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REVIEW ARTICLE

The impact of climate change on migration: a synthesis of recent empirical insights

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Abstract

Concern about the human impact of climate change has led to predictions of how people living in areas vulnerable to drought, flood, and temperature changes will respond to such events. Early studies warned that climate change would lead to dramatic increases in human migration as households became unable to adapt to the impacts of climate change. More recently, empirical studies focused on observed climate events and trends have documented how migration flows vary as a function of both the severity of the event and the ability of the household to migrate, among other factors. In this paper, we provide a systematic review of this literature, based on a conceptual framework in which climate shocks (e.g., drought, floods, or temperature extremes) affect (a) household capability to migrate, by depleting household resources necessary for migration, and (b) household vulnerability in staying, by increasing the risk that a household falls (further) into poverty. In combination, these factors help explain four key patterns seen in the empirical literature: (1) climate-induced migration is not necessarily more prevalent among poorer households; (2) climate-induced migration tends to be more prevalent for long-distance domestic moves than local or international moves; (3) slow-onset climate changes (such as droughts) are more likely to induce increased migration than rapid-onset changes (such as floods); and (4) the severity of climate shocks impacts migration in a nonlinear fashion, with impacts influenced by whether the capability or vulnerability channel dominates.

Kaczan and Orgill-Meyer contributed equally to all parts of this work and share equal co-authorship.

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1 Introduction

The impact of climate change on human migration is a topic of growing attention among scholars and policymakers. Climate change is recognized as a key driver of mobility in the Agenda for Humanity, the 2016 United Nations Summit for Refugees and Migrants, and the Global Compact for Migration and the Global Compact on Refugees. The 2030 Sustainable Development Goals (SDGs) contain a target (10.7) to "facilitate orderly, safe, and responsible migration and mobility of people, including through implementation of planned and well-managed migration policies," as well as a separate SDG (13) on climate action itself, focal areas that did not feature explicitly within the earlier Millennium Development Goals. Popular media has covered the topic extensively, with migration sometimes described as the "human face" of climate change (Klepp 2017; Gemenne 2011).

This increasing prominence is built on an improved understanding of the mechanisms through which climate-induced migration occurs, as well as high-profile studies estimating potential migrant numbers. With varying degrees of empirical rigor, these studies have warned that climate change will create hundreds of millions of environmental migrants,[1] likely moving from environmentally threatened, mainly rural areas, due to increased drought frequency, floods, sea level rises, and desertification, among other environmental changes. For example, Myers (2002) warned of mobilization of some 200 million people, based on the population living in areas at greatest risk from climate change. Biermann and Boas (2010) similarly concluded that the number of climate "refugees" by 2050 "could [conservatively] well be around or over 200 million," by compiling regionally specific estimates of migration from a variety of climate shock types. More recently, Rigaud et al. (2018) predicted that 2.8% of the population of three regions—Sub-Saharan Africa, South Asia, and Latin America—over 143 million people, will be forced to move within their own countries by 2050 as a result of climate change. Other studies attempted to quantify the existing environmental migration flow, with estimates ranging from 10 to 30 million people annually (El-Hinnawi 1985; Westing 1992; Myers 2002). Rapid-onset climate-related disasters were estimated to forcibly displace 24 million people in 2016 (IDMC 2017). To put these numbers into the context of overall mobility patterns, the number of internal migrants globally is estimated to be around 750 million, including almost 70 million forcibly displaced persons. Around 250 million people are cross-border migrants (UNDESA 2017; UNHCR 2018). If accurate, these estimates suggest that potential climate migration could represent a large proportion of total human mobility in the next few decades.

However, confidence in these estimates is low (Biermann and Boas 2010; Stapleton et al. 2017; Gemenne 2011a; Hartmann 2010; IPCC 2014) although modeling efforts are becoming more sophisticated (e.g., Rigaud et al. 2018). Notable criticism has been made on conceptual grounds: The migration process, with its many social and economic modifiers and the considerable capacity for human adaptation in many circumstances, is a more complex phenomenon than had been presented in earlier examples from this literature, which often based estimates on the likelihood of natural disaster and the potential numbers of people affected (Gemenne 2011b; Kibreab 2009; Maystadt and Mueller 2014; Perch-Nielsen et al.

[1] We define environmental migrants as per the International Organization for Migration definition (IOM, 2009): "Environmentally induced migrants are persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad." The term environmental migrants has largely replaced the term 'environmental refugees' (see Kibreab 2009; Etienne Piguet 2010; Biermann and Boas 2010).

2008; Stapleton et al. 2017). This deficiency is a product of what Suhrke (1993) described as a "maximalist" viewpoint, suggesting environmental factors are the primary drivers of human movement. The other extreme, a "minimalist" position, is to argue that environmental factors are a contextual factor about which not enough is known to assert causality. Both are simplifications that, when influential over policy, can limit the options for facilitating household mobility or for building resilience in situ and thus limit adaptation to a changing climate (Stapleton et al. 2017).

Naturally, neither extreme viewpoint represents many situations. By contrast, a growing number of empirical studies from the past ten years have provided the data and insights required to confidently estimate past causal climate impacts on migration in particular settings and thus predict future impacts[2] (Gray and Wise 2016). Taken together, these studies provide an increasingly nuanced and causal understanding of how climate change has impacted migration so far and what climate-induced migration may look like in future years. In this paper, we summarize the findings that are emerging from this literature, based on similarities found among studies despite their varied environmental, economic and cultural contexts. Informed by these findings, we develop a simple conceptual framework that helps explain the large variation seen across contexts. While the focus of our paper is on migration, we acknowledge that migration is one of many possible climate change response strategies. Households may engage in other strategies such as selling assets, intensifying livelihood activities, investing in in situ resilience measures, reducing nonessential expenditures, and using social networks or public programs for assistance. Households are likely to choose a strategy based on expected net returns and risk inherent in that strategy, as well as their situational understanding, values, social connections, and cultural norms (Adger et al. 2009). All of these strategies are challenging, particularly in a developing country context, for varied reasons: "lumpy assets" (such as livestock) make it difficult for households to quickly raise capital through sales, alternative livelihood options are often limited, resilience measures (such as alternative crops or stronger structures) are expensive, nonessential expenditures may be non-existent (among the poorest households), and social networks and public assistance programs may be insufficient. As a result, migration remains an important and common response.

Migration is also a multi-causal phenomenon, and droughts, floods, or any other climate-associated factor are only some of the many factors which contribute to households', or individual household members', decisions to move (Kibreab 2009; Laczko and Aghazarm 2009; Stapleton et al. 2017). Hence, we restrict our review to those papers that use multivariate statistical analysis and a plausible identification strategy (discussed in Section 3) for isolating the marginal impact of weather anomalies from other factors in the household's migration decision. Although we are fundamentally interested in climate change, we recognize that what is most observable, and thus what is reported on in the empirical literature, is the impact of weather anomalies (which may or may not be indicative of a permanent change in climate). To the extent that weather anomalies, in frequency or severity, are a function of long-term climate trends (which in general terms are well-established, see IPCC 2014), this distinction does not detract from our purpose. For precision, we use the term weather rather than climate from this point forward.

[2] The relatively recent development of this literature is highlighted by the sparsity of studies available for citing in previous reviews (see, for instance, Laczko and Aghazarm, 2009; Gray, 2009; Piguet, et al. 2011). While a large literature has existed for several decades on both theoretical models of migration (summarized briefly in Section 2) and on empirically determined *general* determinants of migration, studies that demonstrate causally the role of environmental factors in migration are much more recent.

The studies we systematically select for this review (introduced in Section 3) do not in aggregate support a maximalist viewpoint of climate-induced migration, nor even present consistent findings on whether weather shocks increase or decrease migration flows. Nevertheless, the studies we review support the notion that certain parts of the planet are becoming less habitable due to climate-related factors. It is similarly not disputed that climate change has the potential to mobilize large numbers of people, and it is clear that in many cases, weather shocks are contributing to large migration flows. Our review shows that the literature contains some consistent insights despite the diversity in geography, livelihood strategy, and culture. Four broad themes emerge. First, weather-induced migration is often seen more frequently among wealthier households than among poorer households. Rather than being forced to leave, poorer households are often forced to stay. This relationship is also modified by the ownership of land, which due to higher labor requirements and weak land tenure often discourages migration for a household of given financial means. Second, weather shocks more frequently drive long-distance domestic moves rather than local domestic or international moves, although in all cases, cities remain the most common destination. Earlier concerns over potential mass international migration are not supported (e.g., Myers 2002), although some exceptions exist. Third, rapid-onset shocks result in different migration outcomes than slow-onset shocks. Rapid-onset shocks, such as floods, quickly deplete household resources, thus constraining the ability to migrate. On the other hand, slow-onset shocks, such as extreme temperatures or droughts, tend to induce migration, possibly by allowing households more time to gather the resources required to migrate (Nawrotzki and DeWaard 2016). This is a valuable insight given that the most comprehensive database of environmental migrants at present (IDMC 2017) does not include slow-onset shocks, given data and definitional challenges. Finally, the severity of the weather shock, along with economic and cultural factors, affects the extent to which migration occurs. This relationship is nonlinear, with the severity of impacts driven by the way in which household capability and vulnerability scale in proportion to the severity of the weather shock in a given context.

In the following section, we consider theoretical explanations of migration and propose a conceptual framework for understanding the role of weather-related factors. In Section 3, we briefly describe the process we used for systematically selecting literature for this review. In Section 4, we summarize findings from the review in four different themes: socio-economic modifiers, migration destination, onset speed, and severity of weather shock. These findings broadly support the framework we propose in Section 2. Section 5 concludes, with a synthesis of these themes, a discussion of caveats and an outline of areas in need of further research.

2 Understanding the weather–migration relationship

2.1 Relevant theories of migration

The most prominent earlier theories of human migration are neoclassical and historical-structural theories. In the neoclassical approach, individual agents consider the costs and benefits (primarily wages) of current and alternative locations (Castles et al. 2014). Benefits differ due to capital-labor ratios and thus different marginal productivities of labor across locations. Costs differ due to distance, information, and personal preferences (Rothenberg 1977). Migration continues until the economy is in equilibrium—when the marginal productivities of labor between different sectors are equivalent (Lewis 1954). The influential pushpull theory (Lee 1966) is an example of the neoclassical approach that also incorporates characteristics beyond wage differentials of the receiving and sending areas (which could include climate factors), along with intervening facilitators, obstacles (including institutional and social factors), and personal characteristics (Castles et al. 2014, p. 25). The historical-structural theory of migration, by contrast, does not consider individual agency. Instead, migration is an inevitable part of structural social and class change (Wood 1982). These two approaches were largely replaced by the New Economics of Labor Migration (NELM) theory, which built on the neoclassical viewpoint to incorporate risk, self-insurance mechanisms, and incomplete information (Stark and Bloom 1985). NELM considers a larger set of microeconomic drivers than the neoclassical approach and strikes a more realistic balance between structural and individual considerations than the historical-structural approach.

NELM departs from the neoclassical viewpoint by considering the household to be the decision-making unit rather than the individual.[3] The two main influences on a household's decision to migrate are relative deprivation and risk diversification (Stark and Bloom 1985). The model assumes that households compare themselves with others in their social setting and make migration decisions to improve their relative income (Stark 1984). Households also try to reduce risk over expected future income by migrating to diversify their income (Massey et al. 1993; Rosenzweig and Stark 1989). NELM thus predicts migration to be more prevalent in areas with fewer formal and informal insurance mechanisms and among more risk-averse households.

2.2 What causes weather-induced migration?

Our understanding of migration, like that in the majority of studies we review, is based on NELM in terms of considering the household as the decision-making unit and viewing risk aversion as a driver of migration decisions. We extend this theory by arguing that weather shocks impact migration by affecting both households' vulnerability and capability. Capability is what households (and/or individuals) are able to do (their "functionings") and their capacity to choose and live a life they value (Sen 1999). Capability includes both material resources and non-material rights, which in combination permit households to *choose* mobility in response to adverse weather shocks. Capability can be undermined by weather shocks, which may deplete households' capital or labor. Vulnerability, meanwhile, is an expression of a household's exposure to weather shocks and the sensitivity of the household to such shocks (Adger 2006). Adverse weather shocks increase vulnerability by undermining households' future earnings and livelihood strategy, increasing the *need* for risk-reducing strategies such as migration. For example, weather shocks may negatively affect the long-term productivity of a household's natural capital, such as land quality (Gray and Mueller 2012a), or a livelihood strategy, such as rainfed agriculture. Or, given spatial correlation, weather shocks may undermine informal insurance mechanisms (Kazianga and Udry 2006). Importantly, vulnerability captures not just a present state but a future possibility, specifically, the risk that a household falls into or remains in poverty (Calvo and Dercon 2013).

We note that capability itself is a component of vulnerability (Adger and Winkels 2014; Adger 2006; McLeman and Hunter 2011). A household with high capability can lessen its exposure to future potential shocks and decrease its sensitivity to those shocks. However, vulnerability is a broader condition than simply an absence of capability (Fig. 1) and thus, while

[3] This does not mean that household must be the migrating unit, however. For instance, households could send members to live temporarily or permanently for the sake of supporting the remaining household members.

related, is not its inverse. A household may have high capability in the form of present wealth, but because of institutional and situational factors, or livelihood strategies, may simultaneously be highly vulnerable. By extension, a low capability household may have low vulnerability if its livelihood strategy is low risk and unthreatened by weather shocks; it may have little need to send migrants even if it had the capability to do so. Because changes in capability may drive migration decisions in a sometimes opposing direction to changes in exposure and sensitivity, we treat capability independently in this review while still recognizing it to be an inherent component of a household's susceptibility to harm (Adger 2006; Gallopín 2006).

In addition, there are a number of non-weather-related factors that may affect both capability and vulnerability as defined above (Adger 2009; Black et al. 2011). Credit, income, and presence of social networks all have positive effects on the capability to migrate, while also reducing vulnerability. Land tenure has an ambiguous effect: on the one hand, we would expect households with greater tenure security to have greater capability to migrate due to the correlation between wealth and land. However, households with more land have higher labor requirements and exposure to agricultural productivity changes (i.e., weather shocks). This overall framework (Fig. 1) gives rise to a number of predictions, described and tested in Section 3, through a review of a specific set of empirical papers.

Finally, we note a distinction between two overlapping types of migration in terms of their risk profile: "risk reducing" and "discretionary" migration. We note that migration may either increase or decrease risk to household income and thus welfare. NELM would predict that more vulnerable households will send migrants to diversify income (i.e., reduce risk) in response to weather shocks.[4] Certainly, vulnerable households may invest in purposively "risk reducing" migration, such as seeking temporary employment in nearby urban areas when a poor agricultural harvest is experienced or expected. However, less vulnerable households with greater capabilities may alternatively invest in "discretionary" migration, such as marriage and educational or international migration, which may not necessarily be risk-reducing and may in fact be risk-increasing in the short term. Such "discretionary" migration aims to increase expected income over time or to increase some other forms of household welfare (such as utility through marriage). Discretionary migration is not necessarily risk-reducing and is also more likely to be high cost, while risk-reducing migration is more likely to be low cost (e.g., local domestic and temporary movement). This distinction between types of migration helps explain differences in migration patterns we see in the empirical literature, presented in Sections 3 and 4.

3 Review approach

To explore factors affecting the relationship between weather shocks and migration, we conduct a systematic review of the literature. We define inclusion criteria to enable us to make comparisons across quantitative empirical papers that attempt to establish causal relationships. Papers included in our review had to meet all of the following criteria: (1) study the relationship between weather and migration in a specific developing country,[5] (2) include

[4] This may occur before, during or after a weather shock. The process of changing expectations is important given shifting climate regimes, where a series of weather shocks may be indicative of a permanently more hostile climate. Dillon, Mueller, and Salau (2011), for example, present evidence of ex-ante diversification efforts in the face of potential drought in Nigeria.

[5] We define developing countries as per the United Nations country classification system. This includes low-income, lower-middle income, and upper-middle income countries (per capita GNI less than $12,055 in 2019) of the World Bank country and lending groups.

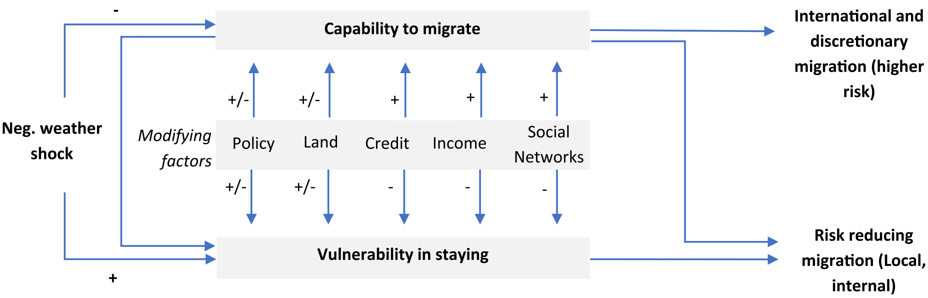

Fig. 1 Conceptual framework. A negative weather shock is expected to increase vulnerability and decrease capability, leading to ambiguous effects on migration

measures of actual weather shocks (rather than predictions or perceptions), (3) include multivariate regression analysis of observed migration, (4) use data from a household or individual-level panel or life history data, and (5) employ an identification strategy that controls for average weather and other community characteristics.

Our first criterion limits the review to climate impacts in developing countries. Given infrastructure and social policy weaknesses, populations in these countries are more vulnerable to weather shocks, and the human welfare impact of climate change in these settings is likely higher (Eckstein et al. 2018). We also focused on papers with national or sub-national analyses, rather than broad, regional analyses, to ensure that each study contained sufficient consistency in data across space and sufficient descriptive detail in cultural and institutional factors to draw conclusions. Our second criterion limited studies to those with measures of actual weather shocks. While the effect of perceptions of climate change on migration is an important question (Alam et al. 2016; Etzold et al. 2014; Koubi et al. 2016), our review focused on objectively observed weather shocks on migration decisions. Third, to ensure that the papers we analyzed were comparable in their empirical approach, we required included studies to use multivariate regression. Fourth, the use of either panel or life history data was required to help ensure temporal variation, and fifth, we required papers to control for average weather conditions and other community characteristics at a local level, through fixed effects or covariates for average weather and other factors that may affect migration decisions. The latter two criteria together ensure that included papers present plausibly causal results rather than correlations.

We first searched selected Web of Science databases for papers published within the last 15 years using the following keyword pairings: "climate and migration," "weather and migration," "floods and migration," "drought and migration," and "temperature and migration." These searches yielded a total of 4318 articles (Fig. 2). Based on titles, we removed articles that were not addressing human migration or that were clearly focused on developed countries. From the 432 articles remaining, we searched abstracts and removed papers that clearly did not meet our inclusion criteria (e.g., papers focusing solely on perceptions of climate change or papers using qualitative approaches[6]), reducing the total to 99. From these, we removed those that did not meet all inclusion criteria defined above, based on a full reading. This process left us with 17 articles. Many articles were removed in this final stage

[6] While qualitative approaches are clearly immensely valuable for understanding migration decisions, we maintained an exclusive focus on quantitative empirical papers for consistency and comparability.

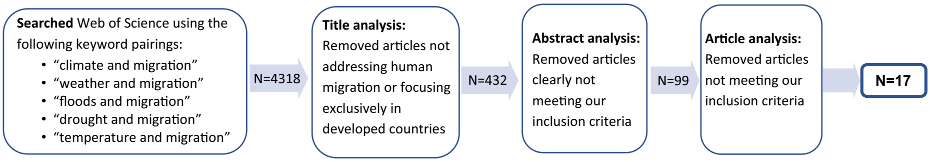

Fig. 2 Search and exclusion process

because they focused on perceptions of climate, analyzed cross-sectional data, or did not control for average local conditions. We list the main empirical conclusions from the remaining articles in Table 1.

4 Four lessons from the empirical literature

We draw four major lessons from this systematic review (Table 1), which together considerably modify the "conventional narrative" of weather-induced migration (characterized by disproportionate participation by the poorest, cross-border movements, and greater migration flows from more severe weather shocks) (Fig. 3). First, the impact of modifying socio-economic factors (such as poverty) on weather-related migration decisions is ambiguous. Most modifying factors affect both household vulnerability and capability in opposite directions, which have mutually opposing impacts on the migration decision (Fig. 1). Hence, weather-induced migration should not necessarily be more prevalent in poorer households. Second, the type and degree of weather shock may affect the decision on migration destination: international, long-distance domestic, or local. Specifically, we observe that climate-induced migration results in relatively more long-distance domestic moves. Third, the nature of the shock, rapid- or slow-onset, is likely to have different relative impacts on capability and vulnerability, leading to different migration outcomes. Finally, the severity of the shock affects the degree to which a household's capability and vulnerability will be affected. For example, a severe shock may affect a household's capability to migrate more than its vulnerability, resulting in less migration than a milder shock.

4.1 Household capability and migration

Poorer households are more vulnerable to climate change. Given an understanding of migration as an adaptation of last resort, undertaken when households reach budget and credit constraints, we may expect poorer households to be more likely to migrate in the face of weather shocks. In such a view, poor households are "forced to move." However, those same resource and credit constraints may prevent households from migrating due to an inability to cover upfront costs (Laczko and Aghazarm 2009). In such a view, migration is a (costly) investment in risk-mitigation, afforded primarily by better-off households (i.e., migration as "adaptation"), while poorer households are "forced to stay." In addition, much (likely most) migration occurs regardless of weather and occurs for a variety of reasons such as marriage, education, and economic opportunity. Weather shocks may undermine migration undertaken for such "discretionary" purposes because of decreased capability, while simultaneously increasing migration because of increased vulnerability. Aggregate statistics would then either fail to see an impact on migration or would show counterintuitive results differentiated by household characteristics.

Table 1 Studies included in review with a summary of key results

Study	Setting	Data	Weather shock	Impact of modifiers			Destination		
				Gender	Land	Shock severity	International	Long distance	Short distance
Bohra-Mishra, Oppenheimer, and Hsiang (2014)	Indonesia	Panel, 7185 HH, 1993–2008	Temperature (−, non-monotonic); precipitation (−, non-monotonic); floods (n/s)	N/A	N/A	N/A	N/A	N/A	N/A
Bohra-Mishra et al. (2017)	Philippines	Retrospective, 138 provinces, 1990–2000	Temperature (+)	Men (+) > women (+)	N/A	N/A	N/A	N/A	N/A
			Monthly max precipitation in the wet season (n/s)	Men (+); women (n/s)	N/A	N/A	N/A	N/A	N/A
			Monthly max precipitation in the dry season (n/s)	Men (−); women (n/s)	N/A	N/A	N/A	N/A	N/A
Curran and Meijer-Irons (2014)	Thailand	Panel, 5618 HH, 1984–2000	El Nino (drought) (+)	Men (+) > women (+)	(−)	Short-term (−); long-term (+)	N/A	N/A	N/A
Dillon, Mueller, and Salau (2011)	Nigeria	Panel, 199 HH, 1998–2008	Temperature (+)	Women (−); men (+)	N/A	N/A	N/A	N/A	N/A
Gray and Bilsborrow (2014)	Ecuador	Retrospective, 585 HH, 2001–2008	Rainfall deviation (− and +)	Men, (+) long-distance and (−) international; women, (−) local and (−) international	N/A	International (−); long-distance (non--monotonic); local (−)	(−)	(+)	(−)
Gray and Mueller (2012a)	Ethiopia	Panel, 1500 HH, 1994–2009	Drought (+)	Women (n/s); men (+)	(−)	Men (+); women (−, non-monotonic)	N/A	(+)	N/S
Gray and Mueller (2012b)	Bangladesh	Panel, 1700 HH, 1994–2010	Drought[1] (− and +)	Women (+); men (+)	(−)	(+)	N/A	(+)	(−)
			Flood (n/s)	Women (+); men (n/s)	N/S	N/S	N/S	N/S	N/S
Henry, Schoumaker, and Beauchemin (2004a)	Burkina Faso	Retrospective, 3911 individuals, 1970–1998	Drought (− and +)	Women (−); men (+)	N/A	N/A	(−)	Men (+); women (−)	N/A
Hirvonen (2016)	Tanzania	Panel, 4336 individuals, 1991–2010	Precipitation (n/s)	N/S	N/A	N/A	N/A	Men (n/s); women (−)	N/S
			Temperature (−)	Men (−); women (n/s)	N/A	Men, more severe (−) > less severe (−)	N/A	Men (−); women (n/s)	Men (−); women (n/s)

Table 1 (continued)

Study	Setting	Data	Weather shock	Impact of modifiers			Destination		
				Gender	Land	Shock severity	International	Long distance	Short distance
Hunter, Murray, and Riosmena (2013)	Mexico	Retrospective, 23,686 HH, 1987–2005	Drought (− and +)	N/A	N/A	Short-term (−); long-term (+)	N/A	N/A	N/A
Jessoe, Manning, and Taylor (2018)	Mexico	Panel, 8107 individuals, 1980–2007	Precipitation (+) Temperature (+)	N/A N/A	N/A N/A	N/A More severe (+); less severe (n/s)	(+) International (+) > domestic (+)	(+) International (+) > domestic (+)	N/S N/A
Mastrorillo et al. (2016)	South Africa	Census, 5050 individuals, 2001 and 2011	Temperature (+) Precipitation (−)	Women (+); men (+) Women (−); men (−)	N/A N/A	N/A N/A	N/A N/A	N/A N/A	N/A N/A
Mueller et al., 2014a	Pakistan	Panel, 583 HH, 1991–2012	Temperature (+) Floods (−) Precipitation (n/s)	Men (+) > women (+) Women (−); men (−) N/S	(−) N/A N/S	Men (+) > women (+) N/A N/S	N/A N/A N/A	(+) (−) Men (+); women (n/s)	(+) (−) N/S
Nawrotzki and DeWaard (2016)	Mexico	Retrospective, 110 HH, 1961–1999	Temperature (+) Precipitation (n/s)	N/A N/A	N/A N/A	N/A N/A	(+) N/S	N/A N/A	N/A N/A
Nawrotzki, Riosmena, and Hunter (2013)	Mexico	Retrospective, 80,455 HH, 1995–2000	Rainfall decrease (+)	N/A	N/A	More severe (+)	(+)	N/A	N/A
Robalino, Jimenez, and Chacón (2015)	Costa Rica	Census, 81 cantons, 1995–2000	Floods (+)	N/A	N/A	Less severe (+); more severe (−)	N/A	N/A	N/A
Thiede and Gray (2017)	Indonesia	Panel, 14,421 individuals, 2000–2008	Temperature (−)	Men (−) > women (−)	N/S	N/A	N/A	N/S	(−)

(+) indicates an increase in migration in response to a weather shock, (−) indicates decreased migration. > indicates that one factor has a greater impact on migration propensity than another factor. For example, women (+) > men (+) indicates that both men and women are more likely to migrate in response to the shock, but that women's propensity is greater. HH = households.

[1] Gray and Mueller (2012b) do not explicitly study drought, but rather study non-flooding-related crop failure. However, they state that this crop failure was "driven primarily by rainfall deficits." We thus label this type of crop failure as drought to facilitate comparability across studies

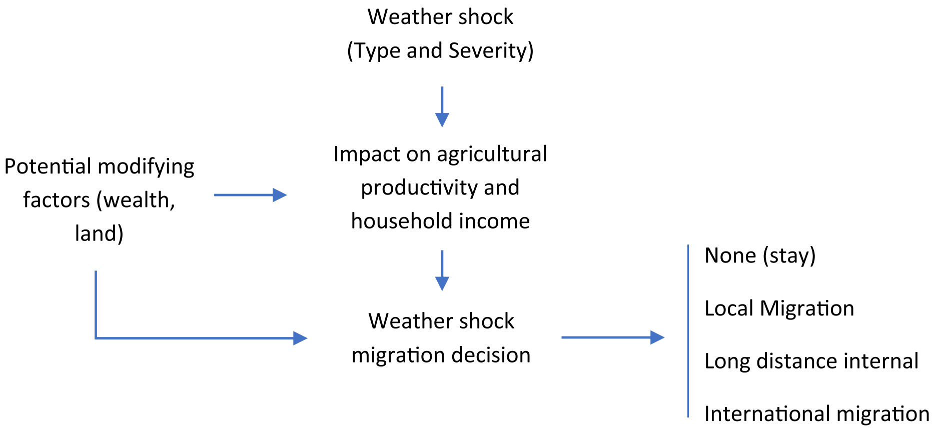

Fig. 3 The relationship between weather shocks and migration is likely to be modified by (1) household characteristics, (2) weather shock severity, and (3) type. These likely influence (4) destination choice

Many of the papers we review consider elements of household[7] capability and vulnerability as modifying factors of the weather shock–migration relationship (for example, through the use of an interaction term between weather shocks and household characteristics in the migration likelihood regression[8]). We first consider direct measures of household financial capability—income or expenditure. We second consider land ownership, which we consider to be a special class of socio-economic status. We thirdly consider gender, another determinant of vulnerability, which helps explain shifts in *types* of migration due to weather shocks. Migration motivation differs greatly for men and women. In low-income settings, men move relatively more often for economic reasons, while women move relatively more often for family reasons (Findley 1994; Gray 2010).

Bohra-Mishra et al. (2017) and Gray and Mueller (2012a) use education as a proxy for financial and human capital and find that the probability of weather-related migration increases with education, suggesting that household resource-constraints may be an important factor impeding weather-related migration. However, other studies that use more direct measures of household resources (e.g., income, expenditure, or asset ownership) find mixed results. Many studies do not find that such resources affect the likelihood of weather-induced migration (Thiede and Gray 2017; Gray and Mueller 2012b); whereas Mastrorillo et al. (2016) find positive weather-related migration for both low- and high-income individuals, but a stronger positive effect for low-income households. Hirvonen (2016) provides further supporting evidence of this nonlinear relationship between wealth and weather-induced migration: while heatwaves in Tanzania result in less migration among males, this effect is significantly dampened among households with higher asset ownership. One reason for these differing results is that income is endogenous to weather shocks. Such shocks may directly increase

[0] There are of course community or regional factors, beyond the household level, that affect the decision to migrate, for example, conflict and political instability. While we acknowledge these as important factors, the studies included in our review exploit differences at the household level or, at most, differences at a district level. Political instability, which affects entire countries or regions over long periods of time, is thus not explicitly considered.

[0] This differs from the more common approach of considering household capability or vulnerability as a simple control variable, which provides a general characterization of whether richer or poorer households migrate but not in respect to weather shocks specifically.

migration because of increased vulnerability (Gray and Mueller 2012b; Thiede and Gray 2017). However, if at the same time the shock significantly reduces income, resulting in reduced capability, households may be less likely to migrate (Hirvonen 2016; Mastrorillo et al. 2016). There is a need for future studies to account for changes in income over time, rather than relying on baseline or lagged income, to better disentangle the direct effect of shocks on migration and the indirect of shocks on migration through reduced income/capability.

Land and wealth are closely correlated in most settings; owning little or no land suggests lower migration capability and increased vulnerability to weather shocks. We posit that the relationship between land ownership and migration is ambiguous and depends largely on the strength of land tenure in a particular setting. Weather shocks may reduce migration among landowners for a variety of reasons: (1) land ownership suggests greater wealth and thus greater adaptive capacity (i.e., lower vulnerability), and thus less need for migration; (2) land holdings also increase a household's labor requirements, reducing the ability of a household to send migrants who are required at home for farm work; and (3) weak land tenure, or weak enforcement of property rights, acts as a disincentive to leave land underutilized because of the possibility of losing large wealth holdings. On the other hand, weather-induced migration may increase migration among landowners because land ownership also suggests a higher capability to finance investment in migration. On the whole, the research suggests that land ownership reduces weather-induced migration, all else equal (Gray and Mueller 2012a, b, 2014a; Curran and Meijer-Irons 2014; Thiede and Gray 2017). This finding is consistent with the understanding that land ownership decreases general migration (i.e., that not necessarily related to climate considerations) from rural areas (Gray, 2009) for the three reasons discussed above.

Weather shocks may also have differential effects based on the gender of household members. Gray and Mueller (2012a) find that drought reduces women's marriage migration, but increases men's economic migration simultaneously. Henry, Schoumaker, and Beauchemin (2004a) find a similar pattern in Burkina Faso: men are more likely to move domestically in drought conditions, while women are less likely to migrate. Similarly, Dillon, Mueller, and Salau (2011) show that extreme temperature shocks in Nigeria increase male migration, but decrease female migration. This differential migration by gender is observed but to a lesser extreme in Curran and Meijer-Irons (2014), Mueller et al. 2014, Mastrorillo et al. (2016), and Bohra-Mishra et al. (2017). These studies show that while both heavy precipitation and heat stress encourage migration of men and women, the impact on men is stronger.[9] These studies suggest that women in these settings have less capability than men to migrate as a response to climate shocks. Both Thiede and Gray (2017) (in Indonesia) and Hirvonen (2016) (in Tanzania) find that higher temperatures reduce migration more among men than among women. Consistent with our model of capability, Hirvonen (2016) reports that an increase in the temperature of the previous year's growing season reduces yields and likely the financial savings required for subsequent migration, should that be necessary or desirable in the following year. Women's migration is motivated by marriage in this context and is less affected. Hirvonen (2016) also shows that this effect is significantly stronger for poorer males, which again suggests that poverty constrains one's ability to migrate.

These three socio-economic modifiers of the weather–migration relationship, income/wealth, land tenure, and gender, have different, but consistent, impacts. Evidence on the

[0] The only departure from this trend is found in Mastrorillo et al. (2016), who find that large positive heat anomalies increase migration for both women and men, with a larger effect on women (although the statistical significance of the difference is not reported).

impact of income and wealth is thin, but its limited significance is tentatively supportive of our framework of opposing impacts on capability and vulnerability. Studies including interactions of land ownership show that weather shocks decrease landowners' probability of migration despite landowners' higher capabilities, which is likely due to reduced vulnerability (land is a close proxy for wealth) as well as the ties to a location, and demand for labor, associated with land ownership. The opposite plays out when comparing men and women. Men (who typically have more decision-making power in developing countries and move for economic purposes) are more likely than women to migrate in response to a weather shock.

4.2 Migration destination

Earlier research on climate and migration focused on international migration due to data availability (Laczko and Aghazarm, 2009). A number of the papers reviewed here, however, consider not only domestic migration but also in many cases provide a direct comparison between international and different types of domestic migration.[10] We expect that a weather shock's impact on capability will affect all forms of migration, while the shock's impact on vulnerability will disproportionately affect local "necessary" migration (for instance, that for employment purposes rather than marriage or education purposes). Vulnerability will have a lesser impact on international migration when such a move represents a larger, higher risk investment. Once again, we differentiate between the larger number of studies which seeks to explain the choice of migration destination in general and those which explain destination with regard to weather shocks. The general literature is relatively consistent and intuitive: younger, wealthier, landholding, and better-educated individuals are more likely to move internationally relative to their older, poorer, less-educated peers.

Gray and Mueller 2012a, 2012b, and Gray and Bilsborrow (2013) all find that drought induces out-of-district migration relative to local migration. In Ethiopia, these moves are largely observed for men and are for employment and thus likely represent migration to districts or urban areas that do not face the same drought shock (Gray and Mueller 2012a). Henry, Schoumaker, and Beauchemin (2004a) show that in Burkina Faso, men are more likely to move domestically in drought conditions and are less likely to move internationally, than in other circumstances. Women are less likely to move both internationally and domestically. Similarly, in Ecuador, Gray and Bilsborrow (2013) find adverse rainfall conditions reduce local migration and international migration, but increase intermediate domestic migration. The intermediate category affects men more strongly, while the local migration effect is strongest for women. Again, this finding supports the distinction between changes in employment-related migration, prompted by increased vulnerability, and changes in international and discretionary migration, prompted by a reduction in capability.

Three papers in our review (Jessoe, Manning, and Taylor, 2018; Nawrotzki and DeWaard, 2016; Nawrotzki, Riosmena, and Hunter, 2013) find positive weather-related international migration from Mexico to the USA. Both Nawrotzki and DeWaard (2016) and Jessoe, Manning, and Taylor (2018) find that extreme temperature shocks increase this international flow, and Jessoe, Manning, and Taylor (2018) also show that moderate shocks induce domestic migration. They suggest that "migration may be viewed by some individuals as a strategy for mitigating costs of negative shocks and, by others, as a costly but desirable opportunity."

[0] This may take the form of a distinction between rural and urban migration (the latter usually represented a longer move), or between within-district and out-of-district migration.

Similarly, Nawrotzki, Riosmena, and Hunter (2013) find that large rainfall deficits increase migration from Mexico to the USA. While these results differ from the other papers in that the shock is increasing apparently discretionary high-risk migration, it is likely that international migration (to the USA) is more feasible from Mexico than from the other destinations (given both proximity and dense supporting social networks) and thus still represents a risk-mitigating action (equivalent to domestic relocation in other contexts).

4.3 Slow-onset versus rapid-onset environmental changes

Previous research has focused less on slow-onset environmental changes relative to more dramatic disasters (Laczko and Aghazarm, 2009). For the purposes of this study, we categorize slow-onset events as drought and elevated temperatures, which tend to occur (either due to their nature or the way they are defined in studies) over an extended time horizon. We categorize flood as a rapid-onset environmental change. Table 1 highlights the different migration patterns seen across these types of change. The overall trend for slow-onset environmental changes is increased migration (Bohra-Mishra et al. 2017; Curran and Meijer-irons 2014; Dillon, Mueller, and Salau 2011; Gray and Mueller 2012a, 2012b; Hunter, Murray, and Riosmena 2013; Jessoe, Manning, and Taylor 2018; Mastrorillo et al. 2016; Mueller et al., 2014; Nawrotzki and DeWaard 2016). There are a few departures from this trend (Bohra-Mishra, Oppenheimer, and Hsiang 2014; Henry, Shoumaker, and Beauchemin 2004b; Hirvonen 2016), which we discuss in other sections of this paper.

The trend for rapid onset of environmental conditions is decidedly different. Both Gray and Mueller (2012a) and Bohra-Mishra, Oppenheimer, and Hsiang (2014) show that floods have a limited or non-significant effect on migration. Mueller et al. (2014) find that floods decrease the likelihood of migration in Pakistan. While Robalino, Jimenez, and Chacón (2015) find a small overall positive effect of flooding and other hydro-meteorological emergencies (e.g., landslides) on migration, they find that migration decreases for more severe emergencies. One possible reason is that floods quickly deplete households' capabilities. Sudden losses reduce the ability to undertake new, costly migrations and may even decrease overall migration; that is to say, fast-onset environmental shocks decrease capabilities, resulting in reduced migration.

These insights suggest that households experience an adjustment period in which to make a decision over the best mix of adaptation strategies when faced with slow-onset environmental change. Slow-onset shocks may also allow households time to collect the resources to make migration possible, thus increasing capability to migrate (Nawrotzki and DeWaard, 2016). Rapid-onset environmental shocks do not provide adjustment periods, and thus, households are more likely to experience sudden depletion of their capabilities, leaving them less able to migrate. Of course, sufficiently mild yet rapid environmental shocks will not deplete all capabilities: for example, migration occurred under less severe flooding episodes in Costa Rica (Robalino, Jimenez, and Chacón 2015). Overall, the result with regard to shock type is notable in the context of environmental migrant numbers compiled by IDMC (2017): their substantial and widely cited estimate of at least 24 million displaced persons due to weather-related shocks (in 2016) is thus likely a considerable underestimate of the total, given their focus on rapid-onset shocks only.

4.4 Shock severity

A conventional narrative of weather-induced migration would suggest that greater shock severity is monotonically associated with a greater likelihood of migration. Our vulnerability and capability framework would support this prediction if the relative impact on the weather-shock on both of these qualities remained the same over differing shock severities. This is unlikely to be the case for many situations: a threshold level of vulnerability, for instance, might need to be reached before a household responds with migration; alternatively, as a shock increases in severity, migration might occur until a point where a capability threshold is reached, and no further investment in migration is possible. A related possibility is that households run out of household members to send. If a period of severe drought tends to follow a period of moderate drought (i.e., conditions deteriorate over time) and households exhaust their supply of members who can migrate, the data will show higher migration under moderate conditions and lower migration under severe conditions. These varied possibilities mean that almost any shape of the severity migration function could be expected to occur. Our prediction is limited to simply raising the possibility of such alternatives (Fig. 4).

Robalino, Jimenez, and Chacón (2015) study hydro-meteorological events such as floods, storms, and landslides. All shocks increased migration, but notably, moderate shocks had a larger impact than severe shocks in the case of non-metropolitan migration. Gray and Bilsborrow (2013) also find a non-monotonic relationship for rainfall variation in Ecuador. While international and local migration decreases as a function of severity, intermediate migration increases and then decreases.

Mueller, Gray, and Kosec (2014) examine temperature by quartile to investigate the impact of severe temperature deviations on migration in Pakistan. They show that only temperature in the fourth quartile (i.e., the most extreme temperature deviations) drives outward migration. Interestingly, Mueller, Gray, and Kosec (2014) also show that the severity of rainfall deviation has no effect on migration. Nawrotzki, Riosmena, and Hunter (2013), on the other hand, show that more severe rainfall deficits in already dry states increase international migration from Mexico. Bohra-Mishra, Oppenheimer, and Hsiang (2014) examine nonlinear effects of temperature and rainfall on migration decisions in Indonesia. They estimate a U-shaped relationship between temperature and rainfall severity and the probability of migration. However, like Mueller, Gray, and Kosec (2014), they find that the effect of temperature on the likelihood of migration is more pronounced than the effect of rainfall.

Hunter, Murray, and Riosmena (2013) investigate the short-term and long-term effects of shock severity in the case of severe drought. They find that in the short term, severe shocks decrease the likelihood of Mexico to US migration, but in the long term, severe shocks have the opposite effect. Curran and Meijer-Irons (2014) find the same effect for internal migration in Thailand. One potential explanation for the discrepancy in short- and long-term effects of

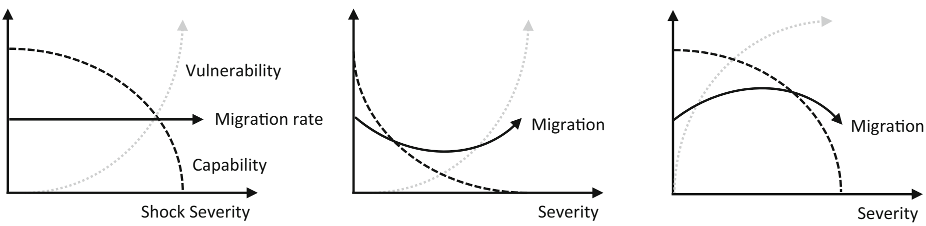

Fig. 4 Hypothesized responses of migration to climate severity

severe shocks is that capabilities are directly stunted following a severe shock. Thus, directly after an extreme weather shock, households have significantly fewer resources to finance migration. However, after being exposed to a severe shock, households may feel more vulnerable and want to protect against future severe shocks (ex ante risk reduction). Therefore, after recovery (i.e., in the long term), we would expect to see more migration.

Overall, as depicted in Fig. 4, the effect of shock severity on migration depends on whether the capability or vulnerability effect dominates. The literature in this review suggests that, in the long term, the vulnerability effect tends to dominate for severe shocks. However, directly following a severe weather shock, the capability effect tends to dominate, undermining the ability of households to migrate.

5 Conclusion

This review builds on previous reviews of climate change and human migration (Klaiber 2014; Gemenne, 2011a) by presenting a framework of the ways in which weather-related shocks impact household migration decisions, based on household capability and vulnerability. Based on this framework, we use patterns in recent quantitative empirical literature to formulate four main points: (1) weather-induced migration is not necessarily more prevalent among more impoverished households; (2) weather-induced migration tends to have the largest positive effect for long-distance domestic migration rather than short-distance or international migration; (3) slow-onset weather shocks are more likely to induce migration than rapid-onset changes; and (4) the severity of the weather shock impacts migration in a nonlinear fashion, with the extent of migration influenced by both household capability and vulnerability.

While our findings are based on studies which consider observed weather, these insights are valuable for understanding the potential migration impacts of climate change (given expected climate change impacts on droughts, floods, and temperature) and for understanding the responses different types of households are likely to make. While our review has focused on historically observed circumstances, severe climate changes such as 4 °C of global warming relative to the pre-industrial average, for instance, would present weather shocks well beyond those experienced in the past. Such extremes would greatly limit in situ adaptation options (Gemenne, 2011b) and could force migration which is unaffordable without a major shift in livelihood strategy, for instance, by selling productive assets. Our analysis also does not consider likely impacts of sea-level rise (SLR) even though it will certainly be a driver of considerable climate-related migration (Perch-Nielsen et al., 2008), with projections of 0.26–0.98-m mean sea level rise by 2100 (IPCC, 2014). Much analysis on this topic makes use of different empirical techniques to those considered here, specifically modeled projections of exposure rather than ex post causal evaluations (see Neumann et al. 2015; Davis et al. 2018) and are thus not considered in this review. There is a need for systematic evaluation of the initial impacts of SLR on migration, including from salinization and storm surge, given the likely severity of its expected future impacts.

We acknowledge that the inclusion criteria that we chose for comparability across studies also impose some limitations. We focus on observed weather shocks and observed migration, which preclude us from understanding how perceptions of climate change drive migratory responses (Abdul, Joarder, and Miller, 2013; Etzold et al., 2014; Koubi et al., 2016). Our focus on rigorous quantitative papers attempting to establish causal relationships is important to draw comparisons across studies. However, we acknowledge the need for important qualitative work that seeks to document climate migration narratives which allow us to more deeply understand migration motivations and contextual factors (Hirsch, 2015). Our selection of papers was strongly focused on migration and its causal determinants, limiting our ability to draw conclusions on how migration fits into the larger suite of climate response strategies. Studies based on more detailed qualitative insights, or that include quantitative measures of in situ adaptation as additional outcomes, would give a deeper understanding of how households prioritize between adaptation options.

Moreover, while there has been considerable growth of studies investigating this topic in the past fifteen years, the empirical literature is still sparse. We identify three critical areas of future research. First, the NELM theory (see Section 2) suggests relative depravation should be an important driver of migration (Stark and Bloom, 1985), and it would be valuable investigating the effect of social inequality on climate-induced migration. Second, policies and institutions profoundly shape the household response to weather shocks. Future research should investigate the impact of policies and institutional differences, both in terms of the migration outcomes they facilitate or inhibit and the resulting welfare impacts. Finally, migration is just one of the many coping strategies that households can employ to mitigate the effects of climate change. Other mitigation strategies may include switching to low-risk crops, purchasing insurance, changing livelihoods to depend less on climate-related factors, and investing in technologies that lessen the negative effects of weather shocks (for example, irrigation). It is important to understand how migration fits into a larger pool of coping strategies. Future research should seek to understand how these strategies interact and what conditions encourage which strategies.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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