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Water stress and human migration: a global, georeferenced review of empirical research



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Water stress and human migration: a global, georeferenced review of empirical research

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Foreword

Migration is a universal and common process and is linked to development in multiple ways. When mainstreamed in broader frameworks, especially in development planning, migration can benefit the communities on both ends. Migrants can and do increase the resilience of their home communities and support them through remittances as well as the knowledge and skills while playing a positive role in the host communities' development. Migration can also be a part of climate change adaptation efforts. Safe, orderly and regular migration can contribute to agricultural development, economic growth, food security and rural livelihoods. Yet, those migrants who are poor and low-skilled face the biggest challenges emanating from migration that occurs on involuntary, unsafe and irregular basis.

International cooperation and sound policies in dealing with migration can help establish critical linkages between emergency efforts and development with important positive outcomes. The domain for these policies and cooperation spans from very local to global, and many sectors of the socio economic life. A good understanding of the many aspects of migration is therefore essential to dealing with migration.

Patterns of human settlement and population movement have always been affected by long-term changes in climate and weather patterns and the availability of and access to natural resources. Today, concerns over how changes in the environment and climate might affect migration have been growing. It is intuitive to link impacts of climate change, water scarcity, and droughts to migration. Indeed, important claims and assertions about these interactions abound in the media and in many policy documents. But what are the scientists and researchers saying about them?

To help guide future policy work in the areas of food security, agriculture, rural livelihoods and integrated water resources planning, FAO Land and Water Division (CBL) and GWP Technical Committee (TEC) initiated a multi-phase effort. The first phase of this effort was about understanding the migration phenomena from this particular perspective and researchers who specialize in migration, water resources and geography at Oregon State University were asked to look into this question by examining the peer-reviewed and empirical literature on how water stress affects and is affected by migration. The result is this analytical literature review, "Water stress and human migration: a global, georeferenced review of empirical research." The review, which was conducted over four months, reveals important lessons learned, suggestions on needed research, and sometimes surprising gaps in research on this area of focus.

The study geocoded the results of 116 peer-reviewed papers and plotted them against watershed sub-basin-level maps of indicators of water stress and compared them to the projected changes in surface temperature and annual cumulative precipitation. These maps were examined to identify geographic disparities between existing water stress-migration research and likely future regions of water stress.

The findings from the reviewed literature provide important material for policy development for improving migration as a strategy for adapting to water stress. A key finding of the review is that migrants rarely, if ever, cause resource conflicts. Another is about the fact that agricultural adaptation strategies affects people's need to migrate and should be explicitly incorporated in the respective policies, including in climate change adaptation. Another finding that can complement this is that a delayed migration reaction to water stress allows time for intervention. All these make a case for proactive adaptation as a more effective and sustainable strategy than a reactive humanitarian response.

FAO Land and Water Division and GWP Technical Committee hope this literature review will assist in the understanding of water stress and migration and will be useful for ongoing policy efforts.

**Dr Jerome Delli Priscoli,
Chair,
GWP Technical Committee**

**Dr Olcay Unver,
Deputy Director,
FAO Land and Water Division**

Acronyms and abbreviations

CMIP5	Coupled Model Intercomparison Project, Phase 5
GMG	Global Migration Group
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
NCAR	National Center for Atmospheric Research
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

This report assesses and maps 184 peer-reviewed, empirical research articles selected for their focus on linkages between water stress and human migration. First and most importantly, this literature asserts that migration is universal. Migration is an extremely common social process and is normal in almost every society on earth. Safe, orderly and regular migration can and do benefit both home and host communities. Environment- influenced migration is rarely, if ever, a resource threat to the regions to which people move.

Migration that is involuntary, unsafe and poorly managed can have negative impacts through increased vulnerabilities, greater pressures on natural resources, including water resources, and lead to tensions between migrants and host communities. The literature does, observe that negative social outcomes can result from narratives that stigmatize migrants and/or cast migrants as a security threat – especially when these narratives are used to justify increased surveillance and monitoring of these people.

A number of the reviewed articles argue for the adoption of proactive policies and programmes that seek to reduce migration. Typically, these articles identify a case for investment in sustainable agriculture and rural livelihood diversification. In water-stressed areas, experience suggests that such policies and programmes can both slow rural-urban migration and reduce the incentive for people to attempt to move across international borders out of desperation rather than out of choice.

The literature reveals a strong consensus that increased water stress can cause people to decide to migrate. There also appears to be a consensus that increasing mean temperatures are correlated with, and are thought to be a cause of, increased water stress. As temperatures rise, water stress may result from less water, increases in evaporation, and increases in agricultural water demand. But the link between temperature and water stress is not unique to drought. Recent papers demonstrate that a combination of higher temperatures and rainfall extremes are correlated with increases in migration rates away from areas where these changes can be observed. This being said, the causal interaction of temperature, water stress and migration is still not clearly understood. More systematic studies are needed.

In an effort to determine where further empirical research may be justified, we initially map the distribution of reviewed articles at the sub-basin level and then compare these data with expected future changes in surface temperature and precipitation. Examination of these maps suggests that linkages between water stress and migration are understudied in India, Central Asia, the Middle East, and the Central Sahel. As data transparency is low and/or insecurity makes field data collection difficult in some of these areas, the use of novel data-gathering techniques, such as crowd-sourcing, passive data collection from digital devices and remotely sensed data, is suggested as a way to speed progress.

1. Introduction

Access to water provides a basis for human livelihoods, culture, and progress (Smit and Wandel 2000). Adams *et al.* (2009) and Smith *et al.* (2009) have found that water stress undermines societies' place-specific livelihood systems and strategies which, in turn, induces new patterns of human migration (Black *et al.*, 2011a). Water stress is defined here as a circumstance in which the demand for water is not met due to a decline in availability and/or quality. Water stress is often discussed in terms of water scarcity, drought, long dry spells, irrigation water shortages, changing seasonality and weather extremes. The aim of this review is to synthesize knowledge on the impact of increasing water stress on human migration.

While this is not the first review of empirical research linking environmental problems to human migration, it is distinguished in three key ways. First, the corpus of empirical environment-migration research has grown sufficiently to enable a review of 184 research papers on the relationship between water stress and migration. Some of these papers deal with the relationship between dryland crops and water stress and others deal with crop water stress as a result of a lack of access to water for irrigation. Some deal with water stress and migration in sending areas, and others deal with water stress and migration in receiving areas. The second specific contribution of this review is to map the geographic distribution of water stress-migration research at the sub-basin level and compare it with expected changes in water stress that are likely to occur as a result of climate change over the next 30 years. This exercise reveals potential geographic gaps in our knowledge of water stress-migration relationships and identifies places where future research efforts could produce useful information. Third, this review imposes a strict sampling frame of peer review and external publication and, from the findings, inductively summarizes the state of scientific knowledge on water stress-migration relationships to identify *what we need to know*.

This review inherits much from previous reviews of scholarly literature on migration-environment linkages. Due to the interdisciplinary nature of the research community, with contributions from demography, anthropology, geography and economics, it has been necessary to frequently synthesize and recapitulate the most common methods and findings. Methodological reviews (such as Pigué, 2010; Pigué *et al.*, 2011, McLeman, 2013 and Fussell *et al.*, 2014) have served an essential role in the maturation of this interdisciplinary research community by identifying the diversity of empirical strategies, and evaluating their quality and contribution. Other reviews have grouped case studies by theme, such as McLeman (2011), which gathered analogues for the most severe adverse consequence of climate change: settlement abandonment. This paper also takes important cues from Obokata *et al.* (2014), which provided the first comprehensive summary of empirical research on environment-related international migration. This paper narrows its scope to water stress, and also includes research on internal migration.

Specifically, we search for knowledge about the key factors that influence water stress-migration relationships so that global leaders can evaluate the potential benefits of pursuing climate mitigation and adaptation policies through a migration lens with greater confidence. In their foundational paper on the relationship between migration and the environment, Black *et al.* (2011a) found that political, economic, social and demographic contexts are crucial in informing how patterns of migration are

established and how, in specific contexts, environmental change may be a contributing factor in the decision to migrate.

Policy-makers also need to know how and when water stress can alter the functioning of ecosystems and, as a result, put pressure on livelihoods. In some cases, a reduction in effective rainfall and/or loss of access to irrigation water and other ecosystem services can render an existing livelihood inoperable, thus making the search for alternative livelihood necessary. The search for alternative livelihoods may or may not entail migration. One of the most compelling findings emerging from recent research is that in dryland agricultural areas increased surface temperature extremes and variability have an influence on migration (Cattaneo and Peri, 2016). It appears that extreme and long-lasting rises in temperature can increase the frequency of long dry spells (droughts), which in turn increase the frequency of crop failure and, as a result, can increase out-migration from agriculturally dependent societies (Gray and Mueller, 2012; Henry *et al.*, 2004; Cai *et al.*, 2017).

New knowledge about the impact of temperature extremes and duration on seasonal agricultural production is one key mechanism that allows us to attribute new patterns in migration to anthropogenic climate change impacts and anticipate the future impacts of climate change on rates of migration. Again, historical, political, economic and demographic contexts explain why people are dependent on agriculture and these factors influence the migration options at their disposal when changing environmental conditions make livelihoods more and more difficult. Peer-reviewed studies of the ways that temperature increases interact with other more well-established drivers of migration, such as labour markets and violent conflict, are lacking and this is an area that could be prioritized.

There is also a dearth of knowledge about the influence of investments that alleviate water stress on migration – especially in areas dominated by irrigated agriculture. Studies in multiple contexts imply that public investments in rural agriculture adaptation could attenuate rapid rural-urban migration (Nawrotski *et al.*, 2017). These findings indicate that rural adaptation measures may deserve greater attention as a means to create opportunities and reduce vulnerability to climate stresses and shocks so that people do not feel forced to abandon their agricultural land. More comprehensive assessments of the impacts of adaptation interventions on forms of forced migration, such as forced displacement, could help policy-makers understand the value of public expenditures towards rural economic diversification. To this end, more research is needed on the effect of rural agriculture adaptation policies on migration, and the effect of migration on coordinated adaptation. Adaptive policies and programmes that might be of assistance include: land tenure reforms; development of robust water-sharing systems; development of drought-resistant crop varieties; crop insurance mechanisms; and other measures to buffer the impact of repeated losses associated with water stress.

What is the international governance landscape for addressing migration related to water stress? As water stress frequently originates in transboundary watersheds shared among nations, environment-related migration is a concern of international agencies – especially those concerned about the potentially adverse effects of climate change (McAdam, 2012). Indeed, the Intergovernmental Panel on Climate Change (IPCC) concluded in its Fifth Assessment that “mobility is a widely used strategy to maintain livelihoods in response to social and environmental changes (high agreement, medium evidence)” while at the same time “climate change will have significant impacts on forms of migration that compromise human security (high agreement, medium evidence)” (Adger *et al.*, 2014; IPCC WGII, Ch.12). Migration is thus a strategy for

adapting to climate change (McLeman and Smit, 2006) and at the same time is evidence of deficiencies in people's capacities to adapt to change (through no fault of their own; see Tacoli, 2009).

Among multilateral international institutions, the policy problems associated with environment-related migration have been addressed primarily by the International Organization for Migration (IOM), which has focused on cross-border labour migration issues, and the United Nations Framework Convention on Climate Change (UNFCCC), which has focused on the potential for population displacement across borders as a result of climate change. Recognizing that migration is a cross-cutting opportunity for international cooperation, in 2006 the United Nations (UN) created the Global Migration Group (GMG), which brings together 22 UN agencies with a view to improving the effectiveness of policy action. The ultimate aim of the GMG is to address the challenges linked to international migration in order to harness its potential and benefits.

While there is no legal category guaranteeing special protections for environmental migrants (i.e. "climate refugees"), the IOM formally defined "environmental migrants" in the UNFCCC (2007) as "persons or groups of persons who, for reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to have to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their territory or abroad" (pp. 1-2). With this definition, the UNFCCC has identified a pressing policy need for initiatives that support understanding of both migrants and the environmental pressures that may produce them (Renaud *et al.*, 2008; Laczko and Aghazarm, 2009). At present, the governing body tasked with studying and devising environmental migration policies is the UNFCCC's Warsaw International Mechanism on Loss and Damage (see Wrathall *et al.*, 2015). Policy norms have been advanced that call on states to mutually recognize the rights of non-citizens migrating across borders due to climate impacts (Warner, 2010). While the UN General Assembly is not likely to achieve consensus on this legal principle, according to the Norwegian Refugee Council, the Nansen Initiative and other proponents, it merits serious consideration by individual member states and people living in high-risk regions (Warner *et al.*, 2013).

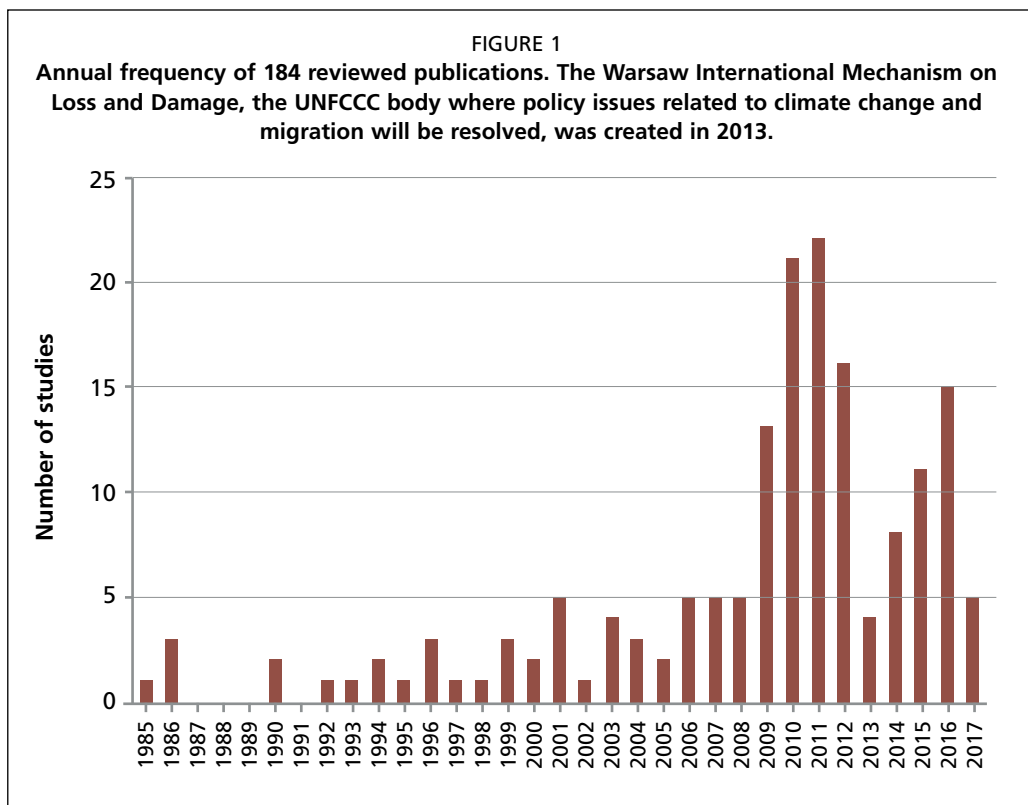
The conceptual and methodological foundation: The "migration as adaptation" thesis (McLeman and Smit, 2006) has emerged as an influential concept in the reviewed literature. This thesis holds that when people experience detrimental environmental change, they can adapt by pursuing alternative livelihood opportunities (Black *et al.*, 2011a). Migration is often an income and risk diversification strategy by which one or more members of a household migrate and remit back to the household. The resultant income can then be used to help adapt to changes in the environment, buffer against environmental as well as economic risks, and absorb losses (Barnett and Webber, 2010).

Individual migrant capacity to absorb the costs and extract the benefits of migration is highly uneven across society. Different people migrate differently in response to drought and water-supply stress (Curran, 2002; Henry *et al.*, 2004). Men and women may migrate differently, as may elderly and young people, and relatively wealthy and poor people. Whatever the population, responsiveness that may result in migration is dependent on the complex cultural, political and environmental context in which decisions are made (see Black *et al.*, 2011a). Concerningly, in recent years, empirical research has identified populations that are unwilling or unable to engage in labour migration (see Adams, 2016). The capacity to migrate of these populations may be eroding gradually over time, increasing the likelihood of a humanitarian crisis and the need for sustained, high-level interventions (see Black *et al.*, 2011a).

2. Methods

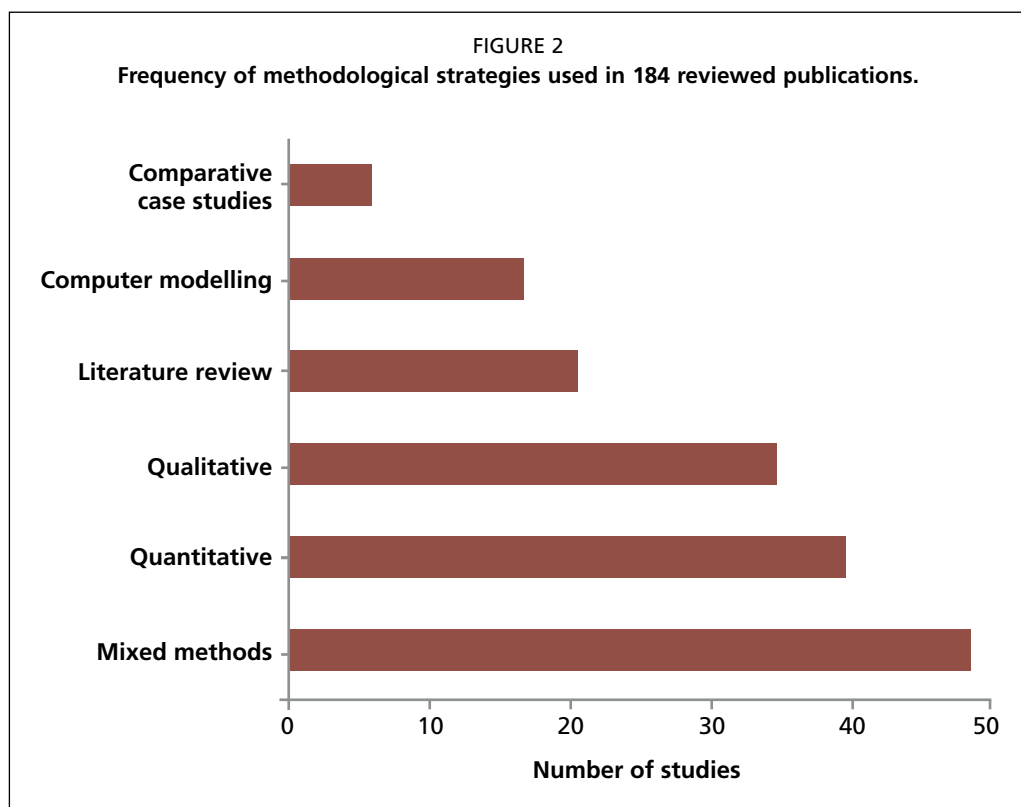
To synthesize the state of knowledge we searched for papers that explicitly focused on linkages between water stress and migration. These included original empirical research papers and reviews of empirical research. To maintain a standard for quality, we excluded papers and reports that had not undergone a process of external scientific peer review. We then narrowed the search to include papers focusing on a direct relationship between four categories of water problems and migration: 1) agricultural problems (i.e. drought, dry spells, changes to growing periods); 2) flooding vulnerability (i.e. rivers, coastal inundation, weather extremes); 3) water infrastructure problems (i.e. water scarcity or water quality); 4) water conflict (i.e. social conflict over access to or use of water resources).

To this end, we followed four sampling strategies. First, we sampled key scientific journals that publish on population-environment issues, such as *Population & Environment*, *Climatic Change*, *Global Environmental Change*, *Nature Climate Change*, etc. Second, upon identifying key publications, we implemented a snowball sampling approach to identify additional publications through the references cited. Third, we examined the publication histories of specific authors with a record of research on water-migration linkages. Fourth, we restricted the search to English language scientific publications; while this restriction biases the total number of publications included in the sample, we do not consider it likely to bias the results of this synthesis (Morrison *et al.*, 2012). Nevertheless, we are cognizant that relevant, high-quality, non-English language scientific publications address key gaps in the literature. The resultant 184 papers left in our sample were, by and large, published in the last ten years, reflecting the relative novelty of the topic (Fig. 1).



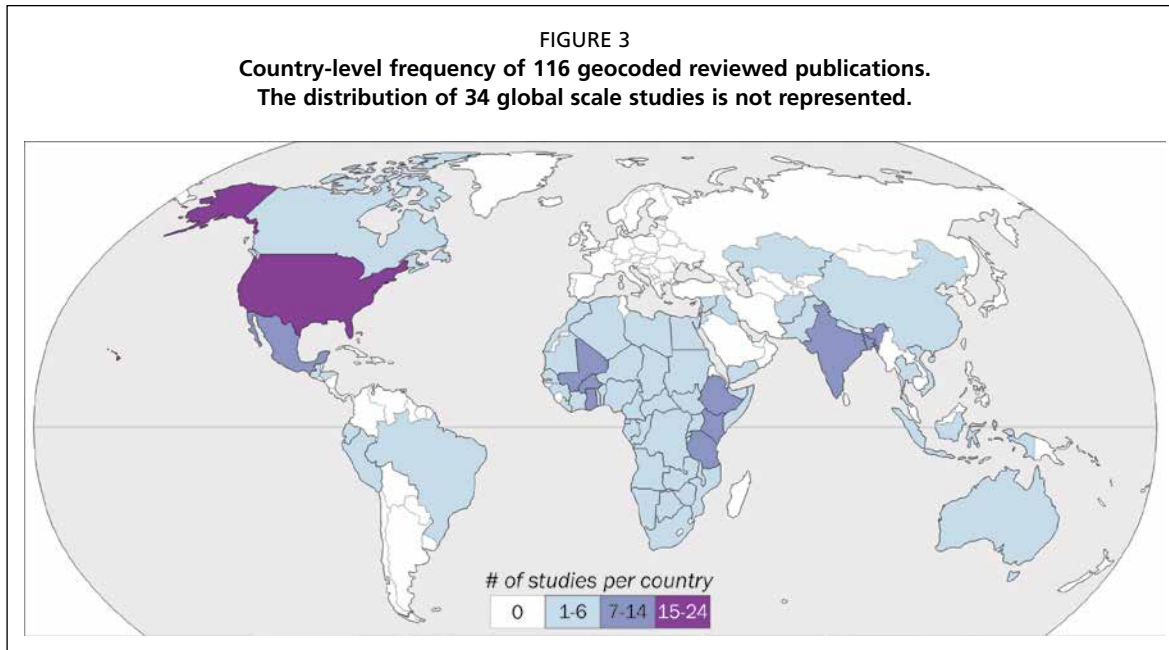
We then coded papers by: 1) methodological strategy; 2) study claims and conclusions (Section 3); 3) study location or extent (Section 4); and 4) manner of engagement with climate change projections. On this last point, 45 percent of reviewed studies were explicitly designed to examine analogues for the effects on migration by water stress introduced by climate change (see McLeman and Hunter, 2010).

Among the studies in the sample, we found examples of anthropological research, computer modelling, environmental field research methods, literature reviews, historical reviews, qualitative research, quantitative research (making use of census data and nationally representative household survey data), mixed research methods, geospatial methods and purpose-fit survey research. For the purposes of this review, we narrowed our focus to a set of mutually exclusive categories: 1) mixed methods; 2) quantitative; 3) qualitative; 4) literature review; 5) computer modelling; and 6) comparative case studies (Fig. 2). The largest group of research reports employed a mix of research methods, which is unsurprising given that population-environment research requires attention to both environmental and social metrics. A majority of papers from this category included methods also employed in quantitative research reports (i.e. survey research, census data or household questionnaires).



We geocoded study location or extent from 116 articles to examine the geographic distribution of reviewed literature. We reviewed each article for evidence of an explicit study location (i.e. place name or latitude-longitude) or region, which might include several sending and receiving areas. Sixty-eight studies could not be geocoded given the vagueness of study site description (e.g. rural areas of a country), association with a natural feature rather than a specific location (e.g. a river of substantial length), or inaccurate transliteration or outdated naming conventions. Overall, we found that the United States was the most studied country (24 articles), followed by Mexico (14), Bangladesh (13), Ethiopia (12) and Burkina Faso (11) (Fig. 3). Thirty-four additional

studies that included multiple global regions or advanced a primarily structural argument were considered “global” in scale.



To complement the national perspective, we measured the global distribution of studies within sub-basins derived from the HYDRO1k drainage basin dataset (USGS, 2003). In each sub-basin, we measured the total number of reviewed water stress-migration articles and identified geographic gaps in coverage (Section 4.1). Finally, we examined the global distribution of studies with regard to changes in near surface temperature and annual cumulative precipitation between historic (1951-1980) and projected (2041-2060) conditions using multi-model ensemble products developed for Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Section 4.2). With this comparison, we identified sub-basins that are critically understudied given projected climate change effects on conditions underlying water stress.

3. Generalizable conclusions

Our aim in this paper is to summarize the empirical findings from peer-reviewed literature about a diversity of water stress-migration relationships across different contexts. The following conclusions found strong consensus in the literature:

3.1 MIGRATION INFLUENCED BY ENVIRONMENT CHANGE CLOSELY RESEMBLES MIGRATION IN THE ABSENCE OF ENVIRONMENT CHANGE

Virtually every study included in this literature review concluded that migration within specific life stages is common and that, to a large degree, migration patterns can be explained by global economic development as well as social and demographic changes in recent decades. These studies, however, show that there are clear instances in which novel conditions of water stress affect livelihood expectations, destroy assets and alter rates at which people change residences on a temporary, seasonal, cyclical or permanent basis. One finding from relatively early work by Munshi *et al.* (2003) is common in many contexts. The authors found that extreme droughts contributed to migration from Mexico to the United States. Long-established migrant communities tended to originate from areas historically affected by drought, whereas new migrant communities originated from areas affected by more recent drought. It is noteworthy that migrants were found to follow existing patterns of migration that had been established earlier and independently of drought. In other words, migrants whose decisions were related to drought followed in the footsteps of previous migrants. These findings are echoed throughout the literature; migrant networks and corridors are not new, and when water stress drives new patterns of migration, they usually fold into existing spatial, temporal, seasonal and economic patterns of migration. Migration is completely normal, and environmental stress can be one driver among many (Black *et al.*, 2011a).

3.2 WATER STRESS AFFECTS AGRICULTURAL PRODUCTION, IN TURN INFLUENCING MIGRATION

In general, water stresses such as drought, dry spells, changing rainfall variability and extremes that result in declining smallholder and subsistence agricultural production may accelerate or amplify migration patterns (e.g. Nawrotski and Bakhtsiyarava, 2017; Cai *et al.*, 2016). In another study, droughts in Mexico were related to migration in both wet and dry climates, and although drought drove migration in both contexts, in wetter climates social networks remained a stronger determinant in the decision to migrate (Nawrotski and Hunter, 2013). In contrast, recent consensus has emerged in the literature around the finding that impacts of catastrophic flooding on homes or assets are much weaker predictors of permanent migration. Studies from a variety of contexts show that flooding and disaster have modest or only short-term effects on migration (Gray and Mueller, 2012; Lu *et al.*, 2016), but can increase the likelihood of impoverishment.

Various studies have characterized the effect of water stress on cross-border migration from Mexico to the United States (see Feng *et al.*, 2010; Nawrotski *et al.*, 2015). Similar relationships have been studied elsewhere; however, migratory responses to water stress remain context-dependent and can vary from region to region. Henry *et al.*

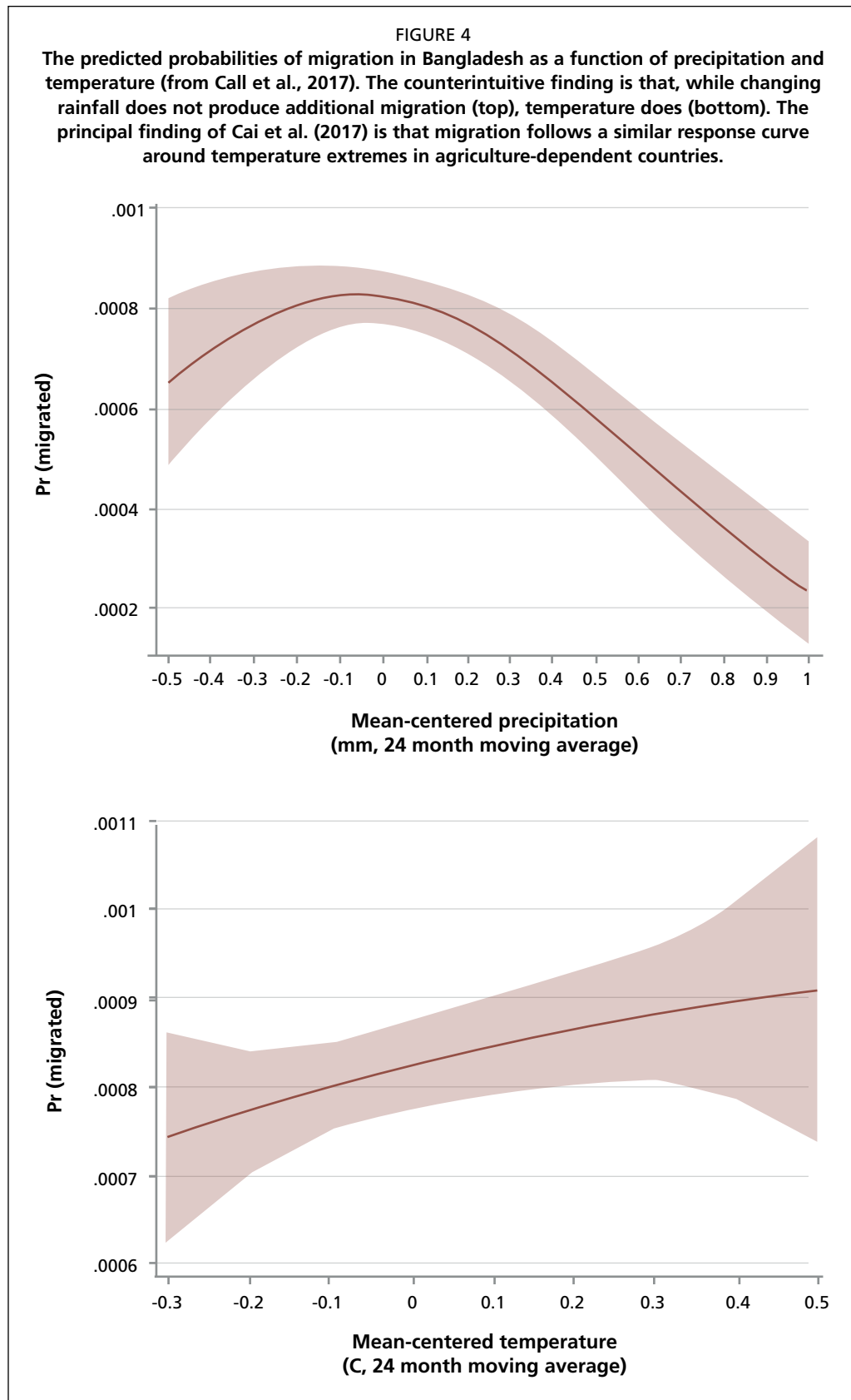
(2004) showed that short-term rainfall deficits increase the risk of long-term internal migration to other rural areas and decrease the risk of short-term distant migrations. While higher temperature increases international migration in some contexts, it has been shown that heat waves have decreased international mobility in Burkina Faso (Nawrotski and Bakhtsiyarava, 2016). The adverse effects of heat waves and droughts on cross-border migration are strongly amplified in highly food-insecure regions of Senegal (Nawrotski *et al.*, 2016).

3.3 HIGH AND SUSTAINED TEMPERATURES ARE STRONGER PREDICTORS OF MIGRATION THAN WATER STRESS

This review finds that by controlling for multiple hazards, heat exposure can be identified as a stronger predictor of migration than drought, increasing climate variability or extreme rainfall and flooding. Heat amplifies the potential for migration across a range of water stresses. This has been shown to be the case in country-level studies in Pakistan (Mueller *et al.*, 2014), Indonesia (Bohra-Mishra *et al.*, 2016), the Philippines (Bohra-Mishra *et al.*, 2017), Mexico (Nawrotski *et al.*, 2015, 2016), West Africa (Nawrotski and Bakhtsiyarava, 2016) and South Africa (Mastorillo *et al.*, 2016), as well as global comparative studies (see Cai *et al.*, 2016). Bohra-Mishra *et al.* 2014, 2016) found that in Indonesia and the Philippines, anomalously high temperatures amplified the migration effect of both drought and extreme rainfall. Significantly, migration responses to heat are non-linear and changes in migration are observed beyond specific temperature thresholds in the form of extreme temperatures (see Cai *et al.*, 2016) as well as long-lasting temperatures (see Nawrotski *et al.*, 2017).

One potential explanation is that extreme or sustained heat increases evaporation and decreases the water content of the topsoil to the detriment of shallow root crops commonly associated with subsistence agricultural production. This phenomenon would explain migration as a response to water shortages, as well, when water storage does not meet agricultural water demands. Another potential explanation is that heat is a variable that can be measured and evaluated comparatively, while drought declaration procedures involve a host of sociopolitical as well as biophysical considerations. As Cai *et al.* (2016) recently reported in a study of 163 countries, there is a positive and statistically significant relationship between temperature and international out-migration in the most agriculture-dependent countries, where “an additional 100 [hours] of exposure to 30 °C+ weather during the growing season would raise out-migration rate by 5 percentage points” (p. 143). Further, the temperature-migration relationship observed in various publications (such as Call *et al.*, 2017; see Fig. 4) resembled a nonlinear temperature yield curve for many crops. This reinforces the notion that changes in agricultural production and migration are tightly coupled. Nawrotski *et al.* (2017) observed that, in Mexico, once a threshold of ~34 heat months (months in which the maximum temperature was more than 1 standard deviation above the 1951-1980 reference period) was surpassed, the relationship between heat months and the rate of rural-urban migration became positive and progressively strengthened. This, too, indicates that the decisions of agriculture-dependent people to migrate do not immediately follow environmental stress, but only happen after people have exhausted other adaptation options.

However, recent papers showing the temperature effect on migration are finding that migration is associated with drought and also with rainfall extremes. The causal interaction of temperature, water stress and migration is still not clearly understood. Future work requires more systematic study of water demand with sensitivity to



regional variations in agricultural land uses, organismal responses of crop varieties to changes in water and temperature, as well as livelihood opportunities and socio-economic conditions.

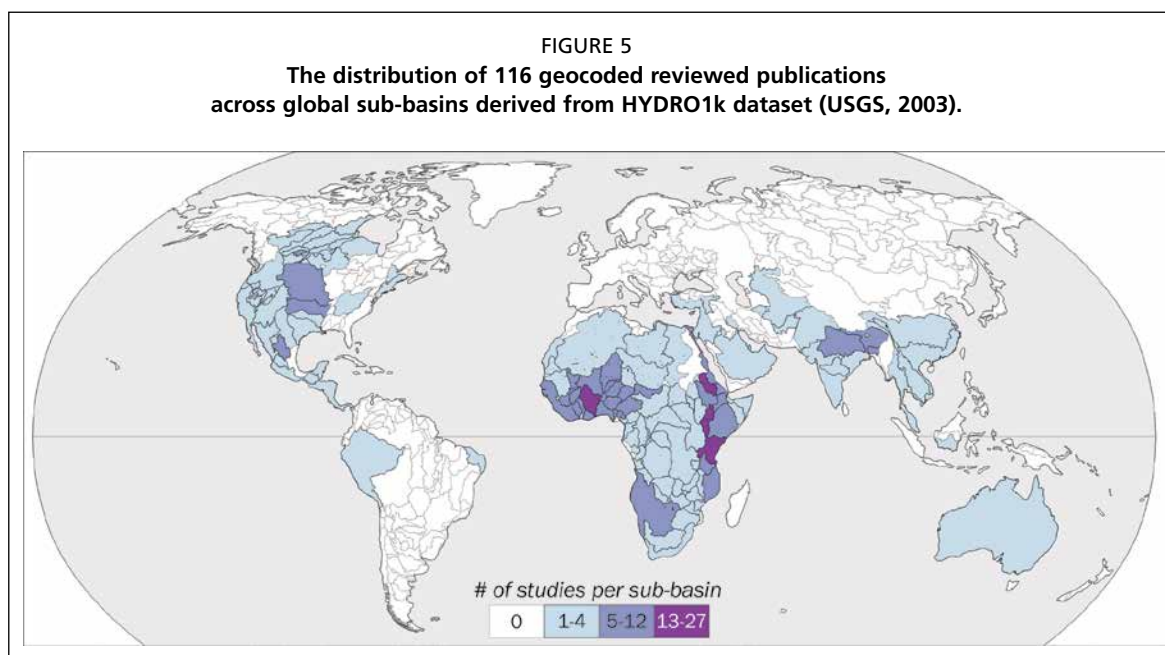
3.4 INSTITUTIONS AND RESPONSIVE POLICIES HAVE TREMENDOUS INFLUENCE ON THE LIKELIHOOD OF MIGRATION

Universally, the literature emphasizes the strong mediating role of institutions and policy on the water stress-migration link. On the one hand, vulnerabilities to water stress that lead to migration can be associated with a legacy of planning decisions with long histories, or may result from short-term institutional failures. For example, the patterns of catastrophic flooding in New Orleans during Hurricane Katrina, which produced large-scale migration, was a result of the failure of a complex history of flood management decisions and zoning by federal, state and local authorities (see Fussell *et al.*, 2014). On the other hand, effective and timely drought and flood responses have been shown to mitigate the incentive for people to migrate. For example, Marchildon *et al.* (2008) have shown that drought incidence is associated with out-migration in rural Canada, except in places where government relief programmes have mitigated the negative consequences of drought. Such findings highlight the effects of intervention in ameliorating the environmental drivers of migration.

4. Geography of reviewed studies

4.1 STUDIES ARE WIDELY DISTRIBUTED BUT CRITICAL GAPS IN GEOGRAPHIC COVERAGE REMAIN

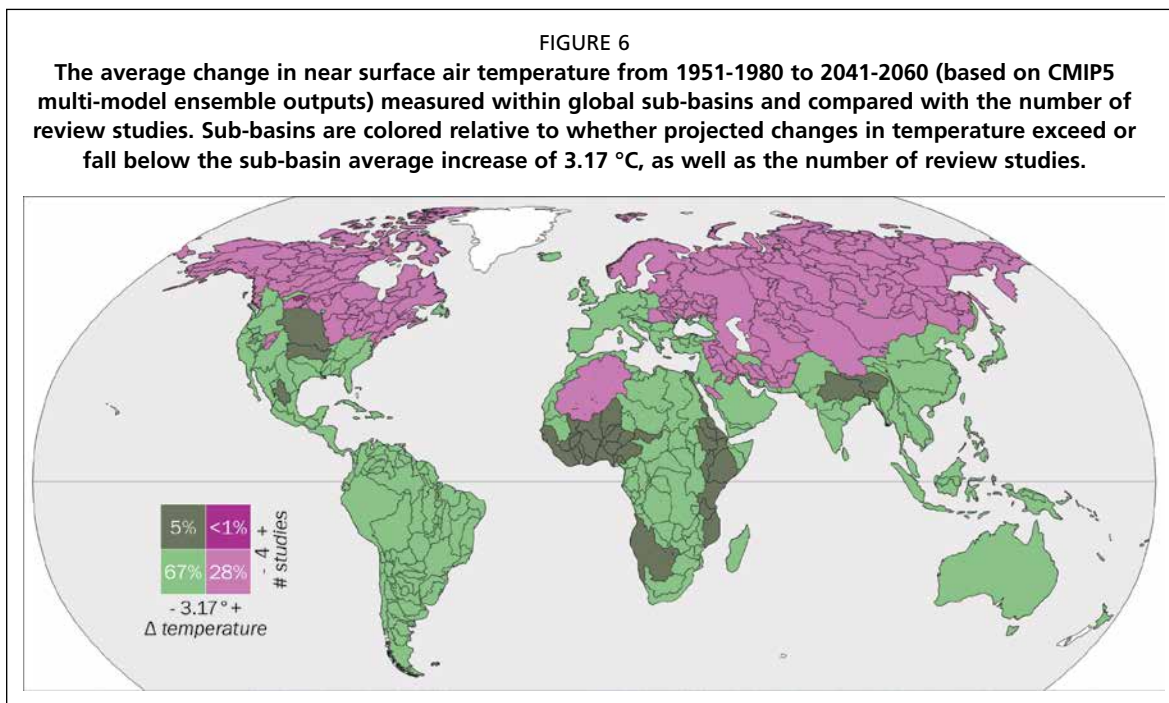
Considering the distribution of studies across global sub-basins, this paper presents a new view of the spatial distribution of knowledge about the relationship between water stress and human migration (Fig. 5). Compared to the national distribution of geocoded studies on water stress-migration relationships (Fig. 3), the apparent dominance of studies examining migration from Mexico and the United States gives way to a concentration of studies in sub-Saharan West Africa, the East African Rift Valley and the Indo-Gangetic Plain, as well as the United States' Great Plains and Mexico's Central Plateau. While only three reviewed studies were explicitly set within a sub-basin, aggregating studies at the sub-basin level not only identifies areas where subnational studies are concentrated, but also reveals the physiographic conditions that influence water stress. From these data we conclude that an increase in the number of sub-basin level studies could lead to a significant advance in knowledge about water stress-migration relationships.



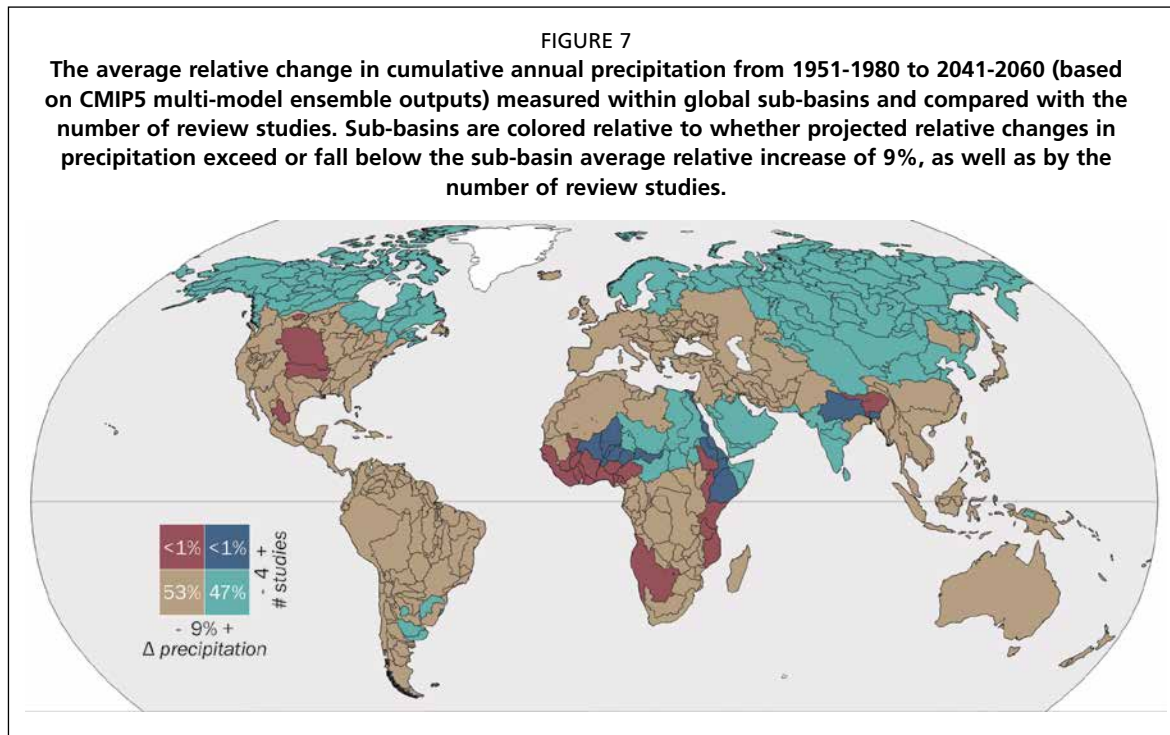
The data in Figure 5 reveal that water stress-migration relationships have been studied in all but two sub-basins on the African continent and that there is broad North American coverage except for sub-basins in the interior lowland, the sparsely populated far north and the Canadian Shield sub-basins. On the other hand, only two sub-basins in South America are represented and the usually non-water-stressed European countries lack representation, as does Asia north of the Mountain Rim. South and Southeast Asia also appear to be relatively understudied, which is surprising given their long coastlines, low-lying river deltas and heavy exposure to tropical flooding. Eastern Asia, likewise, appears to be understudied given the massive rates of migration currently underway. The geographic disparity of studies reflects the English language bias in this review but may also reveal an overarching lack of studies in these regions due to data limitations.

4.2 STUDY GEOGRAPHY IS BROADLY OUT OF STEP WITH PROJECTED CHANGES IN TEMPERATURE AND PRECIPITATION

It is disappointing that most of the well-studied sub-basins (those with at least five articles in this review) are located in regions where surface air temperatures have been predicted to increase by less than the global average expected temperature increase over the next 30 years (i.e. 3.17 °C). These sub-basins span central North America, western sub-Saharan Africa, the East African Rift Valley, and the Indo-Gangetic Plain (Fig. 6). The greatest increase in near surface air temperature is expected in the northernmost sub-basins of Eastern Europe, Central Asia and much of the Middle East. Yet most of the sub-basins in these regions are conspicuously absent from our sample, which is surprising given that they contain some of the planet's most highly trafficked international migration corridors (see Abel *et al.*, 2016). Indeed, of the sub-basins with expected above average increase in near surface air temperature, only one sub-basin in southern Canada has been studied in more than four articles. More research on the influence of temperature change on migration linkages may be warranted.



Sub-basins with greater than average projected changes in cumulative annual precipitation and relatively few review articles include many northern latitude sub-basins as well as the central Sahel, Nile Basin, Horn of Africa, Arabian Peninsula, and basins south of the Indo-Gangetic Plain (Fig. 7). There are only four sub-basins in South America—located in the Pampas region between Patagonia and the Brazilian Highlands—that are expected to have above average increases in precipitation, but the broad absence of water stress-migration research across the continent is worrisome. On the other hand, existing research on water stress-migration in western sub-Saharan Africa, the East African Rift Valley and the Indo-Gangetic Plain may offer a foundation for future water stress-migration research in regions where some of the greatest increases in precipitation are expected.



Given the likelihood of severe water stress in combination with high heat stress in the twenty-first century, more empirical research in India, Central Asia, the Middle East, and the central Sahel could help to improve policy formation in a policy arena that tends to be controversial. While modelled changes in neither precipitation nor temperature are above average across Southeast Asia or Oceania, the lack of research on freshwater problems and migration in these population-dense regions must be acknowledged. By better recognizing the intervening roles of temperature and precipitation (see Bohra-Mishra *et al.*, 2014; Nawrotski *et al.*, 2017), as well as other climate change-related processes such as sea-level rise, resulting information may offer a basis for predicting migration rates and estimating the timing and expected destinations of migrants under different climate scenarios. Such information might also prove useful in identifying populations with the highest likelihood of losing mobility and capacity to migrate and help design interventions to prevent acute humanitarian crisis.

5. Empirical gaps

5.1 HOW DO WE EXPLAIN THESE EMPIRICAL GAPS?

As shown in Fig. 2, the research methods used to study migration and water stress vary. This leads us to speculate that knowledge gaps are greatest in states that are not supportive of data transparency, and either do not implement censuses or do not make census data available to researchers. Notable too are the knowledge gaps in countries that have experienced civil war and/or political instability. In these countries, armed violence may hinder data collection as well as the ability of researchers to engage in field research. In this respect, it is unsurprising that there is so little research in the central Sahel, where famine has been common since the 1970s. Similarly, it is unsurprising that so little work has been done in drought-prone Afghanistan and in and around the water-stressed parts of Syria.

5.2 WHAT WATER PROBLEMS CAN MIGRANTS OF ANY KIND ENCOUNTER?

So far, we have considered environment-induced out-migration. In this section we consider the nature of water stress and other environment-related problems associated with arrival in a new area. Several papers conclude that migration can produce water stress through impacts to ecosystem services that support water provisioning, water distribution systems, flood management systems and safe drinking water (Selby and Hoffman 2012; Biswas and Quiroz, 1996; Jacobsen, 1997; McMichael *et al.*, 2012; Talozzi *et al.*, 2015; Chatterjee, 2010; Metulini *et al.*, 2016; Rufola *et al.*, 2015; Black, 1994; Mbonile, 2005; Wiesmann, 2000). These papers conclude that, in instances where environmental displacement and/or conflict-induced displacement cause migrants (or refugees) to live in informal settlements, those involved can be locked into future water stress (see Rufola *et al.*, 2015). This is especially the case where the informal settlement entails forms of land use that are water-intensive or destructive to local water cycles. To this end, the literature identifies three mechanisms. First, migrants can decide or be forced to settle on marginal or fragile lands in a manner that can increase the risk of water stress. Second, land tenure systems that incentivize water conservation may be disrupted. Third, the construction of new settlements or the expansion of existing ones may damage local water flows as land uses change and land degradation occurs. These observations, however, are far from conclusive and would benefit from further research.

5.3 WHAT ARE THE IMPLICATIONS OF MIGRATION ON FUTURE WATER STRESS?

A handful of articles have shown that policies that are ill-conceived or unresponsive to migrant needs can exacerbate friction between impoverished migrants and the community that hosts them. For example, Bhavanani and Lacina (2015) investigated the Sons of the Soil movement in India, in which migrants (moving in part due to drought) have been implicated in destructive riots. They find that inclusive host communities with access to the resources necessary to accommodate migrants can resolve social conflicts more efficiently than host communities without sufficient

resources to accommodate migrant needs. Without sufficient resources, relationships between hosts and migrants can fray. While this is only one case study, it highlights a causal pathway where natural disasters and, possibly, adverse climate change impacts in one area can lead to violence in another. If this is the case, then efforts to ensure timely resource access and provision could avert problems. We note, however, that speculation that the origins of the Syrian conflict have been exacerbated by drought and migration has received vociferous pushback (see Selby *et al.*, 2017).

6. Methodological gaps

Nearly as many conceptual papers have been written on the subject of environmental stress and migration as there are empirical research papers. One hypothesis for the abundance of conceptualizations is that the topic is important but that reliable data sources are limited. Nationally representative time-series data, however, can and have been used to identify causal mechanisms and, in particular, to identify the determinants of climate-change-induced migration (see Fussell *et al.*, 2015). Data limitations, however, remain a key challenge in some of the most water-stressed regions, including the Middle East and Central Asia, where representative socio-economic data are scarce. In particular, data on internal migration are significantly limited and poorly captured by national statistics. This gap is particularly relevant in the context of environment-related migration, which notably starts as short-distance and within national borders.¹ As a result, researchers may have to start using alternatives to censuses and surveys – especially when it comes to the collection of human mobility data.

Data gaps may also exist when migration occurs across international borders, as not all international migration movements occur through official channels and thus are not captured. That said, there has been considerable research on migration from Mexico to the United States (Feng *et al.*, 2010) and to some extent on migration from Bangladesh to India. However, the most dominant migration corridors on the planet, in Central Asia and the Near East, remain relatively unstudied.

While nationally representative household-level time series data will likely remain the cornerstone of empirical research, as Lu *et al.* (2016a) point out, these data have limited ability to resolve some fundamental knowledge gaps:

“First, migration trajectories resulting from climate-related impacts are highly complex and dynamic and frequently include repeated movements across short distances. Analysis of such trajectories therefore requires detailed mobility data over a range of temporal and spatial scales, which is often not collected, analysed or reported in traditional survey-based research studies. Second, household surveys are vulnerable to recall and interviewer bias, especially when multiple trips by several family members are to be recorded. Third, logistical difficulties of data collection mean that longitudinal household surveys are not always performed at the same time at each follow-up round, which may bias results when significant seasonality exists in migration patterns. Fourth, due to the sudden and unanticipated nature of most climatic events, high-quality survey data on resulting migration patterns is extremely difficult to collect, especially when migrating households are spread across large areas.” (pp 1-2)

To overcome these obstacles, priority might be given to research that uses spatially disaggregated time-series data generated from non-typical sources, such as mobile phones and social media activity. Lu *et al.* (2016) point out that usage of data from mobile phone networks can be used to assess human mobility. Other innovative opportunities include the income tax statements in, for example, the United States (see Fussell *et al.*, 2014; Hauer, 2017). In particular, these data open up the opportunity to

¹ See Melde *et al.* (eds.) (2017) *Making mobility work for adaptation to environmental changes: Results from MECLEP global research*

analyse short-term forms of mobility (evacuation and displacement). Similarly, remote sensing is now being used to improve population estimates (Jean *et al.*, 2016), and holds promise for revealing hidden populations – the so-called Missing Millions not yet included in census data.

Another challenge is the difficulty in aligning social data with the data typically collected by climate scientists. A few exceptions are worth noting, including the research papers being produced by the National Center for Atmospheric Research (NCAR), for example, which have been instrumental in showing that temperature data can be used to predict migration as a result of water stress (see O'Neill *et al.*, 2014). Given the progress made, we suspect more sophisticated multilevel, mixed-method and hybrid studies that, for example, make use of quasi-experimental research designs will become more common.

7. Synthesis and policy recommendations

7.1 TIMELY ADAPTATION INTERVENTIONS TO BETTER MANAGE LARGE MIGRATORY MOVEMENTS

Overall, we conclude that changes in migration patterns (within countries and between countries) can be used to signal that smallholder agriculture problems may exist. By the time migration flows can be observed, however, the impact may have been long past. Migration is usually a delayed response to water stress and its emergence in data sets is even more delayed. Findings from various papers indicated that migration likelihood is low immediately after a water shock, but increases as households cycle through the various *in situ* adaptation strategies available. If the shock is not repeated for an extended period of time (as illustrated in Mexico; see Nawrotski *et al.*, 2015) then migration rates stabilize. This suggests that households can successfully adapt *in situ* to a one-time incidence of water shock.

7.2 INVESTMENT IN ADAPTATION MAY STEM WATER STRESS-INDUCED MIGRATION

Various studies have highlighted the link between agricultural problems and migration. For example, Nawrotski *et al.* (2015), who investigated climate-related international migration from rural Mexico to the United States, suggest that rural agricultural adaptation and livelihood diversification programmes (i.e. drought- and heat-tolerant crop varieties and sustainable intensification technologies) may be useful for attenuating environmental stress as a determinant of migration. More research on the extent to which adaptation programmes can slow rapid, sprawling and/or uncontrolled urbanization could help policy-makers.

7.3 WATER STRESS MAY CONTRIBUTE TO FURTHERING POVERTY

In some contexts, heat and drought are related to decreasing rates of migration (e.g. West Africa), suggesting that these can worsen poverty and slow down mobility. In Ethiopia, for example, it has been reported that marriage movements by women decreased during the drought periods because less money was available for dowry (Gray and Mueller, 2012). These findings indicate impoverishing consequences of water stress for social mobility and social relations and require intervention to avoid deteriorating conditions and acute humanitarian crisis.

8. What do we need to know?

Much of what we need to know to anticipate potential future problems associated with environment-related migration can be learned from historical analogues (see McLeman, 2011). Hurricanes Katrina and Superstorm Sandy, for example, provide analogues for the impacts associated with expected increases in sea-level rise and sea-level extremes (Priscoli and Stakhiv, 2015). The Dust Bowl provides an effective analogue for the intersection of drought, land management and the role of land tenure in building resilience to environmental change (McLeman and Smit, 2006). Similarly, the Syrian refugee crisis provides an example of a sudden, large-scale, migration flow. There remains, however, a dearth of well-known examples of climate-induced water stress in the agriculture sector resulting in significant migration. In fact, the relationship between these two variables is still open to serious debate (see Selby *et al.*, 2017). Nevertheless, the analogues that do exist instruct us about the environmental drivers of migration, and the needs that migrants have in their new lives, including water and food security, health care, education and other basic services. They also instruct us about the potential role of policies designed to mediate both where people go, and how they are accommodated when they arrive.

8.1 MIGRATION AS “ADAPTATION” OR TRANSFORMATION?

Water stress in combination with rising temperatures may render some livelihoods inoperable. The challenges of environment-related migrants looking for work in rapidly urbanizing, saturated labour markets, with high costs of living, heated land markets and generally little opportunity have not yet been seriously considered. As of yet, the “future of work” problems associated with automation of labour and the physical relocation of economic sectors have also not been seriously considered in migration-environment debates. How will the automation of labour affect the ability of future migrants to earn dignified wages, and what does this imply for adaptation to climate change?

More generally, there is a case for supporting development pathways that allow people to choose, rather than be forced, to migrate as a result of adverse climate change. Migration policies can result in desirable outcomes when they prioritize human rights and security and attack the roots of environmentally forced migration – i.e. deficits in the protection of human rights, guarantee of entitlements, and support of human agency and freedoms (Tanner *et al.*, 2015). Examples of supportive policies include:

- sustained investment in local livelihood diversification;
- social protections aimed at people whose livelihoods are especially vulnerable;
- robust programmes of vocational training; and
- universal guaranteed minimum wages.

Finally, there appears to be a strong case for investments in agricultural adaptation techniques and technologies and in the development of rural livelihood diversification programmes that can be used to diminish the economic imperatives that drive vulnerable people to decide to migrate as the best way to avoid water stress.

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Water stress and human migration: a global, georeferenced review of empirical research

Migration is a universal and common process and is linked to development in multiple ways. When mainstreamed in broader frameworks, especially in development planning, migration can benefit the communities at both origin and destination.

Migrants can and do support their home communities through remittances as well as the knowledge and skills they acquire in the process while they can contribute to the host communities' development. Yet, the poor and low-skilled face the biggest challenges and form the majority of those subject to migration that happen on involuntary and irregular basis.

Access to water meanwhile, provides a basis for human livelihoods. Culture, and progress studies have found that water stress undermines societies' place-specific livelihood systems and strategies which, in turn, induces new patterns of human migration. Water stress is a circumstance in which the demand for water is not met due to a decline in availability and/or quality and is often discussed in terms of water scarcity, drought, long dry spells, irrigation water shortages, changing seasonality and weather extremes. The aim of this review is to synthesize knowledge on the impact of increasing water stress on human migration.