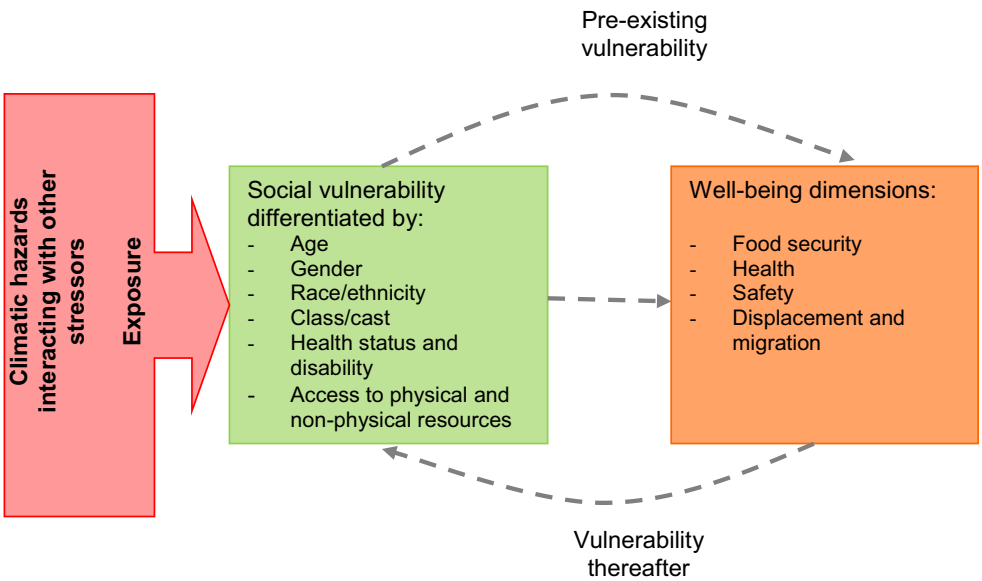

Fig. 1 Conceptualization of the research approach

environmental shocks can decapitalize the poor and trap them in impoverished conditions (Carter et al. 2007). A longitudinal analysis reveals that wealthier households were able to partially rebuild their lost assets in the three years following the shock. In contrast, the lower-income groups were affected more acutely over a longer time frame. The lower-income households who sold their livestock after the shock were at a risk of permanently lowering their consumption (Carter et al. 2007).

Several studies argue that temporary shocks to food security often have long-term consequences. For example, in Zimbabwe, children below the threshold of 2 years, who experienced drought-related malnutrition, lost 15–20% growth velocity, causing a difference in height that was never rectified (Hoddinott 2006). The lost growth in childhood is correlated with lower productivity and lifetime earnings as an adult. In addition, children experiencing slower growth are also found to perform worse in school and in motor skills tests. This might also negatively influence adult earnings (Foster and Rosenzweig 1993; Behrman et al. 2004; Hoddinott 2006). Clarke and Hill (2013) estimate that malnutrition of children under two carries long-term costs of about 14% of lifetime earnings. In some regions, e.g., in South Asia, patterns of child malnutrition may be gender related, reflecting societal norms discriminating against women and girls (IOM 2014; Watson et al. 2013). Practitioner-derived evidence of "famine marriages" is also emerging from Sub-Saharan Africa, where adolescent girls are married off to reduce the number of mouths to feed and/or to generate resources such as cash or cattle (Brown 2012; Marcus 2014). This trend could be exacerbated by climate-related impacts on food security.

Low income groups in urban areas are recognized as the most vulnerable to the effects of increased food prices, with urban poverty rates in some African cities expected to increase by up to a third due to climate-related increase in food prices. In the scenarios assuming the highest impacts on agricultural production, higher grain prices increased the cost of living at the poverty line by 6.3% (Hertel et al. 2010). Parry (2007) suggests that global cereal prices are projected to increase by 30–70% by 2050, before they decline in parallel with the predicted decrease in global population. Under a 4 °C warming scenario, cereal prices could increase by more than 160% by 2080. Poor households in developing countries typically spend a large proportion of their income on food (around 70–80%), and thus a large and sudden increase in prices could ultimately cause hunger and poor nutrition. In richer nations, households tend to spend around 10–15% of their income on food and are thus less vulnerable (Gilbert and Morgan 2010). Food-coping strategies primarily include switching to cheaper, less preferred or lower-quality staples, buying less food or skipping meals, and decreasing the intake of non-staple foods. They lead to poorer diets that often result in micronutrient deficiencies. This is especially likely among those family members with higher nutrition requirements such as women in reproductive age, infants and young children. Mothers often act as a buffer for their children by eating less and keeping the high-quality foods for their husband and children. This can have particularly detrimental effects on a woman's own nutritional status and that of her newborn child. Another reported household coping strategy for dealing with increased food prices is to put more family members on the job market. This may include previously unemployed women, or children who would otherwise be going to school (Ruel et al. 2010). In addition, the dissatisfaction with increasing food prices might spread among other social groups and larger areas. Lagi et al. (2011) suggest that persistently high food prices might result in a global increase in social disruptions. Several studies partially attribute the outbreak of violence in Egypt in 2011 to a food crisis induced by extreme climatic conditions in other regions (Lagi et al. 2011; Sternberg 2012).

Health

Climate change interacts with human health in complex ways. These relate to income, economic development, education, social norms, migration, and the institutional capacity and accessibility of health systems, particularly for poor and socially excluded people (Costello et al. 2009; WHO 2009). Overall, scientific evidence points to an increase in health inequalities caused by climate change, disproportionately aggravating the health of people living in poverty and those with preexisting health limitations (Costello et al. 2009; WHO 2009). Health vulnerabilities also reflect gender differences, as in many societies caring for the sick falls principally to women and girls. This impacts the infection rates and incomes of women (Brody et al. 2008; Budlender and Moussie 2013).

Vulnerability to heat stress

Heat-related risk is stratified across the population and linked to both "intrinsic," person-specific, physiological characteristics and "extrinsic," socioeconomic, location-specific factors. Recent analyses show that old age is the most important, intrinsic risk factor for heat-related mortality across 18 comparable studies; young age used to top the list (Reckien et al. forthcoming). Research in São Paulo found a 2.6% increase in mortality rates among children under 15 for every degree increase in temperature above 20 °C. This is similar to the increase for those over the age of 65 (2.5%) (Gouveira et al. 2003).

Females have a relatively higher risk of heat-related mortality than males (Reckien et al. fortcoming; WHO

2010), which may be due to higher heat intolerance caused by physiological and thermoregulatory differences. Women may also experience more exposure to heat than men, due to the time spent in interior spaces without adequate air flow or air-conditioning. However, among the elderly, men tend to be more vulnerable than women, mainly because of increased loneliness and related behaviors (Canouï-Poitrine et al. 2005; Klinenberg 2002).

Extrinsic, socioeconomic factors causing vulnerability to heat are mainly related to location-specific living and working conditions. They therefore affect manual laborers (Scott 2008), the homeless (Walters and Gaillard 2014) and people who cannot afford air-cooling (Smith et al. 2014; Lowry et al. 2010; Vallejos et al. 2011). Although data on relative risk linked to socioeconomic levels are not systematically reported, the overall trend indicates that lower socioeconomic status and lower education levels increase relative vulnerability to heat stress (Reckien et al. forthcoming). Loughnan et al. (2014) note that heat disproportionately impacts socioeconomically disadvantaged households because they have less access to urban green infrastructure which would reduce the risk (Nogueira et al. 2005; Harlan et al. 2006).

Vulnerability to water related mortality, injuries, and diseases

A study of flood-related mortality in Nepal found the death rate for children to be double that of adults, with preschool age girls being five times more likely to die than adult men (Pradhan et al. 2007). Vulnerability to indirect effects of floods, such as waterborne diseases is also high for children (WHO 2009). Children under the age of 14 are 44% more likely to die or become ill as a result of environmental factors than the general population (Bartlett 2008). The elderly, and people of lower socioeconomic status, are also more vulnerable to the indirect health effects of floods than the population as a whole. This was reported in Bangladesh in 1988, 1998 and 2004 (Khan et al. 2011). A study in Nepal found members of poor households to be six times more likely to die during and after floods than their better-off neighbors (Pradhan et al. 2007). Studies trace this relationship to the spread of sewage in poor urban areas, increasing the incidence of waterborne diseases (Baker 2012; Moser et al. 2010). Increases in incidences of diarrhea are also connected to elevated salinity levels of groundwater in coastal regions, which can increase maternal mortality and morbidity (Neelormi et al. 2009).

Subsequent vulnerability to mental health issues

Mental health problems due to climate change are an increasing concern and relate to (1) direct impacts of climate change, connected to the degradation of or forced displacement from familiar, emotionally or culturally valued environments, and (2) indirect effects, for example, resulting from physical health problems and/or social and economic damage to communities (Berry et al. 2010).

Direct emotional impacts of climate change arising from relocation or from the degradation of the environment to which one belongs are reported by indigenous communities (Salick and Byg 2007). These effects may increase in the future if sea levels rise and flooding renders certain areas uninhabitable (Berry et al. 2010).

The indirect link between extreme anxiety reactions and climate change, such as through acute weather disasters, is also well established (e.g., Berry et al. 2010). For example, a study conducted 2 years after Hurricane Katrina found a high prevalence of hurricane-related mental illness (Kessler et al. 2008), with women, people of low education levels or low income, and disabled, unemployed or unmarried people being most vulnerable. People aged over 60 and Hispanic people were less likely to suffer these effects. Another example of gendered mental health vulnerability comes from Australia. In this country, male farmers face something of a crisis of masculinity and identity, struggling to keep their farms or deciding to sell after repeated periods of drought. Meanwhile, farm women are absorbing the associated stresses by doing both on-farm and off-farm work. An indicator of male vulnerability is the suicide rate, which is higher for male farmers than for urban men and rural women (Kessler et al. 2008).

Safety

Increased conflict, insecurity, and social breakdown are often seen as the potential ultimate negative social effects of climate change (c.f. Buhaug et al. 2008). In recent years, there has been a great deal of research into whether there is a robust association between different aspects of climate change and conflict (Benjaminsen et al. 2012; Gemenne et al. 2014). There is evidence both for (Hsiang and Burke 2013) and against (Buhaug 2010; Gleditsch 2012) such a relationship. Hsiang and Burke (2013) argue that the discrepancy in the results may reflect the wider range of data the authors consider and the methodological rigor of the studies included in their review. Much analysis is based on large-scale datasets and test associations rather than the mechanisms by which they may arise. Hsiang and Burke (2013) cite nine studies, all from the USA, which show increased aggressive behavior and increased violent crime during periods of hotter temperatures. Hsiang et al. (2013) conclude that with a 1 standard deviation increase in temperature or extreme rainfall, the frequency of interpersonal violence rises 4% and the frequency of intergroup conflict rises 14%. Similarly Doherty and Clayton (2011),

also focusing on the USA, found a rise of 24,000 assaults or murders per year for every increase of 2 degrees Fahrenheit (1.1 °C) in the average temperature. Similarly, Berry et al. (2010) found evidence for associations between both heat waves and decreasing temperatures and aggressive and criminal behavior, suggesting that deviation from temperature norms can trigger aggressive behavior (Berry et al. 2010). However, little evidence could be found concerning the circumstances in which heat waves (or cold waves) may trigger interpersonal or community violence, and which individuals are in particularly vulnerable.

Vulnerability to conflicts triggered by resource scarcity

There are many empirical examples of local institutions that have evolved to manage scarce resources (Adano et al. 2012; Kallis and Zografos 2013). In shared trans-boundary water basins with scarce water resources, cooperation has historically been more common than conflict (Kloos et al. 2013). However, other evidence is pointing to tensions that can periodically break out over resources, especially in circumstances involving migrating populations or a changing resource demand that challenges the established rules of the use of the resource and its distribution. For example, in the Sahel, long-term water scarcity pressures periodically lead to pastoralists bringing herds into areas to which agriculturalists also lay claim (Anderson et al. 2010). This can bring these groups into conflict. Similarly, in the Tahou region of Niger, a northward spread of agriculturalists limits land and water availability for pastoralists (Kloos et al. 2013). These differences may be viewed through a prism of ethnicity (pastoralists and agriculturalists are often from different groups), which can inflame tensions. Climate-related migration may contribute to local tensions and outbreaks of violence, particularly if long-term residents perceive that their entitlements are jeopardized by newcomers (Kartiki 2011). Such a situation is likely to occur if government institutions are perceived to be biased (Benjaminsen et al. 2012) or if "political entrepreneurs" encourage the scapegoating of particular ethnic or religious groups or migrants (Crush and Tawodzera 2011; Misago et al. 2010).

Dwindling access to a resource might lead to a growth in vulnerability of the individuals delivering the resource. Skinner (2011) points out that an increased scarcity of water in arid areas makes women and girls, who in many cultures are responsible for fetching water, walk longer distances and so more vulnerable to harassment and sexual assault. Similar situations occur when women and girls have to walk longer distances to fetch fuel.

Other studies warn that climate change induced resource scarcity may weaken social cohesion and local safety nets and thus increase subsequent vulnerability of the affected communities (e.g., Olsson et al. 2014). A study from Mexico reports finding of declining social reciprocity and stress on social networks following droughts and floods that led to an impoverishment of households that were primarily dependent on food production. Women are reported to be more affected than men since they were responsible for maintaining the networks through gift exchange and were more dependent on mutual aid arrangements (Buechler 2009).

Post-disaster vulnerability to violence

Although Slettebak (2012) suggests that the likelihood of antisocial behavior tends to drop during and after disasters as people pull together to cope, other studies argue that people are less willing to help each other as they struggle to survive after a disaster. For example, Kartiki (2011) found a perceived decline in social cohesion and increased tensions over jobs and access to water after Hurricane Aila in Bangladesh. The interviewees who had to move far away from the affected areas, and were excluded from the relief assistance, were particularly affected. Hendrix and Salehyan (2012) point out that post-disaster conflicts might sometimes be externally triggered. Specifically, biased patterns of relief distribution can contribute to grievances, and the disruption associated with extreme events can allow criminal violence to be conducted with relatively impunity; disasters can also increase conflict if humanitarian aid becomes a tool of war, or if they result in certain geographical areas becoming isolated (Hendrix and Salehyan 2012). There is evidence of sexual violence in the aftermath of disasters, both within shelters (Swarup et al. 2011) and in affected communities (Ahmad 2012). Examples can be seen in Bangladesh, Colombia, Ghana, and Senegal, (Dankelman et al. 2008; Tovar-Restrepo and Irazábal 2014). Pichler and Striessnig (2013) report that women interviewed in the Dominican Republic stated that they would not allow themselves to be evacuated because they would not feel safe in the shelters used for evacuation.

Displacement and migration

Generally, there is agreement that climate change will result in population displacements and migration, but the views differ regarding the relative role of climatic versus other factors as a cause of movement (de Sherbinin et al. 2011), the potential volumes of migrating people (Gemenne 2011a), and the relationship between social vulnerability and adaptive capacity (de Sherbinin et al. 2011). Migration has long been a form of adaptation, e.g., to political, economic (Hugo 2011), and environmental changes, including climate variability and change (McLeman and Smit 2006). However, it is also a manifestation of

economic (Grant et al. 2014), social (Thorsen 2012), and educational aspirations (King et al. 2010). Migration is therefore likely to continue (Barnett and Webber 2010; Black et al. 2011a, b; Tacoli 2010) despite climate change. However, climate change may exacerbate immigration through:

- Prolonged environmental stress that undermines rural livelihoods, e.g., through repeated droughts (Adger et al. 2014);
- Rapid onset disasters and related displacement, e.g., after floods and landslides. (Adger et al. 2014; Gemenne 2010);
- Permanently uninhabitable land, e.g., as a result of sea level rise (Gemenne 2011a, b, c; Warner et al. 2009) calling for planned relocation.

Prolonged environmental stress is particularly critical for people with resource-based livelihoods, such as farmers and fishermen, who may decide to move to diversify their livelihood. For example, Barbieri et al. (2010) found that in Brazil—even with relatively modest rates of warming—the greatest increases in migration are likely to come from the currently most productive agricultural areas employing a large labor force. Several studies warn that migrants may continue to be vulnerable in their destinations, since many migrants move to mega-cities, which are predominantly located in low elevation coastal zones (Black et al. 2011a, b). Migrants may also be more vulnerable in their destination than the area of origin if they do not speak the prominent local language and lack access to labor markets, local authorities (Tacoli 2009), and safe and sufficient infrastructure (Tanner et al. 2009). For example, in the 2009 flooding in Jeddah, Saudi Arabia, many of the victims were migrant workers who lived in poorly constructed, informal shanty houses (Verner 2012).

Among the poor, people without or less secure access to land are generally more likely to move (permanently) than those who own land and property (Massey et al. (2007), giving an example from Nepal). However, it is also generally agreed that the poorest and most vulnerable, i.e., those without assets, are potentially the least able and least likely to move (Black et al. 2011a, b). Moving demands some form of knowledge, connections, skills, monetary investment and effort. For example, a large-scale study in Yemen found that the likelihood of receiving remittances and the value of remittances received tend to be lower in districts with lower precipitation and higher temperatures. The authors stipulate that these households may not be able to afford to send migrants, or migrants may obtain worse paid jobs, and are thus unable to send large remittances (Wodon et al. 2014). However, on moving, the poorest migrants are often forced to rely on informal governance structures. These are potentially conducive to crime and are poorly integrated social structures (Roy et al. 2012; Murray and Williamson 2011). For the poorest, there is therefore also the risk of becoming indebted and more vulnerable through migration, than for less vulnerable people (Warner and Afifi 2014).

Post-disaster displacement processes are typically also patterned by socioeconomic factors. For example, when Hurricane Katrina struck the Gulf coast of the USA in 2005, poorer, often Afro-American residents, were unable to leave immediately or to afford the additional food, transport and rent costs of evacuating into a safer area (Gemenne 2011a, b, c). Those who can move, often do so over short distances and then return to their homes as soon as this is feasible, rather than becoming permanent migrants (Barnett and Webber 2010; Black et al. 2011a, b; Tacoli 2009). However, when reconstruction activities fail to incorporate appropriate building design and construction standards, return migrants are put at renewed risk (Singh and Fazel 2010). Reconstruction activities may improve economic opportunities so that post-disaster recovery efforts may fuel not only return migration (Black et al. 2013) but also in-migration by other poor people from more distant areas (Klose 2011). This can put even more people at risk of future climate events, and cause poor households to fall into chronic poverty (UNISDR 2009).

Apart from poverty status, migration patterns differ with age. Regarding slow-onset changes, younger (Barnett and Webber 2010), particularly landless households with few dependents are more likely to move (permanently) than older households (see Massey et al. 2007). Older people and children are more likely to stay behind both in response to slow-onset stress (Warner 2010) and disasters (Smith et al. 2014). This may reflect lower physical mobility, stronger aversion to moving, and/or stronger ties to ancestral homes and areas. Such ties may particularly affect indigenous groups and minorities (Salick and Byg 2007).

Case study evidence also points toward a differentiation of environmental migration across gender. For example, in Colombia, after periods of drought, it is documented that women stay put to look after the property, while men leave to make money in urban or more prosperous areas (Tovar-Restrepo and Irazábal 2014). This pattern seems reverse after periods of excessive rain and damage to houses and property, causing women to migrate to urban centers, trying to start a permanent new life. However, in both situations, single women and female-led households may find it more difficult to find employment or other means of generating a livelihood, particularly where men are viewed as main breadwinners and employers (e.g., Kartiki 2011). Staying put is connected to challenges of food security and water scarcity, while moving to urban centers is often related to security risks, lack of skills to access the labor

market and lack of capabilities in the dominant language, e.g., in Colombia (Tovar-Restrepo and Irazábal 2014).

Overall, quantitative estimates on climate-related international migration have produced highly diverging numbers, in part based on methodological differences (Gemenne 2011b), but also because of difficulties in establishing how far climate change—particularly slow-onset climate change—has contributed to migration (Kniveton et al. 2008). It is difficult to establish robust evidence of the relationship between climate change and migration, let alone determine thresholds. However, a temperature increase of 2–4 °C in this century is likely to make resettlement in some regions of the world virtually unavoidable. This thereby increases involuntary, forced migration movements (de Sherbinin et al. 2011; Gemenne 2011a).

The evidence on critical thresholds

The evidence on thresholds in social vulnerability, that if crossed, significantly change the likelihood of adverse climate change impact on human well-being, is rare. However, a few examples have been identified. Examples of critical thresholds at the individual level include the general age related vulnerability and human heat tolerance. Children below the age of two are more vulnerable to long-term impacts of hunger. Suffering hunger in such a critical stage of human development decreases a child's life chances and future income generation capability (Clarke and Hill 2013; Foster and Rosenzweig 1993). Individuals below the age of 15 and above 65 are reported to be more vulnerable to heat-related mortality (Gouveira et al. 2003). Irrespective of age, long exposure to temperatures exceeding 35 °C seriously induces the likelihood of hyperthermia in humans (Sherwood and Huber 2010). An example of a critical threshold at the household level is the income level of $4 per day. As pointed out by Shepherd et al. (2013), the risk of falling into poverty and long-term impoverishment is greatly reduced above this level.

At the Earth system level, critical thresholds are mainly related to the impacts of different levels of warming. Being close to, or exceeding, 2° C warming above the preindustrial level, implies large-scale changes to ecosystems and agricultural production (Schellnhuber et al. 2016). Crossing the threshold of 4 °C global warming might have enormous consequences for all aspects of human life support systems, including massive changes to ecosystems and agricultural production (e.g., Warszawski et al. 2013; Rosenzweig et al. 2014). Such massive changes in the Earth system imply the end of the world we know in terms of the human-nature interactions and ecosystem services that humanity has been taking for granted. Possible consequences are difficult to project and largely unknown. A study quantifying impacts of multiple pressures across different sectors estimates that with a 4 °C warming, more than 80 percent of the global population would be exposed to severe changes in conditions in at least two sectors (Schellnhuber et al. 2013). Sherwood and Huber (2010) argue that in the tropics, subtropics, and some continental areas at higher latitudes, global mean warming of 4 °C would lead to a temperature increase that would make these areas uninhabitable. Similarly, low coastal areas and small island states are likely to become increasingly uninhabitable with higher degrees of warming (Gemenne 2011c). Massive migration from such areas is likely to pose significant threats to global security. However, increased conflicts and tensions must not always be assumed; under pressure, societies may also find new ways of managing growing challenges (Adano et al. 2012). Climate change could be a chance for world leaders to join forces in face of the tangible danger and to work together to achieve a more just and equitable future.

Conclusions

Many social groups already exhibit high levels of vulnerability to existing climate variability. The poorest and socially marginalized segments of the population are the most vulnerable to climate variability and extremes. This is particularly the case in developing countries where the infrastructure, social safety nets and economic resources, needed to support vulnerable groups, are in many instances insufficient. Alongside its traditional association with the availability of financial assets, vulnerability is heavily shaped by social, demographic, and institutional factors such as gender, age, culture, education and ethnicity. The evidence we referred to shows that intra-household differences of gender and age produce markedly different forms of vulnerability with women, young children and the elderly being more likely to suffer. Young children from disadvantaged households are especially vulnerable to lagged well-being impacts of climate extremes. This raises concerns about inter-generation climate justice and the risk of suffering intergenerational poverty cycles.

The evidence we presented shows that social vulnerability to climate change is shaped equally by physical changes in the climate system and by demographic, economic, institutional, and sociocultural drivers. Policies that are traditionally associated with the wider development sector—such as social protection, the public health system, development of sanitation infrastructure—can have a significant impact on the ability of vulnerable communities to cope with and adapt to a the changing climate (c.f. Jones et al. 2010). More research is needed to understand the interactions among the different environmental and social

drivers and their impact on human well-being. New methodological approaches and more quantitative data at sub-national levels are urgently needed to be able to generalize and distinguish robust trends from the currently available, mostly case study, evidence (c.f. Otto et al. 2015). The rare documented examples of critical thresholds show that the human–environment interactions are possibly characterized by nonlinear relationships and the thresholds beyond which social vulnerability substantially changes must be further examined.

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