POTENTIAL DRIVERS OF HUMAN MIGRATION UNDER CLIMATE CHANGE: A REVIEW

ZHANG, X. P.[1] – PU, H. Z.[2,3] – CAO, Q.[1*] – JI, Q.[4,5] – XIANG, Q.[1] – WANG, W. Z.[1] – ZHONG, W.[1]

[1]*Joint Logistic Support Force University of Engineering, Chongqing 401331, China*

[2]*School of Management, Chongqing University of Technology, Chongqing 400054, China*

[3]*Research Institute of Spatial Governance, Chongqing University of Technology, Chongqing 400054, China*

[4]*School of Management, Putian University, Putian 351100, China*

[5]*State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China*

**Corresponding author*
e-mail: roy1976@163.com

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Abstract. Understanding the drivers of human migration is essential for formulating effective policies and adaptation strategies to address potential population migration induced by climate change. This paper provides a comprehensive review of the potential drivers of population migration under climate change, with special emphasis on environmental factors. Key concepts such as climate migration, displacement, and planned relocation are clarified. Through a synthesis of existing literature and relative importance analysis, we show that climate change is increasingly recognized as a critical driver influencing migration patterns, interacting with and often exacerbating economic, social, political, and demographic factors. Although economic factors remain the primary drivers of migration, environmental drivers—such as sea-level rise, extreme weather events, glacial melt, drought, and ecosystem degradation—are becoming increasingly significant. Among these, floods constitute the largest share of disaster-related displacements (49.54%), followed by rainstorms (37.9%) and droughts (3.27%), highlighting the need for focused research and response efforts on hydrological and precipitation-related disaster. These climate-related factors disrupt livelihoods, intensify resource scarcity, and threaten human security, thereby accelerating both voluntary and forced migration. The study further reveals that the role of environmental drivers is context-dependent and non-linear, often operating through complex pathways that interact with socioeconomic vulnerabilities. The paper highlights the urgency of integrating environmental migration into climate adaptation and development policies. Further research is essential to understand migration thresholds, strengthen adaptive capacity, and support resilient governance systems in the face of growing climate risks.
Keywords: *climate-related human migration, interconnected drivers, relative importance, disaster*

Introduction

Atmospheric carbon dioxide levels are currently the highest in 650,000 years, and the global average temperature has increased by 1.1°C since 1880. Limiting global warming to 1.5°C above pre-industrial levels by mid-century will require not only significant emission reductions but also the achievement of negative emissions by 2100 (The Intergovernmental Panel on Climate Change, IPCC, 2022b). Without drastic mitigation measures, global warming is unlikely to remain below 2°C by the end of the century (Mauritsen and Pincus, 2017; Raftery et al., 2017). Climate change poses serious challenges to human societies, ecosystems, and sustainable development

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(IPCC, 2021, 2014b), exacerbating environmental degradation and natural disasters in many regions (Pamuk et al., 2008; Stults, 2017). Over the coming decades, the combined effects of climate change and other pressures—such as pollution and resource scarcity—will impact urbanization and population growth (IPCC, 2014a). Climate change has already altered migration patterns (De Sherbinin et al., 2011), leading to distress relocation, displacement, and government-led planned resettlement. Many individuals remain trapped in environmentally vulnerable areas due to an inability or unwillingness to move (Black et al., 2011b; Leal Filho et al., 2021). These impacts are widespread and unavoidable for both developing and developed countries. In Bangladesh, coastal hazards and flooding displaced approximately 2 million people during 2001~2011 (Ahmed, 2020) and 110 million people could be exposed to varying degrees of coastal inundation in the e mid-21st century (Hauer et al., 2020). In the US, Hurricane Katrina displaced over 12,000 individuals in 2005 (National Coalition for the Homeless, 2009) and in the future, sea-level rise and related hazards may put up to 13 million Americans at risk of displacement (Hauer et al., 2020).

Population migration is known to be influenced by environmental variables, yet the conditions and drivers that define "environmental migration" might vary greatly (Castelli, 2018; Castles, 2013). But environmental stressors, including those exacerbated by climate change, are not the only factors affecting migration. There is a complex contextual relationship between environmental drivers and other factors that ultimately contribute to migration decisions (World Bank Group, 2023). Environmental stresses play a crucial role in these processes, even if the many multidimensional interactions influencing migratory decisions are not fully understood at this time (Hoffmann et al., 2020). Environmental factors and other drivers interact to influence population migration (Black et al., 2011a).

According to the United Nations Department of Economic and Social Affairs (UN DESA) (2020), the number of international migrants globally has increased from 173 million in 2000 and 221 million in 2010 to 281 million in 2020, with the corresponding proportion increasing from 2.8% in 2000 and 3.2% in 2010 to 3.6% in 2020. There is a growing concern that climate change will lead to large-scale population shifts and forced migration. Is this concern valid? What is the current state of research and knowledge on the relationship between climate and migration? What are the factors driving migration for relevant researchers, policy makers and the public? What are the main drivers affecting population migration? As climate change intensifies, what are the effects of climate on the various drivers? Will each driver face uncertainty in the future (Ghosh and Orchiston, 2022; McNicoll and McLeman, 2014).

With an emphasis on examining the role of the environment, particularly climate change, as a driver of population migration, the study aims to synthesis the many factors linked to population migration and investigate the relationships between them. In order to provide theoretical support for policy makers to formulate relevant climate and population migration policies. The following are the primary queries this study attempts to answer: (1) Which factors influence population migration in the literature and how do they affect population migration; (2) What are the key drivers among the various drivers? (3) How does climate change affect the various drivers of population migration? What is the current understanding of the role of climate and environmental factors in the study of population migration?

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Concept definition and migration classification

Concept definition

The International Organization for Migration (IOM) defines migrant as: an umbrella term, not defined in international law, which reflects the common understanding of a person's temporary or permanent absence from his or her place of habitual residence for a variety of reasons, whether within the country or across an international border. At the international level, there is no universally accepted definition of migration. This term is not meant to suggest or establish any new legal category; Rather, it was produced by the IOM for internal use (https://www.iom.int/about-migration). According to the Human Development Report from the United Nations Development Programme (UNDP, 2009), migrants are individuals who change their place of residence by crossing an international border or moving to another region or city in their country of origin. People are usually considered migrants if they stay outside their original place of residence for at least three months. According to the United Nations High Commissioner for Refugees (UNHCR), a refugee is a person who has crossed a border into another country to escape conflict, persecution and human rights abuses (https://www.unhcr.org/about-unhcr/who-we-protect). There are several definitions to describe environmental and climate change-induced migration, including ecological migration, environmental migration, climate refugees and climate migration (Warner et al., 2010). The IOM defines environmental migration as "the forced or willing temporary or permanent departure from one's home, whether within or outside the country, of those whose living conditions and survival have been negatively affected, primarily as a result of sudden or gradual environmental change". However, the concept of environmental migration is widely accepted internationally because it takes into account key factors associated with population movements, such as the type of environmental change, the manner in which the population is moved and the destination of the population migration (Alarcón, 2011).

The UK Government Office for Science (2011) offers a detailed analysis of the concepts of climate migration, displaced refugees, and planned resettlement.

Displacement, often known as environmental or climate refugees, is a specific type of migration in which people are compelled to relocate against their choice. When people are forced to move within their country of origin, it is called internal displacement. If people move to another country, they may become refugees, but in international law the term is only applied to individuals who meet the definition of a refugee in the 1951 Geneva Refugee Convention and its 1967 Protocol and are recognized as refugees by the host country or by the United Nations High Commissioner for Refugees (UNHCR). Internally displaced persons (IDPs) are people who have been forcibly removed from their homes or places of employment but have not crossed an international boundary in spite of receiving aid or compensation, according to the Internal Displacement Monitoring Center (IDMC) (The IDMC, 2023).

Currently, reports of planned relocation are relatively limited. Planned relocation is defined as: an organized procedure whereby persons or groups are taken from their homes or makeshift shelters, given the means to relocate, and given the space to start over in a new place. Planned relocation generally takes place within national boundaries and aims to protect people from the risks and impacts associated with

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disasters and environmental change, including climate change. Such planned relocation can take place at the individual, household and/or community level.

This paper uses the term "planned relocation" to encompass the terms managed evacuation, resettlement, and strategic evacuation, which are used to describe the process of moving a population to a new location and settling it permanently (Randell, 2022). However, unlike evacuation planned relocation is permanent (Ferris and Weerasinghe, 2020). According to the World Commission on Dams (WCD, 2000), 40~80 million people were relocated worldwide between 1950 and 2000 because of large dam construction (World Commission on Dams, 2000; Wang et al., 2014).

Disasters and environmental change have always affected the environment in which people live. The physical area where people reside vanishes in extreme circumstances, like riverbank erosion, and they are forced to relocate (Mallick and Mallick, 2021). In other cases, livelihoods, property, or public services are so disrupted that residents feel they must relocate to find a suitable place to live (Islam and Hasan, 2016). There are also cases where people continue to live in places where their lives, property and well-being are threatened - whether due to sudden disasters (such as floods or earthquakes) or a slow deterioration in living conditions (such as drought or sea level rise) - and the government decides to move people elsewhere in order to protect them (Wilhite et al., 2000). The acceleration of habitat pressure due to climate change may prompt governments to explore deliberate relocation as a strategy for mitigating disaster risk or adapting to the changing environment (King et al., 2014). However, there are risks associated with planned migration for the people who would be moving, such as income loss and disruption, cultural heritage, and socioeconomic networks (Schade, 2013).

Classification of population migration driven by environment and climate change

Various perspectives classify population movement caused by environmental factors and climate change into distinct categories (*Table 1*).

Table 1. *Classification table for population migration*

Division criteria	Classification	Differences in drivers
Climate change (The UK Government Office for Science, 2011)	Climate change related migration (Moore and Wesselbaum, 2023)	Sea level rise, tropical storms and cyclones, changes in rainfall, rising temperatures, melting of mountain glaciers
Non-climatic changes related migration	Environmental migration (Warner et al., 2010)	Land degradation, coastal ecosystem degradation, earthquakes
Migration Occurrence pattern (Mcleman and Hunter, 2010)	Sudden-onset disasters	Floods, earthquakes, storms, wildfires
	Slow onset of living conditions	Drought, sea-level rise, coastal erosion, desertification, land salinization, deforestation, land loss and ecosystem degradation
Duration of migration (Pavel et al., 2022)	Transient migration	Natural disasters, job opportunities, education or training
	Permanent migration	Ecological degradation, economic development disparities, policy driven
Migration scale (Root and De Jong, 1991)	Individual migration	Personal development needs, economic factors, social factors, policy factors
	Family migration	Family reunification, children's education, economic factors, social environment, policy factors

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Willingness to migrate (Farbotko et al., 2020)	Forced relocation	Political factors (political persecution, State policy), conflict factors, legal factors, natural disasters
	Voluntary relocation	Economic factors (employment opportunities, income levels, cost of living), social factors (educational resources, medical conditions, social welfare), personal and family factors (personal development needs, family reunification), environmental factors (natural environment, human environment)
Leading factor (Farbotko et al., 2020)	Government-led	Policy and planning (regional economic and social development, integrated planning and scheduling), social public interest (ecological protection, disaster response), infrastructure development and resource allocation
	Family spontaneity	Economic factors, social factors, personal and family factors, environmental factors
Destination (Hugo, 2016)	Internal	Employment opportunities and income levels, industrial structure and regional development, social factors, regional development strategies, land policies, climatic conditions and natural disasters
	International	Differences in income levels, employment opportunities, cultural identity and sense of belonging, family reunification, political factors (political stability and security, policy orientation), climatic and environmental conditions, natural disasters

Drivers of population migration

Population movements primarily reflect people's desire to improve their situation, whether in terms of wages, opportunities, security or lifestyle. Every year, millions of people move between countries and even continents for a variety of reasons, including to study, to find better job opportunities, to get married, to reunite with their families, to retire or to flee conflict or natural disasters. While some are compelled to relocate due to violence or natural catastrophes, the majority do so in order to reduce the opportunity gap that separates them from people in more affluent areas (IOM, 2021). Driving factors affecting population migration include globalization, social transformation, inequality, national and human security, technology, labor demand, demographic changes, politics, law and governance and the social dynamics of migration (Castles, 2013).

Climate change-induced migration has grown in importance as population migration as a result of the intensifying global climate change (L Perch-Nielsen et al., 2008). Global climate change is increasingly recognized as an important driver of migration, but there is considerable uncertainty about the extent of climate-induced migration (Piguet et al., 2011). Many studies have analyzed the drivers of migration (Castelli, 2018; Kaczan and Orgill-Meyer, 2020; Urbanski, 2022). According to the push-pull principle (Maheshwor, 2017; Shrestha, 2017), the main driving factors of population migration are mainly divided into three categories: push factors, namely factors related to the migration location, including political factors, economic development factors, social factors, and environmental resource shortages; Pull factors: factors related to immigration location include employment opportunities, higher wages, political stability, and sufficient resources; Intervention factors for population migration, such as policy factors that restrict and encourage migration, mainly include transportation, family, and social networks (Van Hear et al., 2018). There are a number of drivers that influence migration, and there are growing concerns about migration due to climate change (The UK Government Office for Science, 2011). There is a need to analyze and summary the drivers of population migration to support population migration management (*Fig. 1*).

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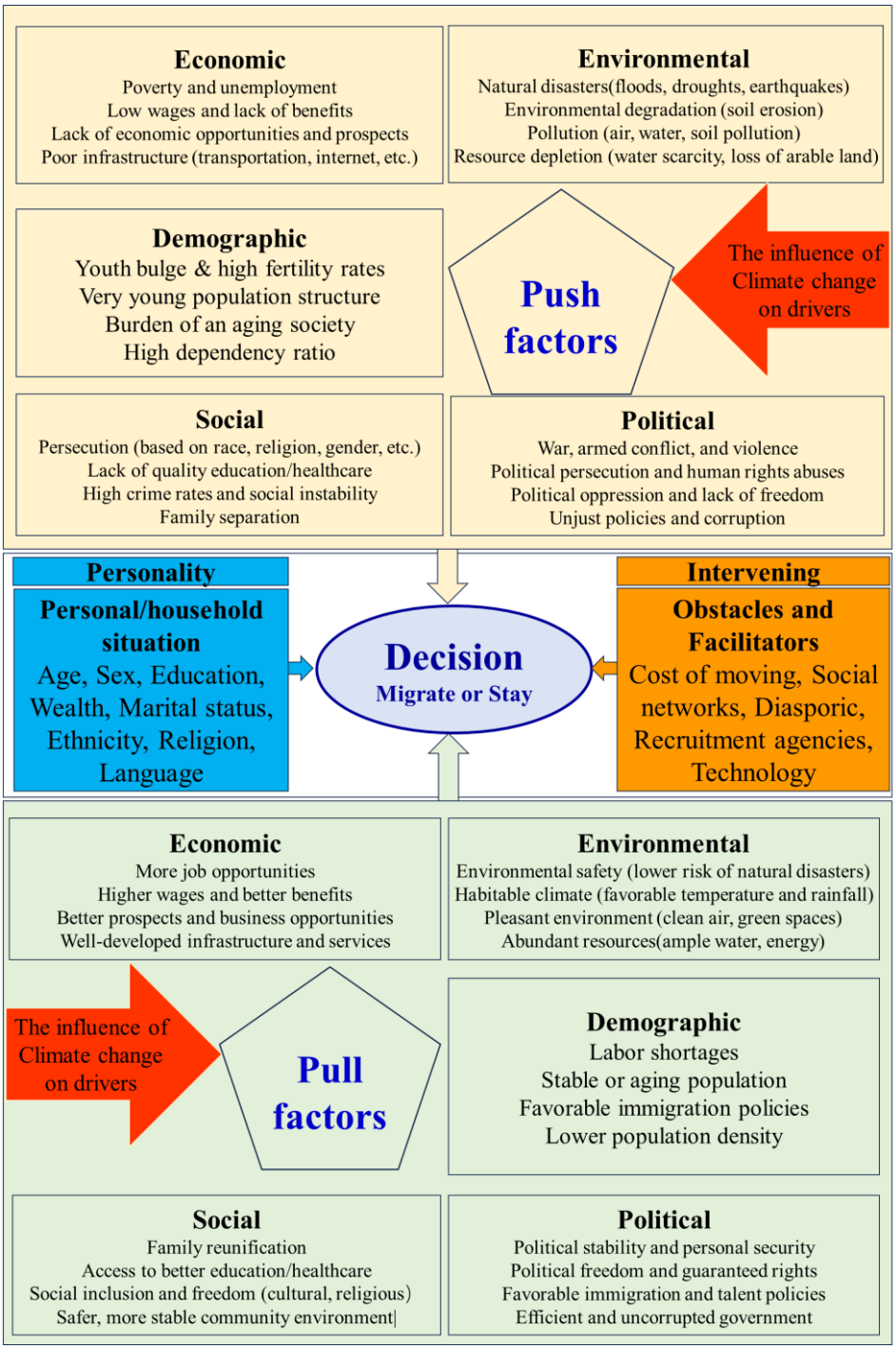

Figure 1. *A conceptual framework of migration drivers and decision-making. This schematic illustrates the multifactorial decision-making process underlying migration, categorizing influencing factors into push factors, pull factors, and intervening obstacles/facilitators. Core drivers are organized into thematic domains: Economic, Environmental, Demographic, Social, and Political. Personal characteristics moderate an individual's perception of these factors. The decision to migrate or stay is presented as the outcome of a complex interplay between these multidimensional drivers, with climate change acting as a cross-cutting influencer. Intervening factors, such as the cost of moving and social networks, can either enable or hinder the migration process. Source: Foresight: Migration and Global Environmental Change (Final project report), The UK Government Office for Science (2011), London, modified*

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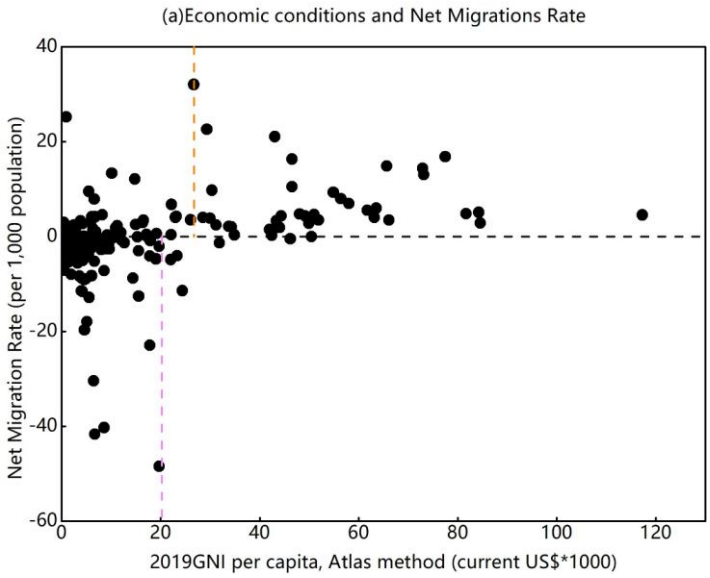
Economic drivers

The main causes of migration are economic inequalities between countries or regions, income disparities between origin and destination (Massey, 1989). In some specific regions, economic drivers including net income and income disparities play a key role in driving migration (Simpson, 2022; Urbanski, 2022). If a region is experiencing significant economic development, income disparity is usually the biggest reason for population movement (Cobbinah et al., 2015; Li et al., 2014; Sanyal and Maity, 2018; Zheng and Yang, 2016). Rural-urban migration is also evident in the urbanization (Chen et al., 2014). Although many rural residents in China have migrated to the cities, some have also migrated abroad in the course of the country's rapid economic growth (Lu and Wang, 2018). Population migration also interacts with wealth distribution (Volpert et al., 2017). Research on the relationship between migration and economic inequality shows that migration flows from low-income to high-income countries, but not in a unidirectional manner from regions with high Gini coefficients to regions with low Gini coefficients. For example, Eastern European countries both send migrants to countries with lower levels of economic inequality and receive migrants from countries with higher levels of economic inequality (Plotnikova and Ulceluse, 2022). Most of the time, migrants go from relatively poor to relatively rich locations rather than from extremely poor to extremely rich areas (Flahaux and De Haas, 2016). The relative changes between the source and destination of migrants also play an important role in driving migration. There is evidence that as average incomes rise in destination countries, the rate of population immigration also increases considerably (Mayda, 2010).

Middle-income countries send more migrants abroad than low-income countries, and outward migration increases with national income per capita. When per capita income reaches a certain level, out-migration begins to decline. There is evidence that the relationship between economic development and migration is non-linear (*Fig. 2*). This implies that rising economic and social inequality does not necessarily lead to greater outward migration. While economic factors are the most important drivers of migration, the choice to move is influenced by a variety of incentives and constraints, and economic factors alone cannot fully explain the complex motivations for migration.



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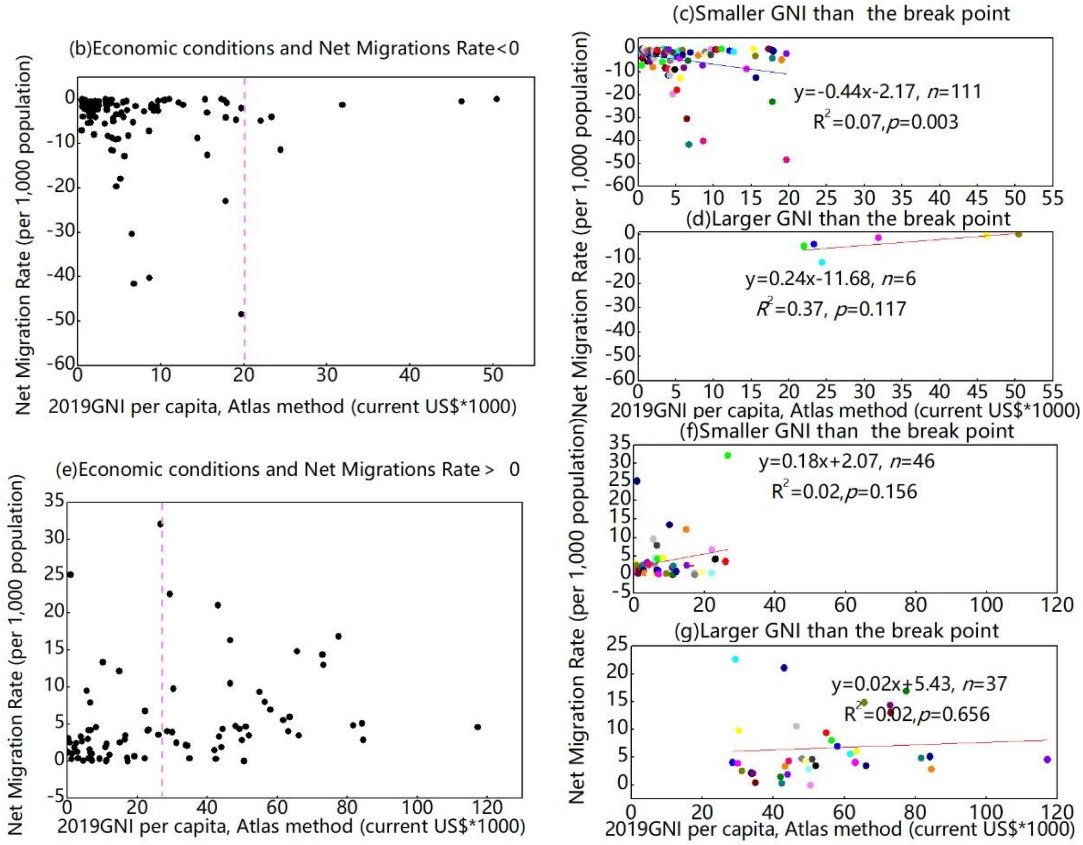

Figure 2. *A nonlinear relationship between Net migration rate and Gross National Income (GNI) per capita. Each point represents a country (economy)'s value during 2019. The dashed line is the breakpoint derived by piecewise regression (a). Figure (b) shows the relationship between economic level and net population migration when net population migration is less than 0, Figures (c) and (d) show that with the improvement of economic level, more people will move out, but when the income level reaches a certain level (breakpoint), the trend of emigration is reversed. Figures (e) shows the situation when the net population migration is larger than 0, Figures (f) and (g) shows that as per capita income increases, the number of immigration increases, but when GNI per capita reaches breakpoint, the speed of immigration slows down. Notes: GNI per capita in current US$ using the World Bank Atlas method. World Development Indicators database of the World Bank, available from https://databank.worldbank.org/data/source/world-development-indicators. The World Population Prospects, available from https://population.un.org/wpp/DefinitionOfRegions/*

Social drivers

Population migration are also influenced by social drivers such as family or ethnic practices, cultural practices, the need for marriage, and the need to find educational opportunities (Mendoza, 2008). Education is an important factor in facilitating migration. In some regions, education-induced migration is even higher than employment-induced migration (Chiang et al., 2012). Increased levels of education enhance people's ability to acquire information, improve their ability to migrate, and increase their willingness to migrate to economically developed regions, especially when the local economy is unable to provide sufficient employment opportunities (Williams, 2009). Educational factors have a clear impact on migration, and people are

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likely to move from educationally disadvantaged areas to educationally advanced areas in order to get a better education for themselves or their children. Language and culture also play an important role in international migration, and where there are significant linguistic and cultural differences, even if the potential economic benefits are greater elsewhere, migrants are likely to choose destinations that are more closely related to their own cultures, preferring to minimize the potentially greater economic benefits of migrating elsewhere (Adserà, 2015). Drivers such as age and gender also play an important role in population migration (Findley, 1994). Social media are new communication channels in migrant networks that facilitate migration in four main ways, mainly by increasing the possibility of maintaining strong ties with family and friends, addressing weak relationships related to the organization of the migration and integration process, creating new infrastructures made up of potential connections and providing a rich source of knowledge for unofficial migrants (Dekker and Engbersen, 2014). Resource inequality is most likely to have an impact on the social drivers of migration, and unequal resource allocation can result in unequal access to information and education.

Demographic drivers

Demographic characteristics play an important role in explaining population migration (Dao et al., 2021). As the population grows, natural and agricultural resources will be under population pressure, leading to outward migration under conditions where the population can move freely (Bilsborrow, 1987). In general, population structure is not a determinant of migration, and demographic pressures are more likely to influence migration through interactions with other drivers rather than being a direct driver of migration (De Haas, International Migration Institute, Oxford Department of International Development, 2010). High population densities have a strong driving effect, with increases in population density stimulating out-migration (Kandil and Metwally, 1992). But there are special cases where the direction of population movement may not always be from areas of high population density to areas of low population density (Bell et al., 2015). The population's age distribution is also significant, with younger people generally moving more frequently (Bell et al., 2015).

Policy drivers

Policy drivers have a direct impact on migration. The political and economic transition in the Mediterranean region has been an important factor in migration. The post-decolonization oil boom in the Middle East has attracted large numbers of migrants to the Gulf Cooperation Council countries. Most obviously, conflicts beyond acceptable levels will trigger migration or displacement. Local conflicts may cause populations to migrate to safer areas, either within the country or across national borders. Violence and war play an important role in shaping regional migration. The Arab-Israeli conflict, the Western Sahara conflict, the Algerian civil war, and the conflicts in Turkey, Syria and Iraq have all created large numbers of migrants and refugees (https://data.unhcr.org/en/situations). Research on the drivers of migration from Africa to Europe between 1990 and 2014 suggests that political repression, human rights violations, ethnic tensions, political instability and civil conflict in African countries of origin are strongly associated with increased migration flows to European destination countries (Giménez-Gómez et al., 2019). While oppression, violence and insecurity tend

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to increase the desire to migrate, their governments tend to create additional barriers to migration, which can make the impact of political factors on migration unclear (De Haas, 2011). Recent studies have shown that climate change can intensify conflicts and drive people to seek sanctuary; A rise in the frequency of droughts might also exacerbate conflicts and drive people to migrate (Abel et al., 2019). Some Governments support migrants through remittances, and such proactive migration policies can facilitate population movements. However, many countries that depend on large numbers of migrants systematically discriminate against migrant workers despite relatively liberal entry policies, which can have a negative impact on migration (De Haas et al., 2019).

Environmental drivers

The empirical research on population movement influenced by environmental factors and climate change has significantly increased over the past few decades (Black et al., 2011a; Cattaneo et al., 2019; Neumann et al., 2015). To date, there is little scientific consensus on the extent to which climate and environmental factors influence population movements. However, it is undeniable that population migration and displacement are affected by climate change and environmental degradation, with extreme climatic events being key triggers of population movement (Xu and Famiglietti, 2023). If early coordinated climate and development action is not taken, the World Bank predicts that more than 216 million people will become internal migrants due to climate change by 2050. Population movements are therefore likely to face greater uncertainty in the context of future global climate change (*Table 2*).

Environmental driven population migration can be divided into climate change induced migration and non-climate change induced migration (The UK Government Office for Science, 2011). Relatively speaking, population migration related to climate change should receive more attention due to its uncertainty. A study of paleoclimate in the Arctic AD 1-2000 shows that the three migrations experienced by Arctic inhabitants were driven by different factors. The first migration is plausibly linked to warming temperatures, warming climate affects prey ranges. The second population movement may have been largely influenced by the search for commercial or salvage opportunities. The growing supply of goods for trade in Europe and a cooler environment may have been the driving force behind the third population movement. However, the authors also point out that climate was not the only driver, and that social factors, including feuds or other conflicts, trade opportunities, and the desire for personal or family prestige, also played an important role in decision-making (Friesen et al., 2020). The changes in the Arctic caused by anthropogenic global warming are affecting the health and well-being of Arctic people, as well as their food security (Ford, 2009). A warming climate causes permafrost to thaw, exacerbates erosion and flooding, damages or destroys infrastructure, and threatens lives and well-being of people living throughout Alaska (Bronen, 2013).

In the past few years, the Arctic region has experienced record low sea ice levels (Kwok, 2018). Reduced sea ice extent leads to fewer animals for local hunting, increased hunting difficulty affects Arctic indigenous livelihoods, and wave action and storm surges due to reduced sea ice extent and sea level rise, as well as continued or accelerated coastal erosion, may lead to further displacement of Arctic coastal communities (Manrique et al., 2018). Due to climate change, melting and erosion of permafrost, Newtok Village is sinking rapidly, causing Yupiks to relocate (Welch, 2019, October 23). Twelve other

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Arctic communities may also need to be relocated (Strawa et al., 2020). There has not been much progress in terms of funding for the evacuation of towns threatened by coastal erosion, despite increased awareness of human displacement in the Arctic due to climate change (López-Carr and Marter-Kenyon, 2015).

Table 2. *Expected impacts of anthropogenic climate change and potential drivers of population migration (IPCC, 2022a; Kaczan and Orgill-Meyer, 2020)*

Expected change	Regions to be affected	Potential drivers of population migration	Source
Decreased snow and sea ice cover	Arctic	Changes in snowpack and sea ice have implications for commercial forestry, reindeer herding, indigenous peoples' access to traditional foods, and the livelihoods and well-being of Arctic inhabitants	(Hovelsrud et al., 2011; Kelman and Næss, Brookings-lse project on internal displacement, 2013)
Water availability changes in regions dependent on mountain snowmelt and glaciers	Glacierized mountain regions, including the Asian Alps region, the Andean region of South America, the European Alps region and the Alaskan region	Affect human societies in diverse ways, including agriculture, livestock, fisheries, tourism, and food security	(Rasul and Molden, 2019)
Heavy rains	Africa, South Asia, Southeast Asia, and Central/South America	Rainfall-related migration is usually triggered by attempts to stabilize household incomes and food consumption by rain-fed agriculture-dependent households	(Warner and Afifi, 2014)
Floods	Siberia, southern and eastern Asia, the islands of Southeast Asia, central and east Africa, much of South America, and scattered areas in North America	Continued crop loss or the unreliability of crop yield due to repeated flooding resulted in a migration decision caused by a lack of alternative livelihood, increasing cost of maintaining livelihoods in the face of flooding, or debt resulting from the loss of livelihood	(Dun, 2011; Kam et al., 2021)
Droughts	African countries, Middle Eastern countries (in particular Turkey, Syria and Iraq), and, Central/Latin America (in particular Venezuela, Guatemala, Haiti and Colombia)	Drought affects agricultural production and food security, with intensive irrigated agriculture leading to a decline in water reserves, coupled with drought events affecting water supply capacity, resulting in reduced crop yields and loss of income and livelihoods, prompting or forcing farmers to relocate to areas close to water sources	(Smirnov et al., 2023; Xu and Famiglietti, 2023)
Extreme heat	South Asia and Western Africa, tropical and subtropical areas of the world	consistently increases the long-term migration of human, driven by a negative effect on farm and non-farm income	(Mueller et al., 2014)
Decreasing crop productivity	Lower latitudes, dry tropics, seasonally dry regions	Climate change have significant implications for agricultural productivity, rural livelihoods and food security and indirectly affect migrants, which can generate additional income, reduce consumption by households of origin and diversify household livelihood strategies to cope with the risk of agricultural crop failure	(Falco et al., 2018)
More frequent typhoons, hurricanes, tsunamis	Coastal regions	Typhoons, Hurricanes or tsunamis caused considerable damage to critical infrastructure (water, electricity and public schools), resulting in short-range and short-term relocation of affected populations	(Kunze and Strobl, 2024)
Sea level rise (saltwater intrusion into groundwater and agricultural soils, coastal flooding, shifts in sediment regimes, coastal erosion and increased inland penetration of tropical storm surges)	Coastal regions	These hazards can permanently damage irrigated and freshwater supplies for coastal agriculture, disrupt vital human systems, reduce property values and ultimately destroy property and infrastructure, threaten coastal livelihoods such as tourism, coastal aquaculture, fisheries and silviculture, and thus drive population displacement	(Hauer et al., 2020)

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Changes in precipitation, as well as snow and ice melt, may lead to large changes in extreme flows downstream, and flood flows may increase significantly, increasing the risk of flooding (Vinke et al., 2017). Studies have shown that up to 20 million people in India and about 26 million people in Bangladesh may be displaced by inland floods brought on by melting Himalayan glaciers and increasing sea levels by 2050 (Maqbool, 2018). Plains adjacent to mountainous areas are prone to severe flooding due to snow and ice melt and increased rainfall variability. The Pakistan floods of 2022 inundated nearly one-third of cultivated land and displaced tens of millions of people (Ahmad et al., 2024). A scarcity of water supplies could be the medium- to long-term consequence of glacier melting, which would have detrimental effects on hydroelectric power generation, small-scale fishing, and irrigated agriculture. There is an important link between glacier-related water scarcity and population migration from irrigated areas, as these people will move to areas close to water sources or to nearby cities (Maqbool, 2018). Over the past two decades, there has been a growing trend of permanent out-migration of entire families, resulting in the depopulation of mountainous areas. In the last census, 36 out of 55 hill and mountain districts in Nepal reported negative population growth rates. A similar depopulation trend has been observed in the Indian state of Uttarakhand. In the upper Ganges basin, the drying up of springs and rising floodwaters have disrupted local agriculture-based livelihoods, leading to large-scale migration, especially of young people, to urban centers in search of alternative livelihoods (Molden et al., 2022). However, the impact of changes in the cryosphere on population migration is only one important factor, migration is also influenced by adaptation measures at the same time and is the result of a combination of drivers.

A review of global climate change trends and an assessment of the potential impact of climate change on extreme events indicate that there has been an increase in certain forms of extreme weather events since 1950 (Agha Kouchak et al., 2020). The recently released Special Report on Extreme Events and Disasters (SREX) of the IPCC predicts a further increase in the number of extreme events and disasters in the 21st century, including an increase in the frequency of heat waves, tropical cyclone wind speeds, and the intensity of droughts. By the end of the twenty-first century, a one-in-20-year “hottest day” event could occur every other year. Additionally, there are more instances of heavy rainfall, which could have an impact on the frequency and intensity of floods as well as, most likely, the frequency of landslides (Banholzer et al., 2014). According to the IDMC (2019), approximately 16.1 million people worldwide were displaced due to weather related events in 2018, of which 33% (5.4 million) were displaced due to floods. Future climate change may exacerbate the risk of population displacement (Kakinuma et al., 2020).

Drought and the resulting land desertification are considered important driving factors for population migration. Although these disasters will not immediately endanger livelihoods, they will continue to threaten human livelihoods for several years (Hermans and McLeman, 2021). In this situation, long-term drought will affect immigration, especially for families who rely on agricultural production for a living. Droughts are predicted to grow increasingly often and severe as a result of climate change brought on by human activity (Dai, 2013). The reasons behind migration brought on by drought are complex, and people’s decisions to migrate are influenced by a variety of factors, with internal adaptive capacity either promoting or inhibiting migration (Adaawen et al., 2019; Ceola et al., 2023).

Extreme high temperature events are important influencing factors for health and death, especially for outdoor workers. Climate change will generate more frequent and

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intense extreme high temperature events. Extreme high temperatures have the greatest impact on the population of tropical and subtropical regions. By the end of the twenty-first century, it is predicted that some specific regions, such as portions of West Africa and South Asia, may endure lethal heat stress temperatures high enough to make the area unsuitable for human settlement (Mueller et al., 2014). This means that in order to minimize the impact of rising temperatures on health or compensate for the decline in work productivity, people may choose to migrate to areas with lower temperatures, thereby reducing the risk of high temperature exposure (Issa et al., 2023).

Climate change will simultaneously affect temperature, precipitation and atmospheric chemistry, which together will affect the productivity of crops (higher carbon dioxide concentrations will favor some crops but not all) and will affect ocean chemistry and thus the productivity of coastal and marine ecosystems. In the absence of alternative sources of income or the implementation of adaptation strategies, environmental change may reduce household income by reducing the productivity of crops, livestock or fisheries in an area, or by destroying assets used for agriculture. Reduced household income and unreliability in income can be migration's important cause (Black et al., 2011a).

Coastal populations are expected to experience more intense and frequent coastal weather events and inundation resulting from climate change (Xu et al., 2014). The majority of the migration brought on by Hurricanes Katrina and Rita will be short-term, short-distance inside already-existing migration systems, according to research on the effects of the storms on population migration systems. The findings of the authors experimentally disprove predictions made by some that climate change will cause a sharp shift in population, such as a large-scale migration of impoverished people from the Global South to the Global North (Curtis et al., 2015).

Sea level rise (SLR) affects human migration in a number of ways. The most obvious impact is the permanent and irreversible inundation of low elevation areas. Continued land degradation results in land becoming uninhabitable and therefore requiring resettlement. Ongoing land degradation, however, also poses a number of other risks that can influence migratory patterns; In fact, these risks will manifest themselves more quickly than floods itself. Hazards include saltwater intrusion into groundwater and agricultural soils, coastal flooding, changes in depositional zones, coastal erosion, and enhanced infiltration of tropical storms into inland areas. These hazards can permanently disrupt irrigated coastal agriculture and freshwater supplies, disrupt vital human systems, reduce property values, and ultimately damage property and infrastructure, thereby stimulating population displacement. Ongoing land degradation also poses a threat to coastal livelihoods such as tourism, coastal aquaculture, fisheries and forestry, indirectly contributing to the migration of local populations through its adverse impacts on job security. With the global coastal population projected to exceed 1 billion in this century, continued land degradation due to sea-level rise may be one of the most costly and permanent future consequences of climate change (Hauer et al., 2020). To properly understand migration responses to SLR, more investigation is required into the basic mechanisms driving SLR migration, thresholds and feedbacks, risk perception.

Disasters displace 23.7 million people in 2021 (Internal Displacement Monitoring Centre Global Report, 2022). According to data from IDMC, the reported disaster events around the world from 2008 to 2022 showed an increasing trend year by year (*Fig. 4*). An investigation of the link between catastrophic events and global temperature indicates a strong relationship between the two (*Fig. 3*). In order to understand the proportion of

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displacement caused by various disaster events, we take the average value of various disaster events from 2008 to 2022, and then calculate the proportion. The findings indicate that the maximum percentage of displacement caused by floods is 49.54%, with rainstorms accounting for 37.9% and droughts only causing 3.27% of the total (*Fig. 5*). The proportion of displacement caused by wildfires, high temperatures, volcanic eruptions, and mass movements (such as shallow landslides, debris flows, rock slope failures, or ice avalanches) is relatively small. This result points out the key points and hot spots for us to study displacement, which means that the focus of displacement should be more focused on flood, rainstorm, and drought disasters.

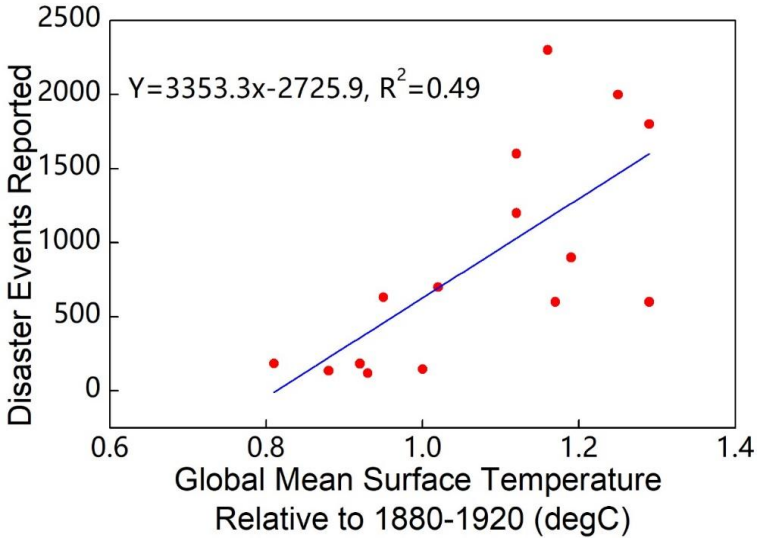

Figure 3. *Trends of disaster events reported from 2008 to 2022 (events/year). Data source: surface temperature data were obtained from National Aeronautics and Space Administration (NASA) (https://climate.nasa.gov/vital-signs/global-temperature), and disaster events data were sourced from the IDMC (https://www.internal-displacement.org/)*

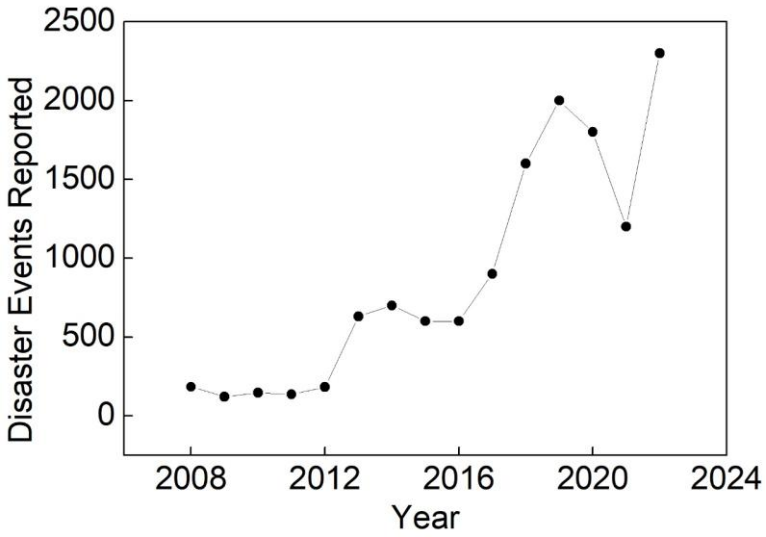

Figure 4. *Trends of disaster events around the world reported, 2008–2022 (events/year). Data source: The disaster events data were sourced from the IDMC (https://www.internal-displacement.org/)*

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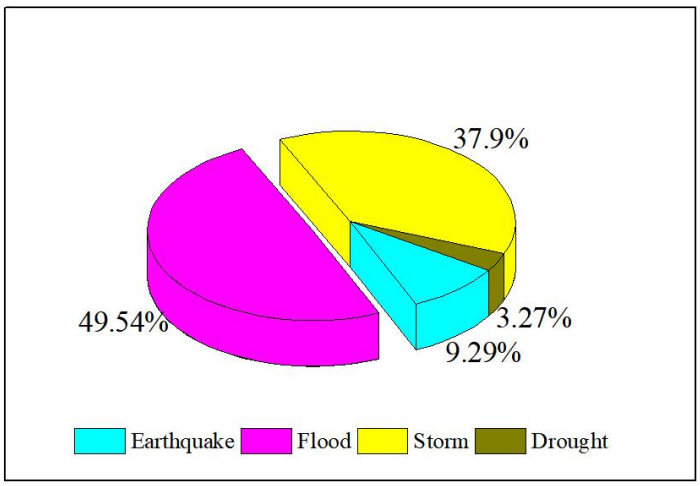

Figure 5. *Proportion of displacement caused by different disasters. Data source: The disaster events data were sourced from the IDMC (https://www.internal-displacement.org/)*

Individual (household) characteristics and intervening factors

The migration drivers are influenced by the destinations, and there are significant differences between the drivers that influence migration within a country and outside of it. For international migration, economic and political motivations, geographical distance, and cultural language all have important impacts on migration decisions. Regional differences also have an important impact on migration decisions, but perceptions of regional differences are highly individualized and are influenced by personal characteristics (including education, age, marital status and gender), individual family characteristics, and an individual's position in the family. In conclusion, these traits can influence how someone views their circumstances and socioeconomic setting, as well as whether migration can help the situation. In an immigration survey of scientists from 16 countries, the drivers of migration were analyzed. For many countries, neighboring countries are the most likely source of immigrants, for example, surveys show that Germany is the most likely source of immigrants for scientists from the Netherlands, Belgium, Denmark, Sweden and Switzerland. Cultural and linguistic links are also important, for example the UK is the number one source country for scientific migrants from Australia. However, geography and cultural language do not always dominate (Franzoni et al., 2012).

Comparing the relative importance of driving factors

The relative importance of migration factors varies from case to case, but economic factors are generally considered to be the most influential, while environmental factors affect only a small proportion of population migration. Some studies suggest that only about 11% of population migration are directly related to environmental factors (Neumann and Hermans, 2017b). It should be pointed out that the relative importance of each driving factor is constantly developing and changing. In different geographical spaces and times, the same driving factor of population migration may change from the most important to the least important, or from the least important to the most important.

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60% of 1668 households in all four research regions indicated that more job and economic prospects were the main motivators for leaving the study sites in a survey on the readiness of people living in the low-lying coastal delta to move. Education was the second most frequently cited issue, with 12.5 percent of respondents reporting that migrants leave for formal education or training. Family obligations accounted for 9.5% of responses, while family reunification was the fourth most cited reason at 7.3% (Adger et al., 2021). Only a minority of respondents (0.6%) reported that the main reason behind the decision to move was related to environmental reasons. This implies that in densely populated delta regions, socio-demographic factors and socio-economic reasons continue to be the primary drivers behind migration aspirations. Despite the small percentage of environmental factors as a driver of past migration, a large percentage of respondents indicated that environmental changes and their impact on household economic security were the main reason for future migration intentions when it came to future expectations, suggesting that climate and environmental changes have simultaneously influenced and altered past migration patterns, which is particularly important (Adger et al., 2021). Another study shares the same view that social and economic drivers are the main drivers of population migration in Sahel countries, with environmental drivers accounting for only 8.1% of all drivers counted (*Fig. 6*) (Neumann and Hermans, 2017a).

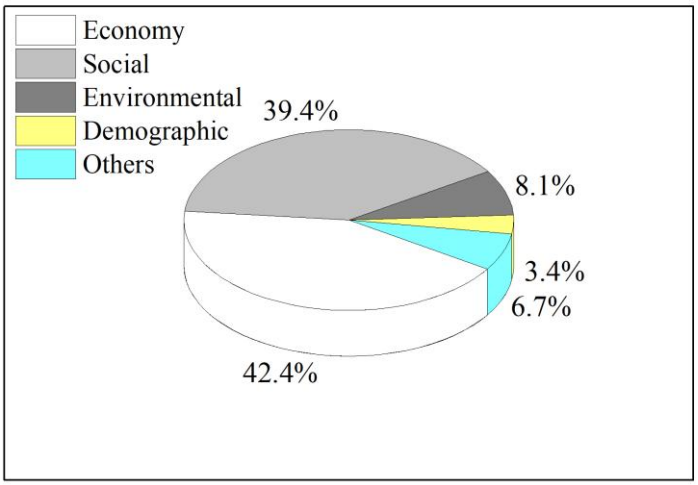

Figure 6. *Relative frequencies of the indicated categories of migration drivers. Source: Neumann and Hermans (2017a)*

In a study of the drivers of migration in 178 countries (regions) around the world, the authors considered income, education, health, government governance, water risk, food production scarcity, natural disasters, and drought risk. After weighing the relative significance of each driver, it was shown that income had the greatest impact on migration, followed by health and education. Slow-onset natural disasters and environmental stresses are also important drivers of migration. In 7% of countries, drought risk and natural disasters are the main environmental variables for migration, followed by water crises and food security (*Fig. 7*) (Niva et al., 2021).

A comparative analysis of driver factors across countries with different income levels reveals significant disparities. In the vast majority of countries, income stands as the most crucial driver, while government governance is perceived as the least important. In

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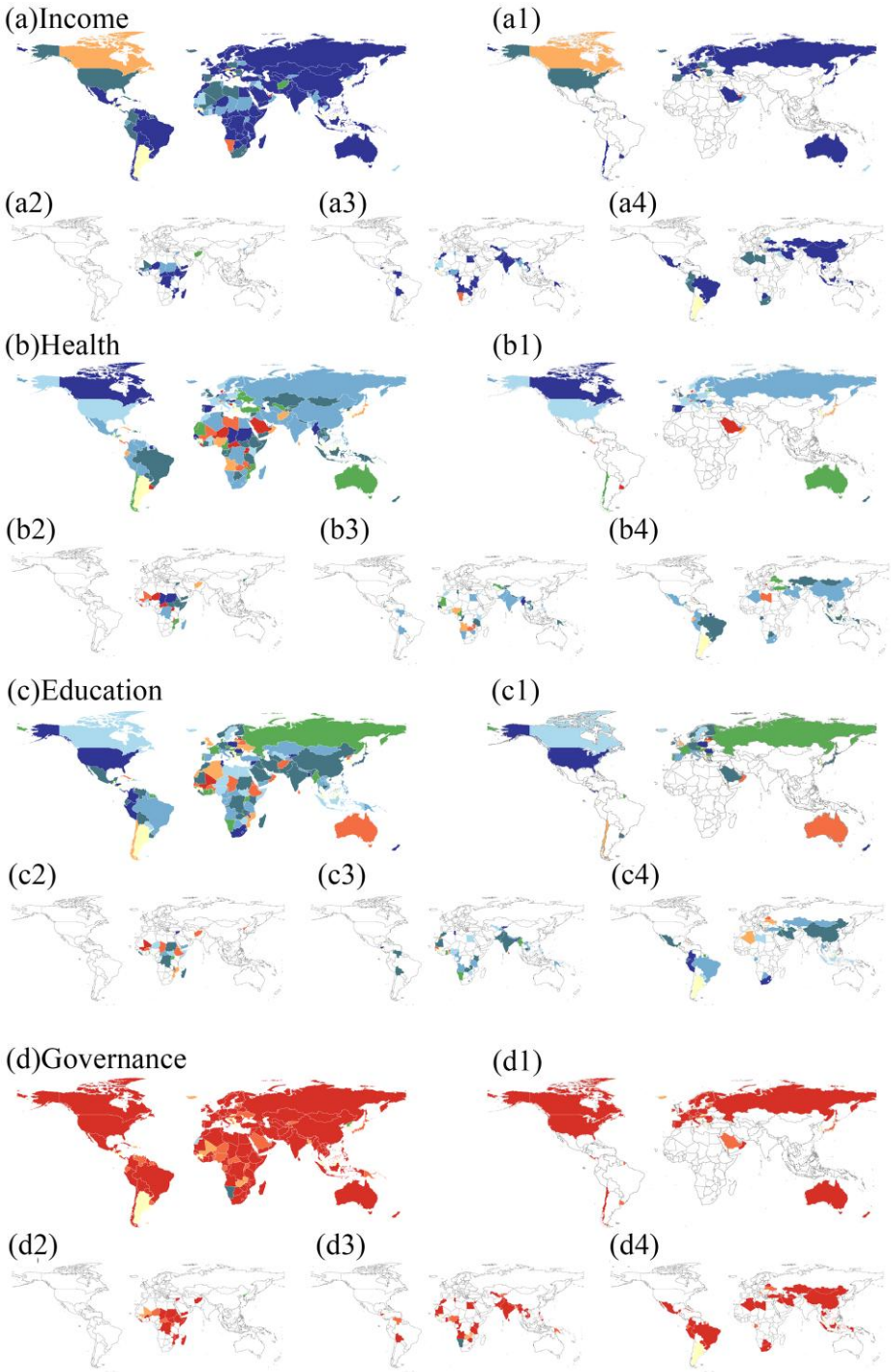
low-income and lower-middle-income countries, the relative importance of health and education as drivers appears comparatively lower. Interestingly, in some high-income countries, food production scarcity demonstrates higher significance as a driver, which may be related to their economic structure. Meanwhile, in low-income and lower-middle-income nations, drought risk, water risk, and natural hazards show greater importance as drivers of human migration. This is likely due to the higher vulnerability of these countries to natural disasters, which can more easily devastate their livelihoods (*Fig. 7*).



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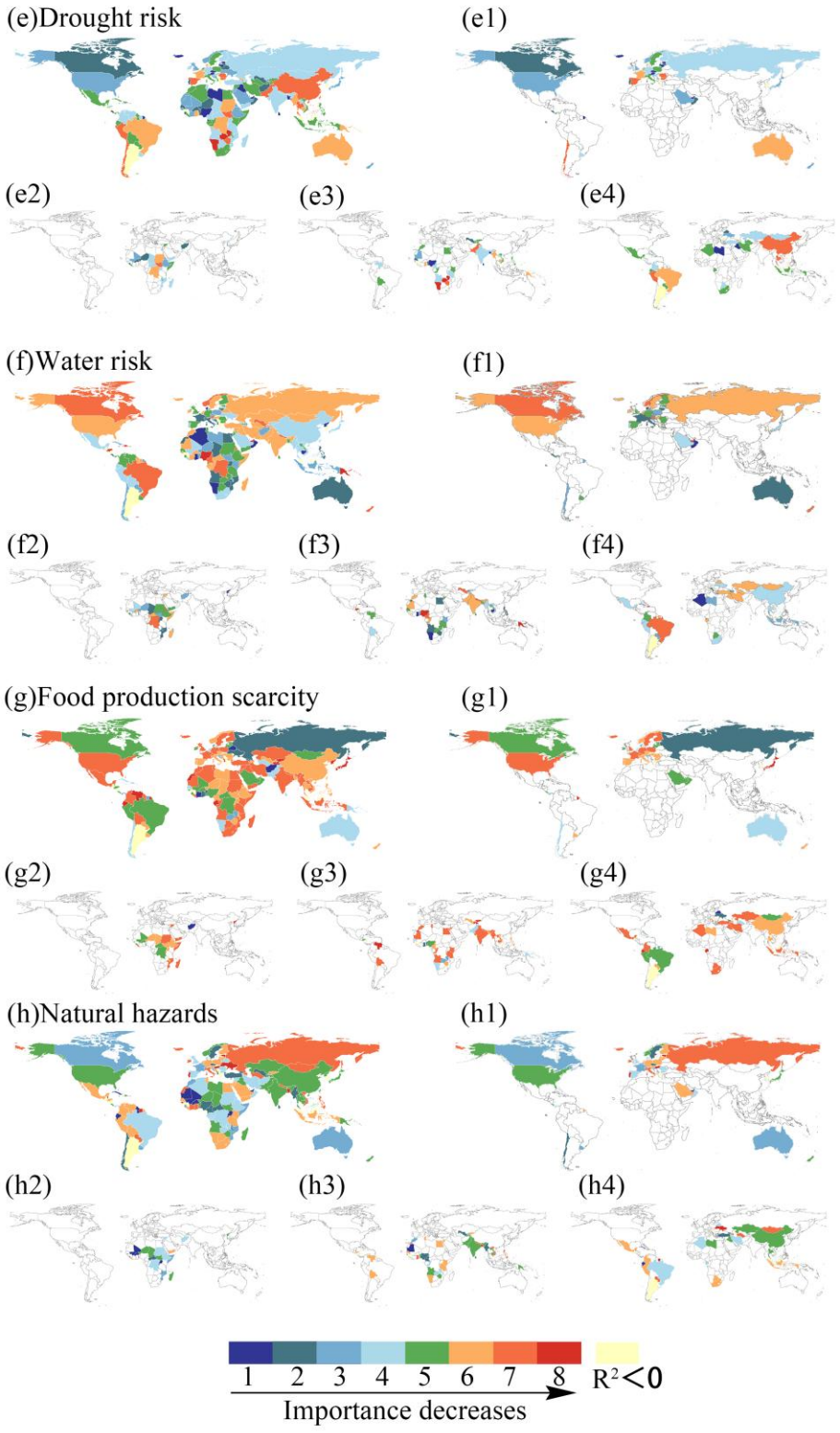

Figure 7. *The relative importance of each feature in explaining net negative migration was evaluated for 178 countries. The importance is quantified on a scale from 1 to 8 within each nation, where 1 signifies the highest importance and 8 the lowest. For each driver factor (a to h), categories 1 to 4 are defined as high-income, low-income, lower-middle-income, and upper-middle-income countries, respectively. Source: Niva et al. (2021)*

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The impact of climate change on the driving factors of population migration

Human migration is a complex and multifaceted process shaped by the interplay of economic, environmental, political, social, and demographic factors. These drivers seldom act independently; rather, they interact in complex, non-linear ways—often reinforcing or mitigating each other's effects (Czaika and Constantin, 2022). A nuanced understanding of how climate change shapes this intricate network is essential for accurately forecasting migration patterns and developing informed policy responses.

Climate change has increasingly emerged as a compounding driver of migration, rather than a standalone trigger (Renaud et al., 2011). Its impacts—rising temperatures, extreme weather events, sea-level rise, and shifting precipitation patterns—exacerbate existing vulnerabilities within economic and environmental systems. As a result, individuals and households are often compelled to migrate due to a confluence of factors, with climate-related stressors acting as catalysts (Burrows and Kinney, 2016). Empirical studies demonstrate that climate change frequently amplifies established migration patterns, such as permanent rural-to-urban migration and seasonal labor mobility. For example, rural communities in climate-sensitive regions may be forced to relocate due to declining agricultural productivity, diminishing freshwater resources, or an increasing frequency of extreme weather events.

Among all migration drivers, economic factors are most significantly influenced by climate change. Environmental shocks such as floods, droughts, and land degradation directly affect agricultural and fishing livelihoods, leading to income loss, food insecurity, and displacement. Rising temperatures and decreased rainfall reduce crop yields and increase drought risks. Cocoa and rice, as examples, are particularly climate-sensitive. Cocoa farmers face yield losses due to drought and pest outbreaks (Asante et al., 2017), while rice productivity declines under extreme heat (Lei et al., 2016; Manandhar et al., 2011). Fisheries and River Systems: Riverbank erosion, changing river flows, and declining fish stocks undermine the rural economy and lead to increased rural out-migration (Lam et al., 2016). Livelihood Diversification: In northern Ghana, farmers and pastoralists respond to climate variability by diversifying income through migration (Akinnagbe and Irohibe, 2014; Black et al., 2008). As environmental stress accumulates, migration becomes an essential risk management strategy. Rural households, facing deteriorating resource bases, often send members to cities or more prosperous regions to secure income and remittances.

Climate change-induced economic decline in rural areas is a key driver of urban-bound migration. Kaczan and Orgill-Meyer (2020) show that climate-related events indirectly affect wages and employment, prompting labor migration to urban centers. Beine and Parsons (2015) further demonstrate that natural disasters significantly increase short-distance migration to nearby urban areas. However, urban areas themselves are not immune. Sea-level rise and intensified tropical storms increase flood risks in coastal cities, threatening economic stability and employment opportunities (Hallegatte et al., 2013). Similarly, uncertainty about rainfall patterns can impair the functioning of hydroelectric infrastructure, impeding energy security and economic growth (Wasti et al., 2022).

While climate change significantly influences environmental and economic drivers of migration, its effects on political, social, and demographic factors remain ambiguous. Migration decisions driven by family ties, education, marriage, or health needs generally exhibit weaker associations with climate-related stressors. Migration typically

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results from the cumulative impact of multiple stressors rather than a single determinant, occurring when various push factors — such as unemployment, poverty, or environmental degradation — surpass a critical threshold. However, even strong push factors may not result in migration if pull factors (e.g., employment opportunities, security, social networks) are lacking or if barriers (e.g., high costs, limited information) are insurmountable (Urbanski, 2022), which highlights the nature of migration systems as complex adaptive systems characterized by non-linearity, feedback loops, and sensitivity (Sugihara et al., 2012). Migration is also shaped by demand for healthcare and other personal services (e.g., social care, domestic work), which are only weakly linked to climate change (Black et al., 2013). Conflict-induced displacement may be indirectly associated with climate stress, particularly when competition over scarce resources exacerbates tensions. Nevertheless, such causal links are highly context-dependent and often mediated by political institutions and the quality of governance.

Effective migration governance in the context of climate change necessitates a multidimensional and systemic approach. Policymakers should integrate climate risk assessments into development and migration planning; strengthen adaptive capacity in climate-vulnerable rural areas to minimize forced displacement; improve infrastructure and public services in urban destinations to accommodate incoming populations; and consider the interconnections among economic, environmental, and social drivers across origin, transit, and destination.

Discussion and conclusion

Discussion

Economic, social, demographic and environmental drivers are critical to understanding migration, but they are also subject to change, so there is uncertainty about the drivers of migration (Bijak and Czaika, 2020). Theoretically, sustained economic growth can attract more people to move in, while economic recession will encourage more people to move out, which can be well reflected in the International Migration Stock 2020: Destination and Origin. The level of urbanization may also lead to significant changes in internal migration patterns. As China's urbanization slows down, the number of people migrating from rural to urban areas decreases, and the sustainability of urban-rural migration is affected. Political drivers of migration can also shift substantially; for example, when a place becomes an economic zone, it attracts migrants. In Venezuela, millions of people have fled their homes as a result of major political, economic and social crises. As a result of ongoing wars, Ukraine and Syria have seen waves of migration. It is crucial to acknowledge that conflict can also result in individuals being trapped in areas of displacement, which renders the prediction and analysis of conflict-related migration particularly challenging. Uncertainties about demographic drivers include sharp declines in birth rates and population ageing. The combination of very low birth rates and population ageing in high- and middle-income countries, particularly in China, will present significant challenges for policymakers. Public health crises play an important role in influencing population movements and destinations. The COVID-19 has caused major interference to human migration, including actually preventing cross-border migration.

Different studies will draw completely opposite conclusions about the effects of climate change on population migration. The World Bank analysis highlights climate

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change as a major emerging driver of internal migration. Migration hotspots are expected to emerge as early as 2030 and intensify through mid-century (Rigaud et al., 2018). By 2050, Sub-Saharan Africa could account for as many as 86 million internal climate migrants, followed by East Asia and the Pacific (49 million), South Asia (40 million), North Africa (19 million), Latin America (17 million), and Eastern Europe and Central Asia (5 million). However, Mueller et al. (2020) demonstrated that climate change influences internal migration in highly heterogeneous ways across African countries, with some regions exhibiting inverse trends. Climate change also shapes international migration, as evidenced in Mexico, where higher temperatures are correlate with increased international outmigration, while rising precipitation is associated with reduced international outmigration (Nawrotzki et al., 2016; Zhu et al., 2024).

Projections of sea-level change (SLC)-induced population migration suggest large-scale migration from vulnerable coastlines. A study indicates that, even when potential adaptations are taken into account, complete SLC is projected to alter the population distribution. This could result in pressure being placed on inland areas that are not equipped to accommodate this influx of coastal migrants (Aerts, 2017; Hauer, 2017). Another study of population migration in Bangladesh, however, shows that until the end of the century, regardless of whether or not sea level change will exacerbate future flooding, under all emission scenarios, people will continue to migrate to vulnerable coastlines region (Bell et al., 2021). The fact is that similar triggers can result in contradictory mobility outcomes. For example, while in Vietnam's Mekong delta, those who are landless are more mobile in responding to environmental pressures, in Ecuador, the landless are less mobile (Ferris, 2020).

Global climate change may have a disruptive effect on the relative importance of the drivers of population migration. The impact of climate change on migration is non-linear, which means that migration under the influence of climate change has a tipping point, where adaptation fails and migration is the last option, at which point the relative importance of climate change or environmental drivers comes to the fore, possibly increasing dramatically from the previous 8% or 11% to become the most important. At the threshold, the impact of other drivers changes significantly and shows a time trend (Owen and Wesselbaum, 2020). Climate change drivers have risen to become the main drivers of migration in Nepal's low-lying frontier Terai region as locals seek to escape recurrent flooding, crop and livestock losses, and associated poverty due to increased variability in intra-annual river flows and increased flood risk (Bardsley and Hugo, 2010). More obvious examples of coastal inundation by sea level rise will force population migration, and climate change has become a major driver of population migration (Lincke and Hinkel, 2021).

However, the introduction of adaptation measures may have the exact opposite effect on migration patterns (Tacoli, 2009). The impacts of climate change on agriculture and fisheries can be mitigated by implementing adaptation measures, such as diversification (including the introduction of new crops with different labor requirements), intensification (including irrigation and industrialization), and other ways of reducing risk (e.g., through insurance schemes) by farmers in response to reduced rainfall. Adaptation policies can reduce the amount of internal migration driven by sea-level rise by a factor of 1.4 to 9, depending on the type of strategy adopted, and the implementation of hard-core conservation measures may even lead to migration to protected coastlines (Reimann et al., 2023).

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Conclusion

Climate change is a driver of population migration, with implications for other drivers of population migration. As global warming intensifies, the drivers of human migration are likely to change significantly. There are still gaps in our understanding of the underlying patterns and uncertainties around how climate change affects human migration and what will ultimately drive future population shifts.

First, the study of population migration involves the clarification of basic concepts, and this paper identifies the main concepts of population migration, including climate migration, displacement, and planned migration, which represent different forms and states of population migration. Climate migration focuses on the willingness to move actively, while displacement emphasizes forced displacement from one's home. The goal of planned migration is to strategically relocate and evacuate populations in order to shield them from the hazards of calamities and shifting environmental conditions. In addition, various types of population migration have been summarized, such as those related to environmental issues and climate change, those caused by sudden-onset disasters and gradual demographic changes, those that are temporary or permanent, those involving individuals, families and large groups, those that are forced or voluntary, those that are government-led or spontaneous for families, and those that are internal or international.

Secondly, the principal factors driving population migration can be broadly categorized as economic, social, political, demographic, environmental and individual characteristics. Additionally, intervening factors in population migration, such as policy factors that restrict and encourage migration, can be further categorized as transportation, distance, family and social networks. Population migration is mostly influenced by economic factors, people typically migrate from relative poverty to relative affluence. However, the poorest individuals may face difficulties due to lack of migration capital. The relationship between economic development and migration is non-linear. While economic factors are the most significant drivers of migration, the decision to migrate is influenced by a range of incentives and constraints. Consequently, economic factors alone cannot fully account for the complex motivations underlying migration. Population migration is influenced by social drivers, with education and the urbanization process playing an important role in migration. The structure of a population is not a determining factor in the migration of that population, the scale and direction of population mobility do not always shift from places with high population density to those with low population density. Policy drivers have a direct impact on population migration. Climate change-induced population movements deserve more attention because of the significant impacts of climate change on humankind. Decreasing sea ice cover, changes in water availability due to ice melt in mountainous regions, heavy rainfall and flooding, droughts, heat and heat waves, reduced crop productivity, more frequent hurricanes, and rising sea levels are all likely to act as climatic drivers of population movements. There is a correlation between global mean surface temperature and reported disaster events. From 2008 to 2022, there is an upward trend in global disaster events. Notably, floods, heavy rains, earthquakes and droughts have caused more displacement. This points to priorities and hotspots for research on disaster-induced displacement.

Third, an analysis of the relative importance of the drivers of migration was conducted. The results show that economic and social factors are the main drivers of migration, with environmental factors accounting for only a small proportion. However,

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this does not mean that environmental drivers are unimportant; the relative importance of each driver is constantly evolving and changing.

Fourth, climate change has a significant impact on the economic and environmental drivers of population migration, while its impact on the political, social and demographic drivers is not significant. Climate change can have an impact on crop and fishery production, altering farmers' and fishermen's livelihoods and, indirectly, the economic motivations of migration. Climate change may also promote migration through its impact on poverty and hydropower-based economic sectors. Climate change may also indirectly affect the economic drivers of population migration through its impact on economic activities in coastal areas due to rising sea levels and more frequent coastal storms. Indeed, there is also uncertainty about the drivers affecting population migration.

In the future, there is an urgent need to strengthen research on the theory and policy of population migration, and both countries of origin and destination need to manage migration strategically. At the same time, there is a need to integrate policies on migration under the impact of climate change into development strategies.

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Conflict of interests. The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interests.

Data availability. Dataset is based on publicly available data. Data can be shared to others subject to valid request.

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