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REVIEW ARTICLE

Migration as adaptation to freshwater and inland hydroclimatic changes? A meta-review of existing evidence

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Abstract

Due to its potential geo-political and environmental implications, climate migration is an increasing concern to the international community. However, while there is considerable attention devoted to migration in response to sea-level rise, there is a limited understanding of human mobility due to freshwater and inland hydroclimatic changes. Hence, the aim of this paper is to examine the existing evidence on migration as an adaptation strategy due to freshwater and inland hydroclimatic changes. A meta-review of papers published between 2014 and 2019 yielded 67 publications, the majority of which focus on a handful of countries in the Global South. Droughts, floods, extreme heat, and changes in seasonal precipitation patterns were singled out as the most common hazards triggering migration. Importantly, most of the papers discuss mobility as part of a portfolio of responses. Motivations to migrate at the household level range from survival to searching for better economic opportunities. The outcomes of migration are mixed — spanning from higher incomes to difficulties in finding employment after moving and struggles with a higher cost of living. While remittances can be beneficial, migration does not always have a positive outcome for those who are left behind. Furthermore, this meta-review shows that migration, even when desired, is not an option for some of the most vulnerable households. These multifaceted results suggest that, while climate mobility is certainly happening due to freshwater and inland hydroclimatic changes, studies reviewing it are limited and substantial gaps remain in terms of geographical coverage, implementation assessments, and outcomes evaluation. We argue that these gaps need to be filled to inform climate and migration policies that increasingly need to be intertwined rather than shaped in isolation from each other.

Keywords Climate migration · Human mobility · Freshwater and inland hydroclimatic changes · Meta-review · Adaptation

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1 Introduction

Anthropogenic climate change is manifested through a wide range of impacts. Among the most serious impacts that have been and are going to be experienced by several billion people worldwide are hydroclimatic changes. These include floods and droughts, the most recurrent climate change-induced water related disasters, glacier melting, extreme precipitation, and erratic rainfall patterns (Caretta et al. 2022). An increase of global warming between 1.5 and 3 °C will potentially double flood risk (Dottori et al. 2018) while, concurrently, the length of droughts is also projected to nearly double (Naumann et al. 2018). Between 0.5 and 3.9 billion people are projected to be affected by these hydroclimatic changes (Gosling and Arnell 2016). The Internal Displacement Monitoring Centre calculates that floods, extreme storms, and droughts were responsible for 98% of the 30 million people displaced in 2020. Additionally, between 2008 and 2020, 49% of all those displaced because of weather related disasters did so because of floods, amounting to a total of 156 million people (IDMC 2021). Particularly in urban areas, by 2050 more than 440.5 million people globally may face water insecurity (Flörke et al. 2018). While acknowledging the epistemological difficulties that these projections present in terms of measuring climate migration and climate change impacts, they do highlight that no region of the world will be left untouched by impactful hydroclimatic changes and stress that impacts are going to be most detrimental in the Global South where most people do not have access to water, sanitation, and hygiene infrastructures (Mitlin et al. 2019).

Taken together, all these hydroclimatic changes will heighten risks globally, requiring human systems to adjust "to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC 2022), i.e., to adapt. Adaptation to hydroclimatic changes is multifaceted and encompasses a wide range of measures depending on the sector taken into account. For instance, in agriculture, changes in crop rotations and irrigation times can improve water use efficiency during droughts. In urban areas, on the other hand, stormwater management infrastructures can help deal with increased flood frequencies (Caretta et al. 2022). Migration is one of those adaptations that have been debated in the literature (Nabong et al. 2023; Sakdapolrak et al. 2023; Boas et al. 2019; Klepp 2017; Piguet et al. 2011, 2018). Given its magnitude, geo-political and environmental implications, climate migration has become an increasing concern to the international community (Faist and Schade 2013; Foresight 2011). While there is considerable attention and literature devoted to migration due to sea-level rise (Montreux et al. 2023; Hauer et al. 2020; McMichael and Katonivualiku 2020), there is a limited understanding of the magnitude of inland and freshwater hydroclimatic-induced migration and the actual characteristics of this adaptation strategy (see, e.g., Hermans and McLeman 2021).

Such is the scope of this paper. Hydroclimatic changes, whether through slow-onset (droughts) or rapid onset (floods) water-induced disasters, affect human mobility and migration (Stoler et al. 2022). Floods and droughts, in particular, with their adverse impacts on agriculture, have had both positive and negative implications for temporary and permanent migration. In fact, the decision to migrate is not only dependent on the nature and gravity of the hydroclimatic change, but also on the perception of that change and the socio-economic context (Nabong et al. 2023; Koubi et al. 2016; Ocello et al. 2015; Thiede et al. 2016). Additional research is necessary to unpack in which context hydroclimatic changes trigger migration (Nabong et al. 2023; Cattaneo 2019; Stoler et al. 2022). While the literature presents hundreds of case studies of environmental change and migration (see Piquet et al. 2018), some of them linking migration to temperature change but not directly

to hydroclimatic changes (e.g., Brottem and Brooks 2018; Gray et al. 2020), comprehensive and conclusive analyses focusing on the role of inland floods and droughts are lacking. Hence, this paper aims to examine the existing evidence on migration as an adaptation strategy due to freshwater and inland hydroclimatic changes through a meta-review approach. The methodology of this paper responds to the need of developing a comprehensive climate assessment for the United Nations 6th Climate Change Report chapter on Water (Caretta et al. 2022). Thus, the paper focuses on case studies documenting migration as an adaptation response to inland and freshwater hydroclimatic changes.

2 Conceptual background

Migration and climate change have been investigated since the 1980s; their links remain debated. While the public narrative magnifies the size, likelihood, and risks related to climate migration, scholarly evidence shows that catastrophic mass migration and conflict due to climate change impacts have not taken place (Montreux et al. 2023; Faist and Schade 2013; Klepp 2017; Piguet et al. 2011, 2018). Most movement is short-term and short distance within the same country. Thus, it has been argued that the term mobility, encompassing voluntary, involuntary migration, and planned resettlement, is more appropriate than migration (Sakdapolrak et al. 2023; Boas et al. 2019, 2022; Foresight 2011). In this paper, we use both terms, specifying their characteristics, e.g., permanent VS temporary, as both were included in our meta-review.

It has long been recognized that environmental factors such as land degradation or natural disasters can contribute to human mobility and migration. Studies link increased mobility to periods of environmental stress, yet socio-economic factors are often the proximate causes of vulnerability (Ginnetti et al. 2013). For instance, commercialization of land, low incomes, and limited access to inputs and markets can also push people to leave an agricultural economy (Tacoli 2007). Therefore, mobility or a lack of it (immobility) is rooted in political, social, and economic power structures (Ayeb-Karlsson et al. 2022; Boas et al. 2022; Foresight 2011; Wiegel et al. 2019). Gender, age, cast, level of education, and social network influence people's decisions to migrate and their perception of risks and opportunities related to migration. In other words, for instance, social networks can be both a pull and push factor for migration (Nabong et al. 2023; Khan et al. 2018; Cundill et al. 2021). Given this composite intersectional set of factors, it is debated whether it is reductive to portray migrants as victims rather than agents of their own destiny (Piguet et al. 2011, 2018) or whether, conversely, systemic vulnerabilities are ignored in the discourse on climate migration which tends to emphasize individual agency and entrepreneurship (Wiegel et al. 2019).

By the same token, whether a migration decision is taken is dependent on the actual and perceived environmental risk. Risk perceptions are context-specific and influenced by social, cultural, and economic views, e.g., livelihood (Nabong et al. 2023; Parsons and Nielsen 2021), past weather events (De Longueville et al. 2020; Koubi et al. 2016; Wiegel et al. 2021), sense of autonomy, self-sufficiency, and lack of connection or trust in government or outside experts (Wiegel et al. 2021). Actual risk is a composite, dynamic interaction of climate-related hazard coupled with exposure and vulnerability. Any of these three elements can be subjected to change, which can be "natural, unintended or deliberate"; that is, climatic or socio-economic changes may trigger the conditions of risk and the related adverse consequences (Reisinger et al. 2020). As an example, drought can be the hazard

reducing irrigation availability and hence, heightening the exposure of the agricultural system to possible failure which, in turn, increases societal vulnerability to famine. Responses to reduce risk exposure need to act on the nature and magnitude of either the hazard, exposure, or vulnerability. For instance, a shift in irrigation technology that enhances efficiency and limits water losses can diminish exposure and therefore, in turn, reduce vulnerability and abate risk. Therefore, adaptation, i.e., how the human or ecological system adjusts to changes in climatic conditions is crucial to reduce risk (IPCC 2022).

Climate migration has been described as an adaptation measure when it can increase the ability of individuals to rely on existing household resources (Warner and Afifi 2014; Wiegel et al. 2019). Migration in response to climatic hazards or changes in climatic conditions can unfold in a variety of ways, ranging from barely observable, incremental changes in pre-existing mobility patterns to abrupt, non-linear population movements. Climate migration takes place progressively, with initial adaptive responses to climate risk typically involving in situ measures that, if successful, lower the risks without the necessity to contemplate migration (McLeman et al. 2021). However, when in situ adaptations cease to be effective, migration is undertaken by one or more members of a household, either temporarily or permanently (McLeman and Gemenne 2018). Temporary migration allows the household to adapt to climatic changes by maintaining its permanent residence in an area with a variable climate (McLeman and Gemenne 2018). Mobility as an adaptation response varies based on intersectionality, and spatial and temporal conditions with the extent of the latter two being determined by the importance that natural resources have in someone's livelihood and how considerable environmental damage is (Sakdapolrak et al. 2023; Baldwin et al. 2019). For example, in Bangladesh, where flooding during the monsoon season is a recurrent phenomenon, rural people often migrate for short distances until flood waters recede (Ahamad et al. 2011; Khandker et al. 2012). Whether migration is an effective strategy in adapting to climate change is context dependent, for instance Williams et al. (2021) showed it to be higher for West and Eastern Africa but low for southern and central Africa. Permanent migration, while eliminating the climatic risk faced, can also be interpreted as a manifestation of the limits of in situ adaptation. In other words, when adapting the household's livelihoods to ongoing climatic changes is not possible anymore; permanent migration is the last available resort (Vinke et al. 2020). Finally, migration rarely is the one and only adaptation measure undertaken (De Longueville et al. 2020; Wiederkehr et al. 2018; Simpson et al. 2023).

There is also increasing evidence on the potential for migration to be maladaptive (e.g., IPCC 2022; Serdeczny et al. 2017). For instance, the increased precarity of agricultural livelihoods in Sub-Saharan Africa might push more people to urban areas where they are going to experience other risks such as infectious diseases, flash floods, and an increase in food prices (Serdeczny et al. 2017). Immobility and impossibility to migrate internationally have been linked to adverse climatic conditions, especially droughts, causing loss of financial resources that could have facilitated migration (Nawrotzki and Bakhtsiyarava 2017), thus, showing the limits of adaptation (Ayeb-Karlsson et al. 2016; Brottem and Brooks 2018; Ferdous et al. 2019; Wiegel et al. 2019; Sakdapolrak et al. 2023). With this in mind, hydroclimatic changes can both facilitate or hinder migration. Existing case studies report conditions that are very context-dependent and responses that are very nuanced in their outcomes. For instance, youth across northern Latin America and the Caribbean reported that they were more likely to migrate in response to natural disasters such as droughts and hurricanes, with strong evidence for migration in response to droughts (Baez et al. 2017). Men's labor migration in rural Ethiopia increased with drought and land-poor households were the most vulnerable, while women's marriage-related mobility decreased

with drought (Gray and Mueller 2012). Likewise, mobility declined by 19% with a 1-standard deviation increase in temperature in Botswana, but equivalent changes of precipitation caused migration declines in Botswana and Kenya but increased migration in Zambia (Mueller et al. 2020). Additionally, while direct inundation alone had negligible effects on migration and agricultural production in Bangladesh, gradual increase in soil salinity led to increasing diversification into aquaculture and internal migration of household members (Chen and Mueller 2018). Thus, despite existing empirical evidence, which, contrarily to the overly media focus on populations affected by sea level rise, has been more preponderant on mobility due to floods and droughts (Piguet et al. 2018), a comprehensive review that clarifies the link between migration induced by freshwater and inland hydroclimatic changes is missing. In the following section, we outline how we conducted such a meta-review.

3 Methodology

The data for this article was derived from a more comprehensive meta-review of current adaptation responses in the water sector carried out for the Chapter on Water in the Working Group II contribution to the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2022; Mukherji and Kumar 2021). The meta-review relied on a database comprising 1682 papers from the Global Adaptation Mapping Initiative (GAMI) database (Berrang-Ford et al. 2021), and 137 papers from the IPCC WGII Water Chapter (Caretta et al. 2022). After selecting only those papers covering (implemented) water-related adaptations, published between 2014 and 2019, the final database comprised 359 peer-reviewed papers, for a total of 1038 adaptation responses (for more see Mukherji and Kumar 2021). Of note, due to the focus on inland waters and watersheds of the IPCC WGII Water Chapter (Caretta et al. 2022), this meta-review did not cover sea level rise as a migration trigger.

Given the aim of this paper to examine the existing evidence on migration as an adaptation strategy due to freshwater and inland hydroclimatic changes, we focus only on migration and mobility as an adaptation response. To be included in our analysis, papers had to meet one of the two following criteria: (i) they dealt with *migration and off-farm diversification* as an adaptation response or (ii) the adaptation took place in the sector of *human mobility and migration*. By applying these conditions, the database was reduced to 96 papers. These papers were then re-checked by 6 independent coders, with two aims. First, the coders established whether to include the paper in our analysis. The reason for exclusion was that the paper was not directly related to migration. Examples include papers that only dealt with off-farm diversification, but not with migration (as the original database does not distinguish between the 2 responses), or papers that only mentioned migration but did not investigate an application for it. Second, the coders provided some details about the characteristics of migration. To this aim, they answered a set of additional questions that were adapted from the original database and codebook (Mukherji and Kumar 2021) to collect information about migration. The questions related to the following:

- Whether the paper addressed migration as adaptation strategy
- Whether migration was initiated by one of the following actors:

  Individual and households
  Civil society (international/multinational/national/sub-national/local)

International or multinational governance institutions
Government (local/national/sub-national)
Private sector (corporations/small- and medium- enterprises)

- Whether migration occurred in response to each of the following hazards:

  Cryosphere change (e.g., melting of glaciers/snow/ice, and permafrost
  Little groundwater availability
  Extreme precipitation (precipitation increased frequency and intensity)
  Soil erosion (e.g., increased sedimentation and sediment load change)
  Drought (e.g., agricultural, hydrological, and meteorological droughts, including soil moisture deficits)
  Climate impacts (no specific hazard identified, but climate change in general mentioned)
  Extreme heat (temperature rise increased frequency and intensity)
  Floods (any type of inland and riverine floods, e.g., flash floods, floods in cities, excluding coastal floods)
  Dirty water (e.g., poor water quality and water pollution

- Whether migration affected each of these outcomes, and whether the effect was positive:

  Economic/financial
  Water related
  Ecological/environmental
  Institutional/sociocultural

- Whether migration reduced any of the risk components:

  Hazard
  Vulnerability
  Exposure

Note that for each study, migration could relate to multiple aspects. Accordingly, migration could be initiated by multiple actors and triggered by multiple hazards and could affect multiple outcomes and risk dimensions.

As a result of this process, 67 papers were included in our analysis. Twenty papers used a qualitative approach, 4 a quantitative approach, and 43 mixed methods.

4 Results

4.1 Geographical distribution

The 67 case studies were mostly focused on a single region (63) and rarely compared or contrasted case studies across different regions (3 studies in two regions and 1 in three regions).[1] The geographical distribution of case studies was uneven, with Asia (32), and Africa (29), catalyzing most of the research, followed by North America (5), Central and

[1] Note that in our considerations that distinguish by geographical dimension, we assign the paper to all the regions to which it refers. This leads to a total of 72 case studies.

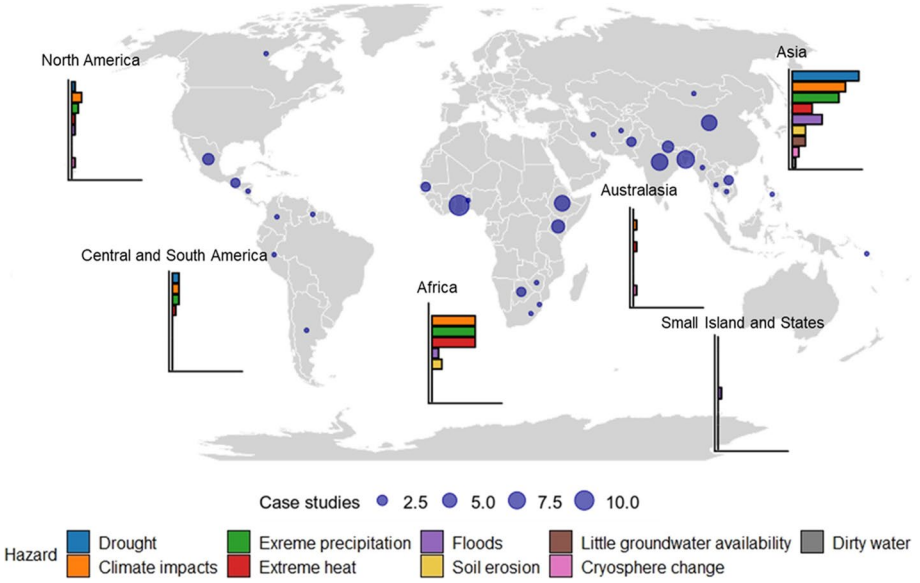

Fig. 1 Geographical distribution of the case studies and hazards triggering migration. The size of the bubble represents the number of case studies per country. The bar plots represent the hazards that triggered migration in those regions. Case studies can involve more than one country and hazards

South America (4), and Australasia and Small Islands States, only accounting for 1 study each. None of the studies took place in Europe. Within these regions, it is worth noting that a handful of countries — i.e., India (7), Bangladesh (8), China (6), Ghana (11), Ethiopia (6) — constituted the focus for almost half of all the papers coded (see Fig. 1). Thus, both the inter- and intra-geographical representativeness is skewed. The geographical distribution of the case studies recalls the picture of the Internal Displacement Monitoring Centre, whereby East Asia and Pacific, South Asia and Sub-Saharan African account for 58%, 22%, and 11%, respectively, of the total internal displacements caused by natural disasters in 2021 (IDMC 2022).

4.2 Hydroclimatic hazards

A multitude of hydroclimatic impacts trigger migration. The papers in our meta-review show drought, extreme precipitation, extreme heat, and general climate impacts of changes in the amount or timing of seasonal precipitation, along with increased warming to be the most prevalent drivers (Birk and Rasmussen 2014; Mashizha 2019; Rodriguez-Solorzano 2014; Yang et al. 2015). In the Central Dry Zone (CDZ) of Myanmar, for instance, climatic variability has been ongoing for several decades, leading to a trend in youth migration (Zin et al. 2019). The impacts of changes in regional climatic patterns such as the Pacific Decadal Oscillation (PDO) are triggering the Koyukon Athabascans of Ruby Village and other coastal villages in Alaska to migrate (Albert et al. 2018; Wilson 2014).

Drought impacts are a major trigger of migration, especially when they co-occur with episodes of increasing extreme heat frequency and intensity (Gao and Mills 2018; Sapkota et al. 2016; Yang et al. 2015). In Ghana, the combination of droughts and precipitation

variability resulting in decreasing crop yields spurred economic migration for remittances (Musah-Surugu et al. 2017). In Senegal, drought, extreme heat, and soil degradation prompted smallholder farm households to migrate (Brottem and Brooks 2018). In the Senegalese Sahel, migration in response to drought and variable rainfall has led to migration to cities in pursuit of non-farm livelihoods (Romankiewicz et al. 2016). Samburu pastoralists in Kenya faced droughts and occasional flooding, which prompted remittance-based migration (Karanja Ng'ang'a et al. 2016). In the Huehuetàn River Basin of Mexico, drought, and precipitation variability compounded with existing social inequalities and political marginalization to impact the food and water security of small-scale coffee farmers, resulting in migration to ease household poverty (Ruiz Meza 2015). For some individuals and households in coastal villages in Cambodia, drought-induced freshwater shortages drove migration when combined with increasing demand for fresh water due to population and industrial growth, alongside a decrease in fish catch due to increased competition and degradation of water quality (Asif 2019).

Extreme precipitation variability is a third major driver of migration, particularly when it co-occurs with droughts (Gao and Mills 2018; Jha et al. 2018; Ruiz Meza 2015; Warner and Afifi 2014), extreme heat (Choko et al. 2019; Jha et al. 2018), and higher storm surges (Islam et al. 2014; Thi Hoa Sen and Bond 2017). In Bangladesh, inland and riverine flooding during extreme precipitation events combined with sediment deposition led lowland households to migrate seasonally (Barua et al. 2017; Fenton et al. 2017). Flooding from melting glaciers is shown to be a major driver of migration in the Upper Indus Basin in Pakistan, where inland and riverine floods as well as recurrent landslides spurred migration (Gioli et al. 2014). However, clear attribution of floods as a consequence of climate change is difficult at present (Ayeb-Karlsson et al. 2016; Choko et al. 2019; Gioli et al. 2014). In the coded papers there was a singular instance in Nicaragua of migration being driven by an increase in the frequency and intensity of hurricanes when combined with drought, precipitation variability, and extreme heat (Radel et al. 2018).

4.3 Strategies

Migration is typically part of a portfolio of adaptation responses. Among the 67 coded papers, only 8 present migration as the only response to hydroclimatic changes, while the others discuss migration as part of a portfolio of responses (see Fig. 2).

Among the case studies reporting migration as only adaptation, Lei et al. (2017) show that in rural China, the government led a relocation of 20,000 households over 10 years in response to extreme heat, severe droughts, and floods. Islam et al. (2014) describe that on Kutubdia Island, Bangladesh, over 3000 households migrated to the mainland due to coastal storms and erosion. Other papers in our meta-review also report seasonal migration and temporary migration as the only response being taken. For example, in Senegal, farmers migrated seasonally because of droughts (Romankiewicz et al. 2016), and in Botswana, hundreds of households relocated to avoid increasingly devastating annual floods, although some people returned to their homes and illegally diverted the flood waters to protect their homes (Shinn et al. 2014).

Documented responses taken by farmers in conjunction with migration include changing crop varieties (36), shifting the timing of planting and harvest (26), selling or diversifying livestock (24), improving soil moisture through irrigation or water conservation, including rainwater harvesting (20), and loans and other financial incentives (18) (Antwi-Agyei et al. 2018; Assan et al. 2018; Fernandez-Gimenez et al. 2015; Gao and Mills 2018;

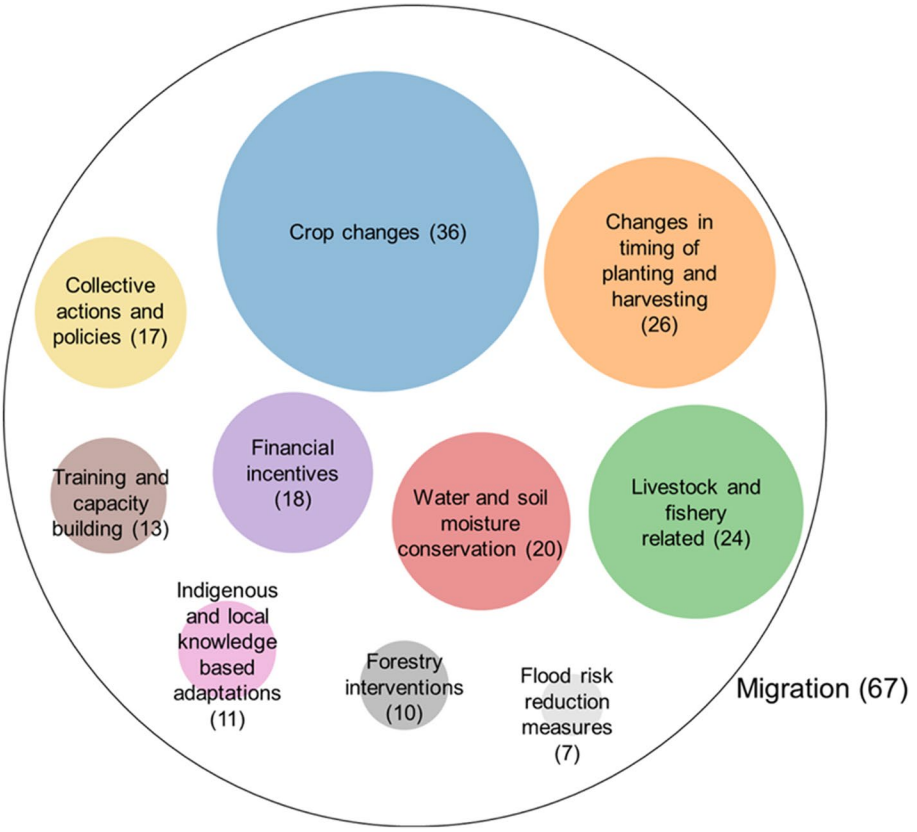

Fig. 2 Additional adaptation responses implemented in conjunction with migration. Case studies can have more than one adaptation response

Guodaar et al. 2017; Singh et al. 2019). A few of the case studies focus on fishing communities; however, as with farmers, migration is often not the preferred option. For instance, a study in the Philippines found that taking flood risk reduction measures, particularly elevating homes on stilts, is a preferred response by households, compared to relocation; however, the authors note that these measures might increase vulnerability to flooding in the long-term (Jamero et al. 2017). In Bangladesh, a coastal community reduced migration as a response to floods from cyclone and storm surges through community-based mangrove afforestation and autonomous farm-based fishing (Rahman et al. 2019).

4.4 Initiators

The absolute majority of the case studies show that migration is autonomously initiated by households (59) or by households in conjunction with other actors (6). Of the households that initiated migration, the majority saw men leaving their hometown, given their primary role of decision-maker and provider (Birk and Rasmussen 2014; Gioli et al. 2014; Sapkota et al. 2016). In some instances, women were left behind to take care of agricultural work and the household (Gioli et al. 2014), while in others, women (and in some cases youth)

were part of the labor migration either to cities (Birk and Rasmussen 2014; Su et al. 2017; Zin et al. 2019) or to agricultural fields close to home (Singh et al. 2019). In terms of household asset sizes, smallholder farmers were more likely to pursue livelihood diversification strategies including off-farm labor and migration (Abass et al. 2018; Aniah et al. 2019; Radel et al. 2018; Waldman et al. 2019).

Of the 6 case studies on planned resettlements in our meta-review, 3 took place in the extremely arid and drought-stricken northwest China, 2 in the island nations including the Solomon Islands and the Philippines and 1 in Botswana. In China, planned migration initiatives of rural residents to reduce exposure to climatic risks, particularly drought, include the Massive Southern Shaanxi Migration Program (Lei et al. 2017), also relocation programs in the Ningxia Hui Autonomous Region (Yang et al. 2015) and the Minqin Oasis, located at the lower reaches of the Shinyang River (Tan and Liu 2017). In the Solomon Islands, there has been a mixture of ad hoc community-initiated relocations based on customary land tenure regimes and government-initiated planned resettlements which have been less successful (Albert et al. 2018), while in the island communities in Tubigon, Philippines, planned relocations have met with opposition from island residents despite significant financial investments from the government (Jamero et al. 2017).

The sole instance of civil-society initiated relocation in response to intensive flooding in Shishmaref, Alaska was led by the Shishmaref Erosion and Relocation Coalition (SERC), in response to extreme flooding and coastal erosion (Albert et al. 2018).

Government- or NGO-led training and capacity building, including extension outreach programs were part of the portfolio of responses in 13 of the case studies, resulting in a reduction of migration by farming and low-income rural households (see, e.g. Patnaik and Das (2017); Singh et al. (2019)). Government-led programs to increase food security, composting to improve soil moisture, early warning systems, and other vulnerability reduction measures increased the adaptive capacities of communities and households and thus reduced migration (Abass et al. 2018; Mesquita and Bursztyn 2017).

4.5 Outcomes

The meta-review explored whether the adaptation measures brought about positive or negative outcomes. We analyzed whether case studies reported changes in the following outcomes: (i) economic or financial, (ii) water-related, (iii) ecological or environmental, and (iii) institutional or sociocultural. Most of the coded papers (51) report whether migration affects one or more of these outcomes. Figure 3 shows that most case studies find an effect on economic or financial outcomes or on institutional or sociocultural outcomes. Overall, the effect appears to be primarily positive; however, there are clear differences in outcomes to the different impact sectors, whereby the outcomes were mostly positive for financial and water-related outcomes and less so for ecological and institutional outcomes.

Migration was noted to have a positive financial outcome in many of the case studies. Examples of positive financial outcomes included farmers in a drought-stricken region of northwestern China increasing their income after relocating to the city, compared to their earlier low agricultural income (Yang et al. 2015). In northern Ghana, male heads of households in a rural farm community temporarily migrated for urban work opportunities (Assan et al. 2018). In Zimbabwe, youth migrated to South Africa or Zambian cities and sent remittances to help their families buy food during drought periods (Mashizha 2019). In the village of Nguith, Senegal, emigrants commonly not only sent remittances to family but also purchased land and provided funds for community improvements (Romankiewicz

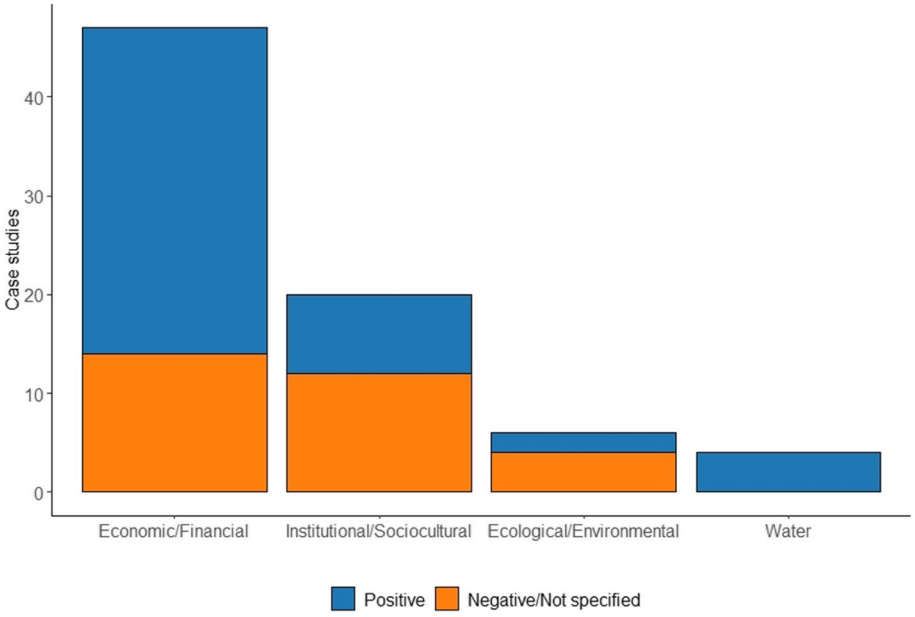

Fig. 3 Number of coded case studies according to the indicator of effectiveness that was mentioned and its direction. Case studies can involve more than one indicator of effectiveness

et al. 2016). Contrarily, several other papers reported negative economic outcomes of migration, either to the migrants themselves or to the community that they left behind. In Chiapas, Mexico, migration drove up land value when migrants sold land to pay for their transportation to the USA, which placed the farmers who chose to remain at an economic disadvantage (Ruiz Meza 2015). In the Ganges–Brahmaputra Delta in Bangladesh, seasonal labor migration during the rainy season provided families with the income they needed to survive, but the short-term outcome forced them to continue the annual seasonal migration (Ayeb-Karlsson et al. 2016). In the southeastern islands of Bangladesh, where households were permanently displaced after losing their homes to floods, some emigrants were not able to find employment, while others reported higher income after relocation, but they struggled due to a higher cost of living (Barua et al. 2017).

With respect to institutional and sociocultural outcomes, the cases studied reported mixed results. In Nguith, Senegal, for example, social networks unified migrants who moved to other areas of Senegal or Europe; however, migrants found it challenging to live according to traditional norms and make the financial contributions needed to maintain affiliation with their home community while adapting to life in their new home (Romankiewicz et al. 2016). Establishing social ties in the new homeland is critical to success for migrants. For migrants from a fishing village on the Cambodian coast, establishing connections in the city facilitated career changes (Asif 2019). Instances in which migration negatively affects institutional or social outcomes included the relocation planned by the Chinese government for farmers in the drought-stricken Ningxia Hui Autonomous Region; however, less than 30% of the 274 relocation homes were occupied (Yang et al. 2015). Furthermore, many middle-aged and elderly who moved to the relocation homes ultimately returned to their homeland because they had difficulty adjusting to the new village life. In Yunnan Province, China, droughts have led many men and young women to migrate to cities, leaving middle-aged women with

more responsibility to care for children and the elderly in addition to agricultural production and collecting water for the household (Su et al. 2017).

Few of the papers discussed water-related or ecological outcomes from migration. Clearly, migrants benefit if they relocate to an area with cleaner, safer, and more accessible water, as is the case for migrants from a low-lying island in Bangladesh to the mainland (Islam et al. 2014). Similarly, pastoralists in Kenya reduced their water insecurity by migrating with their herds to neighboring regions that are less drought-stricken (Opiyo et al. 2015). However, the outcomes can be mixed. For instance, in Senegal, remittances sent back home have been used to fund new deep wells and watering holes, but the increased pressure from grazing around the new water sources has degraded the soil and vegetation (Romankiewicz et al. 2016).

4.6 Risk reduction

To understand whether migration in conjunction with other implemented strategies can be considered an apt adaptation measure to take, we examined whether it did reduce risk. Risk being the composite measure of vulnerability, exposure, and physical hazard, we considered migration as an effective adaptation if it reduced any of these three dimensions. Thirty-eight of the coded case studies reported reduction in vulnerability, 31 in exposure, and 2 in hazard (Fig. 4). Thus, several of the benefits gained from migration yield reductions in exposure and vulnerability.

Migration appeared to have reduced vulnerability through remittances in Burkina Faso (West et al. 2016) and seasonal migration in Ethiopia (Alemayehu and Bewket 2017). The income generated from labor migration allowed smallholders to ensure food access even in times when droughts and floods were hampering local production. In Ghana, remittances helped reduce exposure when money was reinvested in the community to fortify houses so that they would better withstand floods (Musah-Surugu et al. 2017). Similarly, in rural India, remittances were used in conjunction with knowledge gained through agricultural extension service to invest in agricultural technology that diminished food and water insecurity (Jha et al. 2018). Clearly, risk to a hazard is reduced when people move permanently away from the source of risk (i.e., hydroclimatic changes). For instance, youth in Myanmar emigrated from their villages located in the central dry zone and were hence no longer faced with recurrent droughts and erratic rainfall patterns (Zin et al. 2019), and in China resettlement enforced by the government ensured that people were not at risk of climate change-induced drought and water insecurity (Lei et al. 2017).

5 Concluding discussion

This meta-review examined existing evidence on migration as an adaptation strategy due to freshwater and inland hydroclimatic changes. The results suggest that, while mobility is certainly happening, substantial gaps in knowledge remain. In this concluding discussion, we discuss our results pointing at the areas that need further research.

The majority of the 67 case studies we coded focused on marginalized communities in the Global South; however, the geographic range was limited as most of the case studies were in India, Bangladesh, Ghana, China, and Ethiopia. We note that the geographical distribution of existing evidence is skewed, with the widest majority of case studies looking at the Global South, and particularly at a handful of nations in Asia and Africa. Hence, a

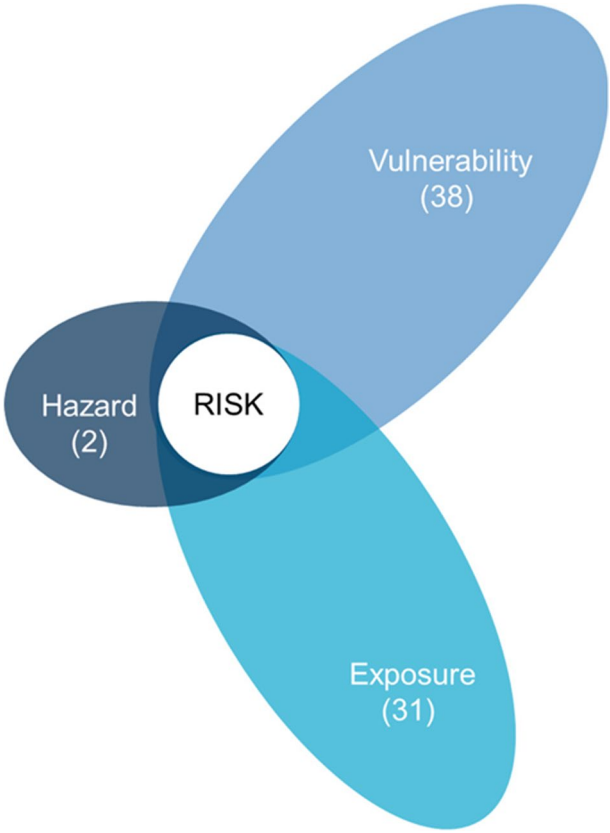

Fig. 4 Number of coded case studies according to the risk dimension that was reduced. Figure elaborated from Lavell et al. (2012). Case studies can involve more than one risk dimension

substantial geographical gap remains in the study of inland and freshwater hydroclimatic change-induced migration. We argue that this gap needs to be filled because hydroclimatic changes have been and are the most common manifestation of climate change that more than half of the world population experience across the whole globe (Caretta et al. 2022). There is a critical need for more studies on mobility patterns in the drying river basins and watersheds and melting cryosphere of the Global North, where marginalized populations are vulnerable to inland and freshwater hydroclimatic changes and have limited resources for local adaptation (e.g., Charlie et al. 2022; Nicu and Fatorić 2023), in addition to continuing studies on mobility in the watersheds of the Global South.

In this meta-review, we considered literature published past the IPCC 5th Assessment (AR5) report to understand whether and how existing evidence has evolved. While AR5 did not focus on hydroclimatic change-induced migration, our meta-review zooms in on novel evidence through a new angle. This meta-review advances this knowledge gap by showing that droughts, floods, extreme heat and precipitation, and general climate change hazards triggered migration in Africa, South Asia, Southeast Asia, and Central America, while decreasing sea ice and permafrost melting motivated migration in Alaska. We report on case studies where mobility takes place, given the scope of our study, and we see that mostly the decision to migrate is initiated at the household level due to motivations ranging from mere survival to searching for better economic opportunities. A small number of the

migrations are government-led or intensive community-planned resettlements. As opposed to burgeoning evidence on planned relocation and managed retreat due to sea-level rise (e.g., Hauer et al. 2020; McMichael and Katonivualiku 2020), our meta-review shows that such evidence in the context of floods, droughts, and extreme precipitations is lacking. We wonder whether this gap is due to a lack of scholarly evidence or to an actual lack of implementation of government-led relocation due to floods and droughts. Improving knowledge on this aspect is crucial to understand the magnitude of this hydroclimatic-induced migration and the policy and financial support required to tackle this challenge. In fact, while the evidence on floods and droughts induced migration is preponderant (Piguet et al. 2018), there is still a tendency to focus on sea-level rise-triggered migration, where evidence of actual migration from atolls is lacking, for example Mortreux et al. (2023).

Importantly, the meta-review highlights that migration does not happen in isolation, but it is part of a portfolio of responses and is often taking place along a range of agricultural adaptation responses in rural communities (see also De Longueville et al. 2020; Wiederkehr et al. 2018). More specifically, migration falls along a spectrum ranging from improving household resilience and reducing agro-ecological dependence to a short-term risk reduction and coping strategy. This spectrum is determined by socioeconomic and intersectional characteristics of the individuals considering mobility as an option, as confirmed by several other authors (Baldwin et al. 2019; Boas et al. 2022; Cundill et al. 2021). Accordingly, our meta-review illustrates, in line with McLeman et al. (2021), the continuum of the migration-adaptation nexus which sees a preference for in situ adaptations as a climatic risk mitigation strategy, and if proven insufficient, resorts to balance migration as one of the many adaptation options to reduce vulnerability and exposure.

Our results resonate with the meta-review by Berrang-Ford et al. (2021) of adaptation responses to climate change of 1682 peer-reviewed articles, which describes migration as one of several ways that individuals and households diversify their livelihoods in response to extreme floods, droughts, and other climatic changes. The evidence that we coded confirms that livelihood diversification, often in the form of off-farm employment and reinvestment of remittances for crop diversification, are the most common benefits resulting from migration and its associated portfolio of adaptation strategies (see also Caretta et al. 2022; Mashizha 2019; Musah-Surugu et al. 2017; Rodriguez-Solorzano 2014). For those who migrate because of water insecurity, migration is beneficial, and in many of the case studies, migration results in higher income. However, migrants are not always able to find employment after moving, and some struggle with a higher cost of living. This evidence shows the context-specific character of migration (see also Williams et al. 2021) and relates to the debate on whether migrants are agents of their own destiny — which the migration as adaptation literature suggests (e.g., Piguet et al. 2011, 2018) – or whether they are victims of pre-existing systemic vulnerabilities in which climate migration happens along pre-existing patterns of mobility (e.g., Boas et al. 2022; Wiegel et al. 2019). Notwithstanding the scope of our meta-review on hydroclimatic induced migration as adaptation, evidence on the positive outcomes of adaptation in terms of risk reduction remain mixed and needs further deepening.

As Berrang-Ford et al. (2021), the evidence we coded ascertain that risk reduction from migration is mixed. One of the most significant findings of this study is the fact that migration is predominantly undertaken to reduce vulnerability and risk of exposure, rather than as a response to natural hazards. Yet, while migration might reduce vulnerability and exposure for the individuals who migrate, risk is not reduced for those who are left behind, and often it increases risk for those who are not able to migrate. Our study further found that risk reduction from remittances was mixed as well. This confirms the conclusion of AR5

(Noble et al. 2015) stating that the adaptive or maladaptive character of climate migration is context specific (see also Williams et al. 2021), both in terms of the geographical location and the community involved.

Notably, while migration has been described as a transformational adaptation strategy in response to hydroclimatic changes (Gemenne and Blocher 2017), our meta-review shows that highly transformative responses such as planned and organized community relocations are rare or not documented. Moreover, migration at the individual or household level does not attain the depth, scope, or scale that Berrang-Ford et al. (2021) suggest is required for a transformative adaptation response. Indeed, our meta-review shows that remittances can be beneficial to the originating community, but it cannot be assumed that migration always has a positive outcome for those who are left behind. This important distinction speaks to the need, not just to look at migration as adaptation or even transformative adaptation, but to recognize that immobility – i.e., the impossibility or unwillingness to migrate due to socioeconomic circumstances – is a reality for many, particularly in the Global South (Baldwin et al. 2019; Ayeb-Karlsson et al. 2022; Thalheimer et al. 2022; Boas et al. 2022; Cundill et al. 2021; Wiegel et al. 2019).

Yet, all in all, there is preponderant evidence that climate migration might become an adaptation response—whether solely or in conjunction with other strategies, whether seasonally or permanently—for an increasing number of people, experiencing droughts and floods across the whole globe. Projections speak of an increased number of people migrating and being displaced, particularly in low-income countries (McLeman and Gemenne 2018; Rigaud et al. 2018). For instance, countries in Africa are projected to be at a higher risk of displacement due to potential flood exposure (Kakinuma et al. 2020). Several estimates exist in terms of the number of people being affected by slow-onset climate impacts such as water stress, crop failure, and sea-level rise. These range from between 31 to 72 million people (RCP2.6, SSP4) and 90 to 143 million people (RCP8.5, SSP4) internally displaced by 2050 in Sub-Saharan Africa, South Asia and Latin America (Rigaud et al. 2018). Another study, taking into account temperature increase and precipitation in low-income countries, estimates EU asylum applications will increase by between 0.098 million (RCP4.5) and 0.66 million (RCP8.5) (Missirian and Schlenker 2017). The magnitude of these projections, noting nonetheless the epistemological difficulties intrinsic in their span, and their geopolitical implications, we assert, speak to the urgency of conducting additional studies on the existing links between inland and freshwater hydroclimatic changes and migration to inform climate and migration policies that increasingly need to be intertwined rather than shaped in isolation from each other. Improving the focus on inland and freshwater hydroclimatic changes and their consequences in terms of migration, vis a vis a significant debate on the role of sea level rise in migration, we argue, is timely, as the majority of the world population is projected to experience climate change through inland floods and droughts (Caretta et al. 2022).

Our meta-review shows that substantial evidence of the benefits of migration as an adaptation strategy in response to hydroclimatic changes is still lacking, making it impossible to state whether migration has positive or negative outcomes in terms of adaptive capacity. As climate change differentially affects regions across the world, impacts at the nexus of food, water and energy security are going to be critical factors in household decision-making and adaptations. Socioeconomic conditions, such as resource availability, access and dependence and intersectional factors including age, sex, educational level, are all critical factors that will drive households to consider migration as an adaptive strategy. Because of its scope and wider assessment purpose, this metareview had to leave out a complete intersectional analysis as well as a breakdown of the results in terms of spatial and temporal scale.

Future research is thus needed to complement our findings. Moreover, the role of natural resources in influencing mobility and migration has been understudied (Cundill et al. 2021; Zickgraf et al. 2022) and there is a need for complex adaptive systems approaches that allow for an understanding of the non-linearities in the relationship between natural resource use and human mobility (McLeman and Gemenne 2018). We argue that, while there is a preponderance of case studies of mobility and migration in different contexts and scenarios, future studies focusing on climate mobility decision-making would benefit from a more in-depth and systemic approach moving towards a greater understanding of a dynamic co-evolution of the natural resource-mobility-adaptation nexus. This focus would particularly help clarify the relation between inland and freshwater hydroclimatic changes, a preeminent manifestation of climate change for the majority of the world population (Caretta et al. 2022), and migration and inform decision-makers on the policy and funding actions to be taken.

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Declarations

Competing interests The authors declare no competing interests.

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