Permanent Relocation Into and Out of Areas Exposed to Natural Hazards: a Multidisciplinary Review of the Literature

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Abstract

This article examines the long-term impacts of natural hazards caused by patterns of relocation into and out of hazard-exposed communities. We address two main questions: (1) what factors influence permanent relocation decisions in hazard-exposed communities? (2) What are the effects of relocation on the socio-economic and demographic characteristics of these communities? To answer these questions, we review studies on theoretical frameworks, empirical analyses, and simulation-based models. Relocation outcomes result from a complex interplay of household characteristics (e.g., wealth, risk perception, place attachment), community characteristics (e.g., economic opportunities, essential services), and government interventions (e.g., collective risk-reduction measures). The reviewed studies report mixed findings on demographic and socio-economic changes associated with permanent relocation. Large-scale analyses suggest that natural hazards have limited effects on pre-existing population trends, while more granular studies show that specific hazards—such as coastal flooding and sea level rise—can alter local dynamics. Effects on communities socio-economic characteristics also vary. Some communities experience post-hazard gentrification, while others face deepened vulnerabilities, with declining property values trapping residents in high-risk areas. We further review simulation-based models that examine hazard-related relocation and the socio-economic changes it can produce. These models often focus on specific aspects, such as individual decision-making, housing markets, or recovery patterns, without integrating all relevant factors. Finally, we identify key research gaps, including the need for more long-term studies on socio-economic changes in hazard-exposed communities, and greater focus on chronic, low-intensity hazards like tidal flooding.

1 Introduction

Residents of hazard-exposed areas typically respond to natural hazards in one of two ways: they either remain in place adapting to the risk, or relocate elsewhere. The decision to stay or to leave depends on a combination of aspirations (what they prefer) and capabilities (what they can afford) (de Haas, 2021). Figure 1 illustrates different ways in which responses to natural hazards can unfold. For example, residents of exposed areas may act individually by taking measures to reduce the vulnerability of their homes, or collectively by implementing community-wide initiatives, such as early warning systems. Likewise, relocation can be unmanaged, where individual households independently decide whether to leave, or managed, with government-led programs coordinating relocation efforts (e.g., neighborhood buyouts) (Weber & Moore, 2019).

In the context of hazard-induced relocation, it is important to distinguish between temporary and permanent relocation. According to Paul et al. (2024), natural hazards can trigger both evacuation and displacement, two forms of temporary relocation. Evacuation is typically a preemptive measure in which individuals leave the exposed area before or during the hazard. Displacement, on the other hand, involves longer durations and affects those whose homes or neighborhoods have been damaged, preventing an immediate return. The duration of displacement can range from a few days to several years, depending on the time needed to repair buildings, restore infrastructure, and reestablish essential services. Permanent relocation often takes place during the recovery period. For example, some displaced residents return to their homes, while others relocate elsewhere with the intent to remain long-term. At the same time, residents who were not displaced may also choose to leave, for instance due to concerns about future hazards. New residents, who were not living in the community before the hazard, may also move in. This population reshuffling, driven by permanent in- and out-relocation, can lead to significant socio-economic and demographic changes, including population growth or decline, gentrification, or increased impoverishment. This literature review focuses on unmanaged, permanent relocation, defined as residents' long-term movement into or out

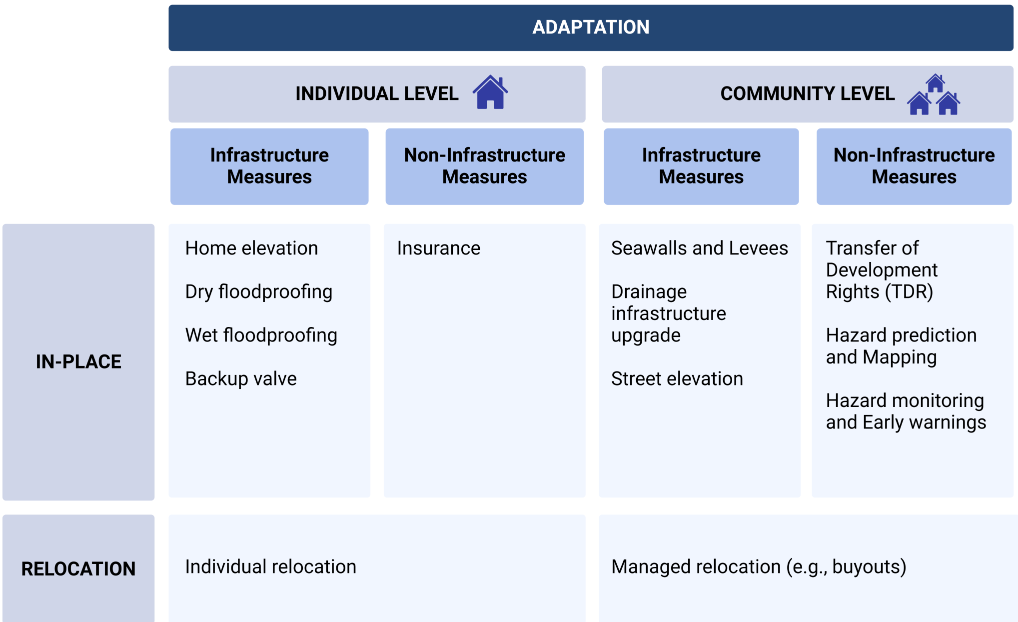

Figure 1. Common adaptation strategies for disaster risk management. Adaptation strategies are categorized by scale (individual-level and community-level) and type (infrastructural and non-infrastructural), with distinctions between in-place measures and relocation strategies. For illustrative purposes, the infrastructure adaptation measures listed here refer specifically to flooding, while this classification applies to any type of natural hazard. Created in BioRender. Malakun, A. (2025) https://BioRender.com/1z4sd7q

of hazard-exposed areas, without government coordination, and the socio-economic and demographic changes it produces in affected communities.

In this paper, we address two main questions using existing literature. The first question is the following: what are the factors that, together with natural hazards, influence patterns of relocation into and out of hazard-exposed communities? According to the reviewed literature, permanent relocation patterns are driven by several factors, including economic trends, political stability, social networks, environmental hazards, and resilience levels at both the origin and destination (Black et al., 2011). These drivers often interact and influence one another. As a result, relocation outcomes may vary significantly across individuals and communities, even when they are exposed to the same hazard. Our second question is what socio-economic and demographic changes can be caused by hazard-induced relocation. Both in- and out-relocation can result in significant changes within a community (van Holm & Wyczalkowski, 2019). For example, if the rate of permanent out-relocation exceeds in-relocation, the total population may reduce. Even if population size remains stable, differences in the characteristics of out-movers, remaining residents, and newcomers can alter the community's composition. For instance, if over time most out-movers are low-income and most newcomers are high-income, the community will become on average more affluent (Graff Zivin et al., 2023). In addressing these questions, we focused primarily on communities in developed economies. As explained in the following section, responses to natural hazards differ fundamentally between developed and developing economies, and covering both would have made our review excessively broad.

To answer our questions, we review studies on hazard-induced relocation from various disciplines, including sociology, economics, urban planning, geography, and engineering. Existing reviews have examined hazard-induced newcomers from specific disciplinary perspectives, providing a fragmented description of the phenomenon. For example, several authors have reviewed studies from the sociological subfield of environmental migration, which investigates migration outcomes in relation to environmental factors. These reviews consider a broad range of environmental factors, including catastrophic events, rising temperatures, and changing precipitation patterns. Reviews from this field focus on three main areas. First, some reviews examined theoretical frameworks from the broader field of migration studies and applied them to environmental migration research (de Sherbinin et al., 2022; Hunter et al., 2015; Piguet, 2018). They use frameworks such as the push and pull theory (Wolpert, 1966; Speare, 1974) and the new economics of labor migration (Stark & Bloom, 1985) to explain migration patterns driven by environmental factors. A second group of authors reviewed empirical evidence on how environmental factors influence migration (Almulhim et al., 2024; Daoust & Selby, 2024; Hoffmann et al., 2020; Kaczan & Orgill-Meyer, 2020; Millock, 2015). They summarized findings from studies that use data analysis or surveys to assess the effects of environmental factors on migration. Lastly, some reviews focused on the empirical methods most commonly used in environmental migration studies, such as spatial statistical analyses and survey-based approaches (Cipollina et al., 2024; Piguet, 2022). Most studies in the environmental migration literature focus on agriculture-dependent communities in developing economies. Moreover, they primarily examine how environmental factors can force out-migration (or immobility, as explained in the following section), without considering the long-term consequences of both in- and out-migration on exposed communities.

A separate body of reviews examined the effects of sea level rise (SLR) on relocation outcomes. For example, Duijndam et al. (2022) and Hauer et al. (2020) investigated the various ways SLR is prompting permanent out-relocation from exposed regions. They analyzed the effects of SLR on developed economies, developing economies, and atoll islands, highlighting their different responses to the hazard. These reviews focus exclusively on one type of natural hazard—SLR—and its influence on permanent out-relocation from exposed locations. Adopting a different perspective, Greer et al. (2019) and Paul et al. (2024) reviewed studies on household-level decisions to permanently relocate out of hazard-exposed communities. Their reviews provide a comprehensive overview of factors influencing permanent relocation outcomes, including place attachment, the extent of hazard-induced damage, and risk perception. Both reviews offer valuable insights on factors that influence permanent relocation out of exposed areas. However, they do not address relocation of new residents into hazard-affected areas or the demographic and socio-economic consequences of relocation patterns on hazard-exposed communities. Lastly, Noy and Iv (2018) and Arcaya et al. (2020) reviewed studies on the long-term consequences of catastrophic natural hazards, each with a distinct focus. Noy and Iv (2018) examined economic impacts, including effects on income, productivity, health, education, and demographic trends, framing all observed changes through an economic lens. Arcaya et al. (2020) reviewed the sociological literature, highlighting key conceptual distinctions within the field. For example, they emphasized the importance of differentiating between individual- and community-level recovery, and between short-term and long-term dynamics. Both reviews acknowledge relocation patterns as a factor shaping long-term post-hazard outcomes, but neither focuses specifically on hazard-induced relocation.

While each of these reviews examines hazard-induced relocation and its effects from a distinct perspective, our work complements these studies by adopting a broader point of view. Our approach considers multiple types of hazards, examines relocation both into and out of hazard-affected communities, and investigates the long-term effects of these relocation patterns on the affected communities. To identify relevant works, we employed a snowball sampling approach (Wohlin, 2014), expanding the pool through references in each reviewed study that addressed our two research questions. We reviewed 141 works, including 125 scientific papers, 6 technical reports, 1 dissertation, 4 book chapters, and 5 news articles. Among the scientific papers, most analyze empirical data, either from publicly available sources (e.g., property sales data) or from surveys conducted specifically for the study. Some articles present theoretical frameworks that help interpret empirical findings, while others develop mathematical models and use computer simulations to explain underlying mechanisms. To guide the reader through this comprehensive literature review, Figure 2 outlines its main sections and illustrates how they are interconnected. First, we provide an overview of the field of environmental migration, contextualizing the role of environmental stressors within the broader scope of migration studies. This section highlights how multiple factors influence hazard-induced migration and how communities with different characteristics can experience varying migration outcomes even when exposed to the same hazard. Building on these insights, the following two sections examine the factors that interact with natural hazards in shaping relocation patterns, and the varying long-term effects of hazard-induced relocation across communities with different characteristics. The final section focuses on existing mathematical models that simulate interactions between natural hazards, the built environment, and human communities. For each model, we assess the influencing factors considered and the long-term effects they reproduce, highlighting potential combinations of different models to obtain more comprehensive results. Finally, we summarize the key findings from the reviewed literature, identify major knowledge gaps, and suggest areas for future research.

2 Environmental Migration

To investigate relocation patterns in areas exposed to natural hazards, we began by reviewing the literature on environmental migration. Environmental migration research examines how environmental factors—such as natural hazards, climate change, and ecosystem shifts—affect long-term migration of human communities. It draws on theoretical frameworks from the broader field of migration studies (e.g., push and pull theory, new economics of labor migration) to interpret migration outcomes in relation to environmental drivers (de Sherbinin et al., 2022; Piguet, 2018). Daoust and Selby (2024) and Gutmann

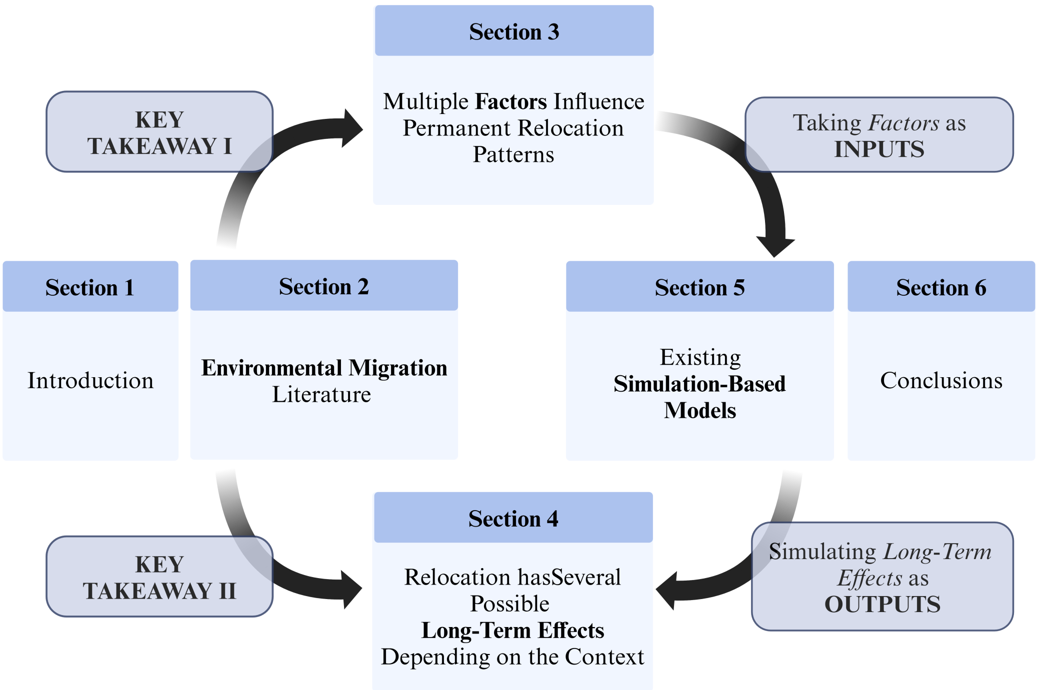

Figure 2. Outline of this literature review. Research on environmental migration (Section 2) highlights two key points: relocation patterns are influenced by multiple interconnected factors, including natural hazards (Section 3), and these factors have varying effects depending on the specific context (Section 4). Several simulation-based models integrate these factors to capture their diverse effects (Section 5). Created in BioRender. Malakun, A. (2025) https://BioRender.com/1z4sd7q

and Field (2010) classified environmental drivers into four categories: environmental calamities (sudden, destructive hazards like cyclones and tornadoes), environmental hardships and benefits (slow-onset phenomena such as droughts and tidal flooding, as well as temporary climatic variations favorable to agriculture), environmental amenities (such as favorable weather or proximity to water and mountains), and environmental barriers and their management (technology and infrastructure that help humans adapt to unfavorable environments, such as air conditioning, flood control, and irrigation systems). In this review, we primarily investigates the effects on migration of environmental calamities and hardships, here referred to as natural hazards[1]. However, as it will become evident in the following sections, all four categories are interconnected and must be considered together.

The main takeaway from the field of environmental migration is that environmental drivers influence migration in conjunction with other factors (Black et al., 2011; Hoffmann et al., 2020; Hunter et al., 2015). For example, Black et al. (2011) differentiates between macro-scale factors, such as macroeconomic and environmental conditions, and micro-scale factors, such as a household's financial capacity. These drivers—they explain—interact among each other in shaping migration outcomes. For instance, natural hazards may force a large factory to permanently shut down, reducing employment opportunities and prompting out-migration. The fact that migration results from multiple, interconnected factors has an important implication: the effects of natural hazards on migration are highly context-dependent. Communities with different socio-economic, environmental, and institutional characteristics can experience vastly different migration outcomes, even when exposed to the same environmental drivers. For example, Chen and Rosenthal (2008) and Graves (1979) investigated the relative influence of different migration drivers across demographic groups in the US. They found that younger individuals primarily migrate for economic opportunities, while older populations are more drawn to natural amenities. Moreover, several studies have shown that natural hazards have a stronger impact on agriculture-dependent communities, as damage to agriculture directly affects their local economies (Bohra-Mishra et al., 2014; Cipollina et al., 2024; Dragomir, 2021; Piguet, 2022). For example, Dragomir (2021) examined how slow-onset environmental changes disrupt agriculture-based livelihoods in South India, driving out-migration in search of alternative economic opportunities. This effect is particularly pronounced in developing economies, where subsistence farming is common, compared to market economies where widespread insurance may mitigate risks. Research on internal migration in the US supports this contrast between developed and developing economies: in the early 20^{th} century, when subsistence agriculture was widespread, environmental hardships were a major driver of out-migration. However, as the economy developed and populations became more affluent, environmental hardships had little influence on migration, while environmental amenities began attracting residents to high-amenity areas (Gutmann & Field, 2010). Given these differences in responses to natural hazards between developed and developing economies, we chose to focus our review on the former. Therefore, most of the studies examined in the following sections are based on developed economies, such as the contemporary US.

Another key takeaway from the environmental migration literature, further illustrating how environmental migration is context-dependent, is that natural hazards can simultaneously drive out-migration and cause immobility. Schewel (2020) and Zickgraf (2021) frame this duality through different theoretical frameworks, including the aspirations-capabilities framework (de Haas, 2021). According to this framework, natural hazards, in conjunction with other factors, can shape both the aspiration to out-migrate and the

[1] In this review, we adopt a broader perspective on natural hazards, including geophysical events such as earthquakes and tsunamis, which, while not classified as environmental hazards in strict scientific terms, pose similar risks to human communities as events like flooding and tornadoes.

capability to do so, potentially leading to either forced migration or forced immobility. For example, a homeowner in a high-demand neighborhood may lack the resources to rebuild after a flood, but still be able to sell their property at a high price and relocate to a more affordable area. Even if they would have preferred to stay put, out-migration becomes their most practical choice—a form of forced migration (Piguet, 2018). Conversely, a resident in a low-value housing market may experience severe flood damage that depletes their savings, while their property is not valuable enough to finance relocation. In such cases, despite wanting to leave, financial barriers prevent out-migration, a situation commonly described as poverty trap. Empirical findings confirm the dual outcome of forced migration or immobility for similar levels of exposure to natural hazards. For example, Letta et al. (2024) analyzed household-level responses to environmental stressors in Nigeria, finding that households with greater resources are more likely to out-migrate. However, the relationship between wealth and out-migration is not always the same. As discussed in the following section, wealthier households may also be more likely to stay, as they have better financial means to face hazard-related damages.

In summary, two key insights emerge from the environmental migration literature. First, migration in hazard-exposed communities is shaped by a complex interplay of factors, with natural hazards being just one of them. Second, this interplay makes migration outcomes highly context-dependent, varying across communities with different socio-economic, environmental, and institutional characteristics. The common assumption that exposure to natural hazards inevitably leads to permanent out-migration oversimplifies this complexity. In the following sections, we first analyze the most relevant factors that, in conjunction with natural hazards, can influence permanent relocation. We then examine what are the long-term effects of hazard-induced relocation in communities with varying characteristics, focusing on changes in population size and socio-economic composition.

3 Factors Influencing Relocation Patterns in Hazard-Exposed Communities

Natural hazards interact with several other factors to shape relocation patterns. We classified these factors into four main categories (Table 1). First, different types of natural hazards influence relocation in different ways, depending on their characteristics, such as their intensity and frequency. Second, relocation patterns depend on household-level characteristics, such as risk perceptions, and community-level characteristics, such as macro-economic conditions. Lastly, policies and government intervention can also influence relocation outcomes in conjunction with natural hazards.

3.1 Hazard Characteristics

3.1.1 Hazard Frequency and Intensity

Natural hazards vary in their characteristics, leading to different relocation outcomes. The first distinction that emerges from the literature is between high-intensity, rare events and low-intensity, high-frequency ones. Examples of high-intensity, rare events are earthquakes, storm surges, and tornadoes, while examples of low-intensity, chronic hazards are tidal flooding and seasonal heatwaves. This distinction is especially relevant for coastal flooding, where some communities may only face intense but rare storm surges, while others additionally experience frequent, lower-intensity tidal flooding. Tidal flooding is a type of coastal flooding driven by elevated sea levels due to offshore winds and lunar effects (Gold et al., 2023). As sea levels rise, they can directly submerge parts of urbanized land or indirectly prevent stormwater drainage systems from discharging rainwater into the sea, leading to the accumulation of rainwater on land. This form of flooding results in frequent, persistent flood events affecting low-lying coastal areas. Tidal flooding is usually less intense than storm surges, and its frequent occurrence often prompts

Hazard Characteristics	**Household Characteristics**	**Community Characteristics**	**Policies and Government**
Hazard frequency and intensity Availability and feasibility of in-place risk reduction measures Hazard spatial predictability	Physical damages and financial capacity Place attachment and social networks Risk perception Housing tenure and housing type Demographic characteristics	Essential services and infrastructure Job opportunities Anchors of social networks Natural characteristics	In-place adaptation measures Buyouts Post-Hazard Economic Assistance

Table 1. Factors influencing permanent relocation into and out of hazard-exposed communities.

communities to undertake in-place adaptation measures. However, tidal flooding can still cause severe disruptions that might prompt relocation, as illustrated in The Washington Post report on Carolina Beach, a coastal town in North Carolina, US (Dennis et al., 2024). The article reports that one of the town's main roads experienced flooding 60 times over the past year, making some residents unable to leave their homes for several hours at a time. Tidal flooding is closely linked to SLR, which increases the frequency of flooding events. Over time, rising sea levels can intensify tidal flooding to the extent that some areas of land may become uninhabitable. L. Perch-Nielsen et al. (2008) compared the impacts of rare, severe flooding with those induced by SLR and tidal flooding. In their review of case studies, they explored the direct and indirect effects of these hazards, along with available adaptation strategies (among which out-relocation is one of the options). They conclude that tidal flooding due to SLR, through progressive land loss, is more likely to drive long-term out-relocation than intense but infrequent flood events.

3.1.2 Availability and Feasibility of In-Place Risk Reduction Measures

The specific characteristics of natural hazards also determine the type and feasibility of adaptation measures needed to reduce risk. Some hazards allow for relatively inexpensive risk-reduction measures, while others require costly and prolonged interventions that may be unaffordable for many households. Aerts (2018) provides a review of in-place risk-reduction measures for flooding. As shown in Table 2, house-level risk-reduction costs can vary widely, from a few thousand to several hundred thousand US dollars. Areas exposed to different types or intensities of flooding may require distinct risk-reduction strategies, resulting in varying financial burdens for homeowners. For instance, a building at risk of sewer backup due to heavy rainfall can be protected by installing a backflow prevention valve in the sanitary piping (Sandink & Binns, 2021), a relatively low-cost intervention. In contrast, a house in a floodplain may need to be elevated to meet building code requirements, a complex and expensive process (Aerts, 2018). Beyond direct costs, the complexity of different adaptation measures also varies. Some measures can be completed while occupants remain in their homes or require only short-term displacement (e.g., days or a few weeks), while others necessitate prolonged relocation (e.g., up to a few months), adding the financial and emotional burden of securing temporary housing. The costs, complexity, and duration of risk-reduction works can make in-place adaptation unaffordable for some households, increasing the likelihood of out-relocation.

3.1.3 Hazard Spatial Predictability

Another hazard characteristic affecting long-term impacts on relocation patterns is spatial predictability. For instance, storm surge flooding in the US is typically expected in coastal regions prone to hurricanes, such as the Atlantic and Gulf coasts. Tornadoes, on the other hand, are common in the so-called Tornado Alley. Within these large areas, spatial boundaries of storm surge flooding can be predicted relatively accurately, as they depend on well-known factors like topography. Conversely, the spatial occurrence of tornadoes within the Tornado Alley is far less predictable. Thus, some hazards are more spatially predictable than others. The relevance of spatial predictability for relocation patterns is identified in a study by Indaco and Ortega (2024). In their analysis, they compared US Census tracts within commuting zones and found that tracts with a high frequency of coastal flooding experienced considerably less population growth than neighboring tracts. When applying the same analysis to other types of hazards, they did not observe this trend. The authors suggest that residents in areas with spatially predictable hazards, like coastal flooding, can opt to live in safer locations while still enjoying the region's broader appeal. In contrast, in regions exposed to less spatially-predictable hazards, such as tornadoes, identifying safer areas within a commuting zone is not possible. Interestingly, this reduced population growth was only observed in regions exposed to coastal flooding, but not to fluvial flooding. One possible explanation is that coastal areas, in general, attract more residents than inland areas (Neumann et al., 2015). As a result, differences in population growth rates between high-risk and low-risk tracts may be more noticeable in coastal regions, where overall population growth tends to be higher. The study by Boustan et al. (2020) further confirmed that different types of hazards affect relocation patterns in different ways. By analyzing net relocation patterns in US counties from 1980 to 2010, the authors found that severe floods are linked to higher out-relocation, while severe tornadoes show no significant impact on relocation patterns.

3.2 Household-level Characteristics

Household-level characteristics play an important role in shaping relocation outcomes following a natural hazard. For example, some residents may be forced to leave due to financial constraints or extensive damage, while others may remain due to strong community ties or limited relocation options. The literature reviews by Greer et al. (2019) and Paul et al. (2024) examine the characteristics of residents in hazard-exposed communities that shape out-relocation outcomes. Here, we build on their findings by incorporating insights from additional studies.

3.2.1 Physical Damage and Financial Capacity

According to both Greer et al. (2019) and Paul et al. (2024), one of the primary factors influencing out-relocation after a destructive natural hazard is the extent of physical damage experienced by the individual households. Generally, households that suffer greater damage are more likely to permanently relocate (Bukvic et al., 2015; Mayer et al., 2020). Paul et al. (2024) explained that severe damage often leads to longer recovery times, extending the period of dislocation, which increases the likelihood of permanent relocation. Additionally, higher levels of damage require substantial economic resources for repairs or reconstruction. Greer et al. (2019) emphasized that the relationship between damage and out-relocation is closely tied to a household's financial capacity, including access to insurance, external aid, private credit, and personal savings. For example, Nejat and Ghosh (2016) surveyed residents heavily affected by Hurricane Sandy and found that access to home insurance and financial assistance from government and

Table 2. Summary of house-level, structural flood adaptation measures from Aerts (2018). Cost estimates are primarily derived from case studies in the US, UK, and Germany, converted to 2016 US dollars using inflation-adjusted consumer price indices. The reported cost ranges represent the minimum and maximum values found in the literature, reflecting variations due to building type, material costs, labor rates, and regulatory requirements. Duration and necessity to vacate during works are not directly reported in the article, but are inferred based on the description of the necessary works and on the engineering judgment of the authors.

Adaptation Measure (1)	Description of Works (2)	Cost (USD, 2016) (3)	Duration (4)	Need to Vacate (5)
Elevation (Average Building)	Lifting the structure above flood level, modifying the foundation, adjusting plumbing/electrical systems.	\$19,481–194,496 per building (US)	Weeks to months, depending on elevation height and complexity.	Yes (home is lifted, utilities are disconnected).
Dry Flood-Proofing (+0.6m)	Sealing walls, installing waterproof coatings, using removable flood shields for openings.	\$9,298–15,354 per building (US, UK)	Days to a few weeks, depending on material application and size of building.	No (minimal disruption, unless extensive work required).
Dry Flood-Proofing (+2m)	Similar to +0.6m, but with stronger barriers and reinforcements to withstand higher water pressure.	\$14,105–36,695 per building (US)	Weeks, depending on complexity and structure type.	Possibly (if major modifications are required).
Wet Flood-Proofing (Basement, +0.6–2.7m)	Applying waterproof sealants, sump pumps, drainage improvements, raising utilities above flood level.	\$35–206 per m^2 (US, Germany)	Days to a few weeks, depending on basement size and waterproofing method.	No (unless major excavation or retrofitting needed).
Wet Flood-Proofing (Residential, +0.6m)	Raising electrical sockets, using water-resistant materials, modifying interior walls and floors.	\$2,412–5,461 per building (US, UK)	Days to weeks, depending on extent of retrofitting.	No (can be done with minimal disruption).
Wet Flood-Proofing (Residential, +2.7m)	More extensive retrofitting including raising appliances, sealing walls, and modifying floor levels.	\$9,561–21,655 per building (US, UK)	Weeks, as more structural modifications are needed.	Possibly (depending on structural changes).

charitable sources were among the strongest predictors of remaining in place rather than relocating. However, the relationship between a household's economic status (income and wealth) and out-relocation is complex. On one hand, households with fewer economic resources may struggle to finance repairs, increasing the likelihood of relocation (Paul et al., 2024). On the other hand, limited financial capacity can also constrain relocation opportunities, as households may lack access to credit to purchase a new home or sufficient income to afford alternative housing. As a result, some households may remain in damaged homes despite wanting to leave. In general, we can conclude that residents with greater financial resources tend to have greater capabilities when deciding whether to relocate or remain.

3.2.2 Place Attachment and Social Connections

Place attachment is another factor influencing out-relocation. It refers to the emotional and functional bond individuals form with their communities and has two key dimensions: place identity, which reflects how a community shapes an individual's sense of self, and place dependence, which describes how well the community fulfills practical, everyday needs. Both Greer et al. (2019) and Paul et al. (2024) highlighted the role of place attachment in reducing out-relocation among residents of hazard-exposed communities. Closely related to place attachment are social connections. Both Greer et al. (2019) and Paul et al. (2024) found evidence that social connections influence out-relocation decisions. Connections among family members, neighbors, or community organizations foster a sense of belonging and mutual support, which can lower the likelihood of permanent relocation out of hazard-affected communities (Henry, 2013; Fraser et al., 2003; Myers et al., 2008; Nejat et al., 2016). Interestingly, Greer et al. (2019) noted that extensive damage to the built environment can reduce place attachment. For instance, if a hazard results in widespread destruction and the rebuilt environment differs significantly from its pre-hazard state, some residents may feel disconnected and become more likely to relocate.

3.2.3 Risk Perception

Risk perception is another factor influencing relocation in hazard-exposed communities. Both Greer et al. (2019) and Paul et al. (2024) found that high risk perception contributes to permanent out-relocation. However, they noted that its significance relative to other factors remains under-explored. Bakkensen and Barrage (2022) surveyed households in Rhode Island, US, including residents of flood-exposed areas and residents of regions not exposed to flooding (for residents of non-exposed areas, participants were asked to imagine living in a flood-prone community). The study found that (1) residents of flood-exposed communities were less concerned about flood risk compared to their non-exposed counterparts, and (2) residents of exposed areas with higher concerns about future flood risk were more likely to consider out-relocation in the near future. In line with Bakkensen and Barrage (2022), Tonn and Guikema (2018) also found that risk perception is strongly influenced by past hazard experience. Generally, individuals who have experienced a hazard in the past exhibit higher concerns about future risks. Moreover, Tonn and Guikema (2018) additionally found that near-misses—instances where individuals narrowly avoid the impact of a hazard—can sometimes reduce risk perception. Residents spared by the hazard may gain confidence that they will continue to be unaffected in the future.

3.2.4 Housing Tenure and Housing Type

Two additional factors influencing out-relocation outcomes are housing tenure (owning vs. renting) and housing type (e.g., detached single-family vs. multifamily buildings). Regarding housing tenure, the literature consistently shows that homeowners are, on average, less likely to out-relocate after a destructive hazard compared to renters (Lee & Van Zandt, 2019). Paul et al. (2024) identified several reasons for this: first, homeowners are more likely to have developed stronger place attachment, as noted by Nejat et al. (2018); second, they often have financial obligations tied to their property, such as active mortgages; and third, government reconstruction aid has historically favored homeowners in resource allocation for repairs (Dickinson et al., 2023). For housing type, Paul et al. (2024) suggested that owners of detached single-family homes generally have greater control over repairs and investments compared to owners of units in multifamily buildings. Limited control over the repair process in multifamily housing can result in prolonged recovery times, which, in turn, increases the likelihood of out-relocation.

3.2.5 Demographics

The effects of demographic characteristics, such as age, education level, and family status, are nuanced and often underexplored. Greer et al. (2019) reviewed findings from a limited number of studies on these characteristics, noting mixed and sometimes contradictory results. Moreover, demographic characteristics can indirectly influence relocation outcomes by shaping how individuals prioritize factors like economic concerns, infrastructure, and community ties. For instance, Nejat et al. (2018), in a survey of 780 Oklahoma households conducted two years after they were impacted by an EF5 tornado, found that older adults were more likely to prioritize economic factors like debt and insurance, whereas middle-aged respondents placed greater emphasis on infrastructure, public safety and availability of essential services (e.g., schools).

3.3 Community-level Characteristics

Community characteristics are also critical in shaping relocation patterns in hazard-affected areas. Community factors such as infrastructure, services, job availability, and social networks, can influence both out-relocation and the ability to attract new residents. In this section, we examine the community characteristics that have more influence on relocation patterns.

3.3.1 Infrastructure, Essential Services, and Job Availability

The recovery of infrastructure (e.g., lifelines and streets) and essential services (e.g., groceries and schools) disrupted by a hazard is widely recognized in the literature as critical for community recovery (Paul et al., 2024; Chang et al., 2008). Utility outages, such as water and power, can displace residents even when houses are structurally habitable (Chang et al., 2008). Failure to restore infrastructure can lead to prolonged displacement and prevent displaced residents from returning, thereby increasing the likelihood of permanent out-relocation. Restoring essential services is also important in preventing prolonged displacement. For example, (Burchfield, 2016) examined the case of Cordova, a small town in Alabama (US) that was struck by two tornadoes on the same day in 2011, resulting in the loss of most of its buildings and infrastructure. The town allocated public resources to quickly reopen and maintain its only grocery store, even though depopulation caused by widespread displacement had made the business financially unfeasible. Officials viewed the reopening as a crucial incentive for residents to remain in Cordova and rebuild rather than relocate to another town. Similarly, job availability is a significant factor influencing relocation patterns after a destructive natural hazard and throughout the recovery phase (Kim & Oh, 2014; Landry et al., 2007; Wang et al., 2025). Analyses from these studies suggest that job losses caused by hazards can drive permanent out-relocation among current residents. Interestingly, Elliott (2015) also found that destructive natural hazards activate also flows of in-relocation. They refuted a previous hypothesis suggesting that these in-migrants are primarily driven by reconstruction-related jobs, such as construction work (Pais & Elliott, 2008). Instead, they found that in-migrants of different ethnicities typically joined job sectors their ethnic group already occupied before the disaster.

The influence of infrastructure, services, and jobs on permanent relocation extends beyond the disruption caused by natural hazards. They are considered amenities that generally attract residents to communities. In hazard-affected communities, such amenities play a critical role in long-term recovery by helping retain current residents and attracting new ones. For example, Cross (2014) studied US communities where over 50% of structures were destroyed by a natural hazard. This study found that 50% of communities without an elementary school experienced a population decline of more than one-third in the decade following the hazard, compared to only 20% of communities with an elementary school. The presence of elementary schools seems a key predictor of long-term community stability, as communities with a higher proportion of residents in their thirties and forties——those likely to have young children——tend to show greater growth potential (Rosenthal, 2008). For these families, access to an elementary school represents a strong attractor. The importance of schools in long-term recovery is further supported by C. G. Burton (2015), who found a positive, statistically significant correlation between the presence of schools and recovery outcomes in Mississippi Gulf Coast communities (US) five years after Hurricane Katrina. Notably, Cross (2014) examined whether also county courthouses help retain residents, for instance by acting as economic anchors through employee salaries, local spending, and service procurement. However, no significant correlation was found between the presence of a courthouse and post-hazard population trends.

Another example of the importance of services and infrastructure in attracting residents is Paradise, California (US), which was razed by the 2018 Camp Fire (Mauhay-Moore, 2024). Almost 90% of the town's residents were displaced by the disaster. However, since 2020, its population has grown steadily, recently making it the fastest-growing town in California and bringing it back to nearly half of its pre-fire level (of Finance, 2024). To strengthen its appeal and draw new residents, Paradise is undertaking several major infrastructure projects, including installing high-speed internet to attract remote workers and constructing a sewage pipeline to replace individual septic systems. The town also plans to develop a walkable downtown area, which local officials envision as the centerpiece of its recovery efforts. Lastly, Cross (2014) found that communities within 25 kilometers of a metropolitan area were more likely to gain population in the decade following a natural hazard, while those over 100 kilometers away were more likely to experience population decline. This pattern confirms the role of essential services, infrastructure, and employment opportunities in shaping relocation patterns, as metropolitan areas generally offer a greater variety of them.

3.3.2 Anchors of Social Networks

Certain types of services, such as art and community centers, places of worship, and social advocacy organizations, can strengthen social networks through community involvement, thereby increasing place attachment. These services also provide critical support during periods of hardship, enhancing community resilience. For example, C. G. Burton (2015) found a positive, statistically significant correlation between the presence of these services and recovery outcomes in Mississippi Gulf Coast communities (US), based on five years of data following Hurricane Katrina. Similarly, Airriess et al. (2008) documented how the Mary Queen of Vietnam Church in New Orleans (US) mobilized social capital and networks to enhance the recovery of its community. Finally, Nejat et al. (2019) provides a range of services identified in the literature that strengthen social connections and support recovery, referring to them as “Anchors of Social Network”.

3.3.3 Natural Characteristics

Some favorable natural characteristics can also attract residents and influence in-relocationn while, at the same time, be associated with increased exposure to natural hazards. A well-known example of the intersection between favorable natural characteristics and higher exposure to natural hazards is proximity to water, which increases exposure to flooding. Research on housing prices has consistently shown that homes closer to water bodies are typically more expensive than comparable properties located more inland (Jin et al., 2015). This price premium reflects higher demand from buyers seeking the natural amenity of waterfront living. The appeal of proximity to water extends beyond its aesthetic and recreational value. Access to rivers, lakes, and oceans promotes trade and productivity, attracting businesses and generating economic opportunities for residents (Rappaport & Sachs, 2003; Neumann et al., 2015). Similarly, the US population has grown significantly in the wildland-urban interface (WUI), a transitional zone between developed areas and natural landscapes that are often prone to wildfires. Rao et al. (2022) and Radeloff et al. (2018) found that the population in WUI areas roughly doubled between 1990 and 2010. The reasons for this growth in WUI regions are not yet fully understood. However, hypotheses suggest that these areas are attractive because of their affordability, access to natural settings, and recreational opportunities (Radeloff et al., 2018). Despite the occurrence of a wildfire potentially decreasing the natural attractiveness of WUI areas, studies in the national forests surrounding the Los Angeles metropolitan area have found that this decrease is only temporary (Garnache & Lupi, 2018).

3.4 Policies and Government Intervention

3.4.1 In-Place Adaptation Measures

The implementation of in-place adaptation measures can also affect relocation. First, government investments in risk reduction and preparedness, such as improved infrastructure and the organization of preparedness procedures, can enhance community resilience and make communities more attractive. For example, research on coastal property values in Massachusetts found that homes located behind seawalls experienced a 10% increase in value compared to otherwise similar properties, suggesting that protective infrastructure can make hazard-prone areas more desirable (Jin et al., 2015). Similarly, a Washington Post analysis suggests that even high-risk areas can attract residents if they implement adaptation measures that reduce risk and increase resilience (Coren et al., 2024). However, the increased attractiveness of hazard-prone areas due to risk-reduction measures can sometimes have negative consequences, such as the safe development paradox. The safe development paradox occurs when adaptation measures reduce perceived risk, encouraging development in hazard-prone areas and simultaneously lessening preparedness. The safe development paradox heightens exposure and amplifies potential losses during extremely rare events that exceed the protection level. One example is the Netherlands, where extensive development occurred in floodplains following the implementation of the Deltaworks flood protection program (Husby et al., 2014). When associated with flooding, this phenomenon is sometimes referred to as the "levee effect". Fusinato et al. (2024) provides a comprehensive review of studies investigating the safe development paradox and presents substantial evidence supporting its occurrence. The safe development paradox is also linked to non-infarstructure adaptation measures, such as insurance. A vast body of literature explores the various effects of insurance on hazard-exposed communities, which lies beyond the scope of this review. Here, we highlight only one relevant aspect: in some cases, insurance premiums may not fully reflect actual future risk, for instance when subsidized by the government. When premiums do not reflect true risk, they can incentivize risky behaviors or discourage additional protection, such as retrofitting buildings to reduce risk, thereby perpetuating the safe development paradox (Liu et al., 2024).

The second interaction between in-place adaptation measures and relocation patterns occurs when requirements to implement adaptation measures force out-relocation of existing residents. When such measures become mandatory—–often as part of reconstruction efforts following a destructive event—–their high costs can compel some homeowners to leave. For example, FEMA's Title 44 (FEMA, 2025) outlines the requirements for properties in flood-prone areas to meet specific elevation standards. The regulation mandates that homes within Special Flood Hazard Areas (SFHA) that sustain damage exceeding 50% of their pre-flood market value must be retrofitted to comply with elevation requirements. Noncompliance prevents homeowners from obtaining the construction permits needed to lawfully carry out repairs. Barber (2024), reporting in The New York Times, highlighted the case of Pittsburg, Florida, a community highly exposed to hurricane-induced storm surge. The article describes how several residents, unable to afford the mandatory home elevations after suffering damages from Hurricane Helene in 2024, are being forced to sell their homes. McCall et al. (2024) interviewed residents of Plaquemines Parish, Louisiana (US), a low-lying area highly exposed to flood risks. Their findings indicate that FEMA requirements to elevate flood-damaged homes risk causing significant out-relocation, as most residents cannot afford to elevate their houses. The primary barrier to compliance is financial, but other challenges include the high proportion of residents living in mobile homes and trailers, which are difficult to elevate without compromising their mobility. Additionally, home elevation creates physical accessibility issues for older and disabled individuals. The study also highlights how residents unable to meet elevation requirements may struggle to sell their properties. Federally backed mortgages require flood insurance, and premiums for non-elevated properties can be prohibitively expensive. Consequently, residents attempting to sell non-compliant properties may face a significantly reduced pool of potential buyers. Rising flood insurance costs can simultaneously force current residents to leave and hinder their ability to extract equity by selling their homes. This finding underscores how both infrastructure measures, such as home elevation, and non-infrastructure measures, such as flood insurance, can impact relocation patterns. Similar requirements also apply to other types of hazards. For example, in wildfire-prone areas, California Chapter 7A Building Code (California Department of Housing and Community Development, 2010) mandates the use of fire-resistant materials for roofing, siding, and decking in new construction and significant renovations. However, the effects of such mandatory measures on relocation remain underexplored in the literature.

3.4.2 Buyouts

Buyouts—–the voluntary or mandatory purchase of properties in hazard-prone areas by the government—–are a common policy tool for reducing long-term risk, particularly for flooding (New York City Build It Back Program, 2018). In some cases, buyout programs prohibit reconstruction on acquired land and require its conversion into open space. In other instances, properties are sold back to developers with the requirement to implement stricter risk-reduction measures, such as increasing base floor elevations. Buyouts can be implemented at various scales, ranging from individual properties to entire neighborhoods or communities. The impact of buyouts on neighboring properties is mixed. On one hand, converting acquired land into parks or well-maintained open spaces can enhance community desirability(Pierce Holloway & BenDor, 2023). On the other hand, large-scale buyouts may signal high risk to potential home-buyers, disrupt social cohesion, and reduce overall community appeal (Binder et al., 2020; Hashida & Dundas, 2023). The reviewed studies highlight the importance of a clear strategy for repurposing acquired land, along with transparent communication with the public, to minimize negative effects on neighboring properties. Uncertainty about the future use of bought-out land can increase stress among remaining residents, prompting further out-relocation, and deterring potential new residents from relocating into the neighborhood.

3.4.3 Post-hazard Economic Assistance

Finally, we address the effects of post-hazard assistance, which can be classified into two main categories: aid for recovery, such as repair assistance for homeowners and temporary living support for displaced individuals, and economic stimuli. The effects of aid for recovery in retaining residents and reducing out-relocation were discussed in the previous section (Nejat & Ghosh, 2016). Regarding economic stimuli, Pais and Elliott (2008) noted that after a destructive natural hazard in the US, federal funds made available for recovery are often partially utilized by local stakeholders, such as property and business owners, to foster local economic development. These efforts aim to attract further investment, boost the local economy to levels exceeding pre-hazard conditions, and, as a result, encourage in-relocation of new residents.

The factors discussed in this section represent only a subset of the many drivers that influence relocation outcomes in conjunction with natural hazards. Our aim is not to provide an exhaustive list but to emphasize that relocation patterns are shaped by multiple, often intertwined factors, as highlighted in the existing literature (Black et al., 2011). These drivers can sometimes act in opposite directions: for example, proximity to water may attract residents due to its amenity value while simultaneously exposing them to increased flood risk. In other cases, relocation drivers can cascade, such as when hazards disrupt jobs, triggering further economic impacts that influence relocation decisions. Additionally, the same factor can have dual effects: for instance, destruction caused by natural hazards may prompt out-relocation among residents seeking to reduce future risks, while simultaneously driving redevelopment efforts and economic stimuli that attract new residents.

4 Socio-Economic and Demographic Changes in Hazard-Exposed Communities

In this section, we analyze studies that investigate the socio-economic and demographic changes driven by hazard-induced relocation in exposed communities. We identify three primary domains of change investigated by the literature: population size, socio-economic composition, and housing prices (Fig. 3).

4.1 Changes in Population Size

Here, we examine the long-term effects that natural hazards may have on a community's population size. In cases where a community's population size has remained stable over time, we can ask whether a natural hazard (or series of hazards) might cause a population decrease or increase in the long term. Another scenario is when a community is already experiencing population change, such as growth driven by net in-relocation. In this case, we could ask ourselves whether one or more natural hazards can alter these ongoing trends. For example, a community experiencing steady growth over the past decade might see a slowed growth rate or even a reversal if impacted by an intense hazard event. We review both specific case studies and broader statistical analyses that address these questions.

First, we examine a case study by Smith and McCarty (2011) focusing on the aftermath of the 2004 hurricane season in Florida, a series of events that severely damaged approximately 324,000 residential units and temporarily displaced almost 1.6 million people. This study analyzed population data at both the county and city levels, focusing on 11 counties affected by multiple hurricanes during the season. Of these, five counties experienced population losses from 2004 to 2005. Before the hurricanes, all five had been growing, and by 2008, each had surpassed its pre-hurricane population level. The study also examined seven incorporated cities within these five counties, each of which had been growing before the hurricanes as well. These cities saw population declines from 2004

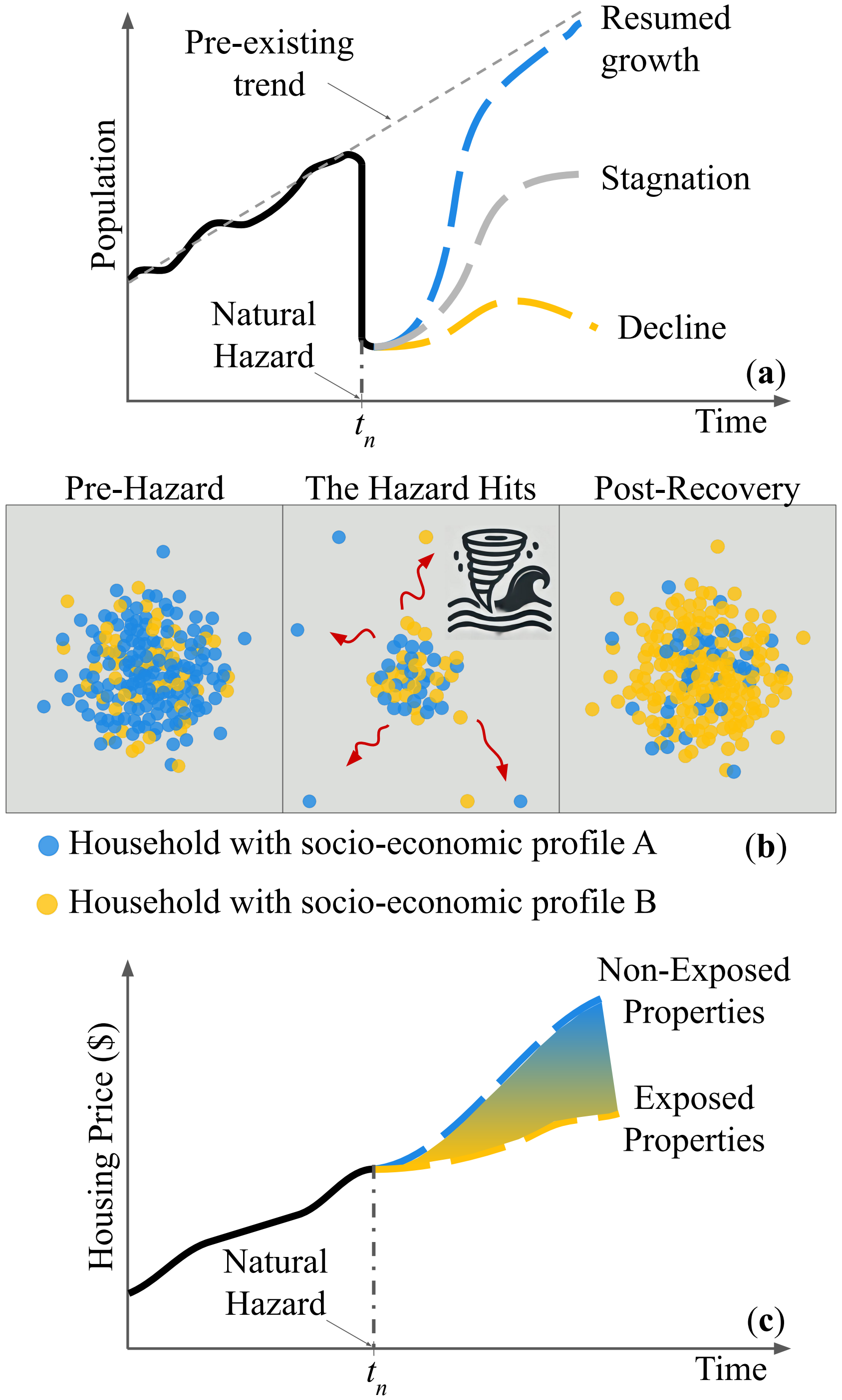

Figure 3. Schematic representation of three domains of change in hazard-exposed communities: (a) Population size, showing a sudden drop after a natural hazard event followed by different possible trajectories. (b) Socio-economic composition, illustrating shifts in population characteristics due to out- and in-relocation. (c) Housing prices, depicting distinct trends for exposed and non-exposed properties after the hazard event.

to 2005 but resumed growth afterward. According to the 2010 US Census, four of the cities had exceeded their 2004 population levels by 2007. The study also references the impacts of Hurricane Andrew in 1992, noting that while severe initial impacts led to significant population declines in areas within Miami-Dade County, such as Florida City and Homestead, these locations eventually exceeded their initial population figures by the end of the decade. The paper concludes that despite the immediate disruptions caused by the 2004 hurricanes, there were no lasting impacts on the long-term population trends within the examined communities. This case study, while insightful, provides specific outcomes from a limited dataset and cautions against broad generalizations without further comprehensive analysis.

A more comprehensive study is provided by Fussell et al. (2017). In their paper, the authors analyzed the impact of hurricanes and tropical storms on future population growth in US counties from 1980 to 2012 by developing a statistical model. They analyzed county-level data annually, using population growth trends and the number and intensity of hazards over the previous decade as independent variables, population growth over the next three years as the dependent variable, and population density as a control. They found that natural hazards-related predictors generally have no significant effect on future population growth compared to past population trends, except for high-density, growing counties where natural hazards appear to stimulate population growth over the subsequent three years. An explanation provided by the authors for this phenomenon could be that reconstruction resources have a boosting effect on the local economy. One consideration with this analysis is that it was conducted at the county level, which may be too coarse to capture the nuanced impacts of natural hazards. For instance, when Hurricane Sandy struck New York City, only the coastal areas were flooded. In Kings County (Brooklyn), for example, less than 13% of the residential units were located within the inundated zones (Department of Small Business Services, 2024; Department of City Planning, 2012). Therefore, analyzing the entire county may not accurately reflect the localized effects of the hazard. Moreover, their analysis relies on a three-year projection of population changes, though recovery can extend further with later adjustments. Repeating the analysis with a longer time horizon could capture effects that emerge beyond three years.

Cross (2014) adopted a finer geographical focus, examining US communities where more than 50% of structures were destroyed by disasters between 1992 and 2008. This selection allowed for a more precise understanding of disaster impacts on localized population dynamics. Cross found that communities previously experiencing population declines were nearly three times more likely to face further substantial declines post-disaster, compared to communities that were previously growing. The author concluded that natural disasters are more likely to accelerate existing demographic trends rather than cause drastic reversals. Nonetheless, there were instances where communities defied this pattern, with previously growing communities turning to decline, and vice versa. This finding aligns with the previous discussion that relocation outcomes also depend on a broader set of context-specific factors.

Another study supporting the thesis that natural disasters do not drastically alter population trends but may accelerate existing patterns is provided by Vigdor (2008), focusing on New Orleans after Hurricane Katrina. The author analyzed population data up to two years after the hurricane, when New Orleans' population was slightly above 50% of its pre-hazard level, and questioned whether the city will ever fully recover its population. The study examined several cities affected by catastrophic events in the 20^{th} century, both natural and man-made. In each case, cities that were growing before the event regained their population and continued to expand. The only exception is Dresden, which was already losing population before being nearly destroyed during WWII. The article then explores historical trends in New Orleans, noting that the city grew in the 1800s as a major port but began declining in the second half of the 20^{th} century due to stagnation of the local economy. The author emphasizes that New Orleans was already experiencing a steady population decline before Katrina. However, lower housing costs—due to a surplus accumulated in past decades—helped slow this trend. The hurricane eliminated this surplus, removing the low-cost housing incentive that had retained some residents. As a result, many did not return. Fig. 4 illustrates population trends in New Orleans. The left plot focuses on the years immediately after Katrina, showing that five years after the disaster, the city's population remained about 20% below pre-hurricane levels. The right plot presents data from 1970 to 2023, demonstrating that New Orleans had been in steady decline even before the hurricane. After five years of recovery following the hurricane, the city appears to have resumed this gradual decline. These data, updated through 2023, confirm the author's predictions made just two years after the disaster.

Indaco and Ortega (2024) analyzed the correlation between hazard frequency and population growth in the US from 1990 to 2020. The study examines population changes at both the county and census tract levels and compares different areas at the national level as well as within commuting zones. According to their analysis, areas with higher hazard frequency experienced greater population growth compared to low-frequency hazard areas, both nationally and within commuting zones. These results may suggest that characteristics making areas more prone to natural hazards, such as proximity to forests (for wildfires) or waterways (for flooding), might also enhance their attractiveness, and their appeal outweigh the negative effects of natural hazards. The authors then expanded the analysis by introducing several control variables, providing further insights. First, by controlling for housing density, they found that the higher growth rates in high-frequency hazard areas are primarily observed in densely populated regions, while in low-density areas, high hazard frequency seems to cause population decline. This finding suggests that in areas already attracting population, other factors outweigh the effect of natural hazards on population changes, while in less attractive areas, natural hazards accelerate population decline. Second, by controlling for hazard type, they found that within commuting zones, only Census tracts affected by coastal flooding grew at a slower rate compared to those less affected. The authors attribute this pattern to the predictable spatial boundaries of coastal flooding, which allow residents to reduce their exposure by relocating within the same commuting zone.

The findings described above primarily concern the effects of intense, rare events. In contrast, slow-onset, recurrent phenomena—such as tidal flooding exacerbated by SLR—may lead to different outcomes, as discussed in the previous section. For example, L. Perch-Nielsen et al. (2008) investigated cases of community abandonment driven by both sudden, destructive flooding and gradual, long-term SLR. They found no instances of abandonment from single-event flooding, regardless of intensity, but identified three cases linked to chronic flooding exacerbated by SLR: Holland Island (Chesapeake Bay, Maryland, US), the Caspian Sea coast (particularly Kazakhstan), and Brownwood (a peninsula near Houston, Texas, US). Holland Island experienced approximately 20 cm of relative SLR between 1850 and 1920, leading to erosion and gradual land loss. Despite efforts to remain, the island was abandoned in 1920 as land loss and population decline made local services unsustainable. In the Caspian Sea region, SLR inundated extensive coastal areas between 1978 and 1995, displacing thousands of residents. Lastly, Brownwood faced worsening tidal flooding that caused its complete abandonment, due to land subsidence from groundwater extraction. Relative SLR caused by land subsidence also threatens several major coastal cities worldwide, including Jakarta, Ho Chi Minh City, Bangkok, Dhaka, New Orleans, Venice, and Tokyo (Erkens et al., 2015). In these cities, geological processes and anthropogenic factors, particularly groundwater extraction, combined with SLR, are increasing tidal flooding frequency and intensity. Jakarta, for example, is subsiding at rates of up to 10–20 cm per year, prompting the Indonesian government to plan the capital's relocation. SLR poses an even greater threat to islands, where the option of inland retreat is limited. Hauer et al. (2020) examined the vulnerabilities of atoll nations such

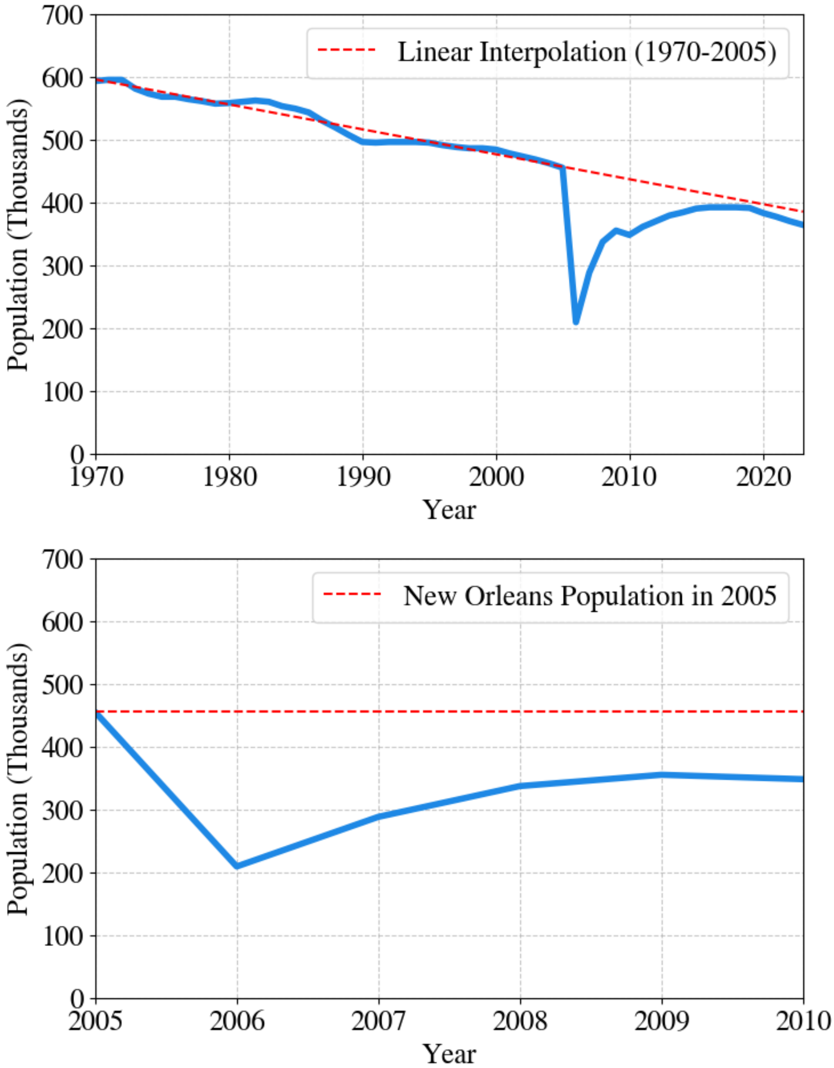

Figure 4. Population trends in New Orleans, illustrating both short- and long-term impacts of Hurricane Katrina. The top plot shows the immediate effects from 2005 to 2010, with a sharp population decline after the hurricane in 2005, followed by partial recovery, reaching about 80% of pre-hurricane levels by 2010. The bottom plot presents a longer-term view from 1970 to 2023, indicating a steady population decline that predates Katrina. As shown in the bottom plot, after a five-year recovery period, the population trend resumed its gradual downward trajectory, consistent with historical patterns. U.S. Census Bureau, Resident Population in Orleans Parish, LA [LAORLE0POP], retrieved from FRED, Federal Reserve Bank of St. Louis (U.S. Census Bureau, n.d.).

as the Maldives, Tuvalu, Kiribati, and the Marshall Islands, where SLR is causing inundation, freshwater scarcity, and soil salinization. In response, some atoll nations are adopting planned relocation policies. Islands also appear more prone to net population loss following natural hazards in general, not only SLR. Two notable cases are Kauai, Hawaii (US), after Hurricane Iniki (1992), and Montserrat (British Overseas Territory in the Caribbean), following volcanic eruptions in the mid-1990s. Coffman and Noy (2012) showed that Hurricane Iniki caused severe long-term economic disruption on Kauai, resulting in approximately 12% lower population two decades after the hurricane compared to projections had the disaster not occurred. In Montserrat, volcanic eruptions beginning in 1995 forced the near-total abandonment of the island's southern two-thirds, including the capital, Plymouth (McLeman, 2011). Since then, the island's population has remained relatively stable, without significant recovery or further decline.

Finally, the literature has also shown that natural hazards can act as a pull factor, something counterintuitive. A study by Elliott (2015) investigated empirically the role of natural hazards as push and pull factors on relocation. They conducted a detailed household-level analysis of relocation patterns across the US, using a sample of households from diverse geographic regions defined by Public Use Microdata Areas (PUMAs). Focusing on the period between 1995 and 2000, the study explored the correlation between relocation and the frequency and intensity of natural hazards—quantified in terms of property losses—in these regions. The findings reveal a statistically significant positive correlation between the intensity of natural hazards and the out-relocation from affected areas (push factor). Interestingly, the analysis also identifies a positive correlation between in-relocation and property losses due to natural hazards, suggesting that such events can also act as pull factors. This pull effect is particularly pronounced among Asian and Latino populations and persists even after controlling for existing foreign communities at the destinations. Notably, the study refutes an earlier hypothesis by Pais and Elliott (2008), which suggested that in-relocation is primarily driven by job opportunities in disaster recovery efforts. Instead, they found that residents relocating into hazard-impacted areas tend to enter job sectors their ethnic groups were already engaged in before the hazardous event. However, the study did not explain this observed increase in in-relocation.

In summary, large-scale statistical analyses of US data generally indicate that natural hazards do not significantly alter ongoing population trends but can sometimes accelerate them. However, finer-scale analyses (e.g., at the US Census tract level) show that certain hazards, such as coastal flooding, can slow population growth. Case studies further suggest that slow-onset, chronic events like SLR have greater potential to cause net population loss compared to rare, destructive events. This effect is particularly evident for islands, which generally tend to be more prone to depopulation due to natural hazards. Lastly, the literature highlights that natural hazards can sometimes act as pull factors, attracting new residents despite increased risks, particularly in areas with desirable amenities.

4.2 Changes in Socio-Economic and Demographic Status

Natural hazards often cause (or influence) shifts in population characteristics through in- and out-relocation. One potential outcome identified in literature is the increase of wealthier residents following a destructive event. For example, Graff Zivin et al. (2023) analyzed mortgage application data in Florida from 2000 to 2016, finding that hurricane-affected areas tend to attract wealthier homebuyers. They attributed this phenomenon to a sudden decrease in housing supply caused by the destruction from the hazard, which in turn intensifies competition among potential buyers, with wealthier individuals outbidding those with lower incomes. Since homeownership typically involves long-term commitments, this demographic shift can potentially lead to enduring socio-economic changes within the affected communities, characterized by a higher proportion of homes being occupied by wealthier households post-disaster. A similar mechanism influences rental housing markets, but socio-economic changes are typically transient due to shorter tenancy durations. However, permanent shifts can occur if the rental housing stock is not fully restored. This was evident in New Orleans, where a 2021 study by The Data Center (Plyer, 2021) found that, 15 years post-Hurricane Katrina, only five neighborhoods had populations less than 50% of their pre-Katrina levels. Four of these neighborhoods had large public housing complexes that were demolished and redeveloped into lower-density, mixed-income dwellings post-hurricane, permanently altering the socio-economic fabric of these areas. Adding to the empirical evidence, van Holm and Wyczalkowski (2019) further explored gentrification after natural hazards by examining neighborhoods in New Orleans from 2000 to 2015. They found that neighborhoods with greater damage from Hurricane Katrina were more likely to undergo gentrification, as defined by an increase in real housing prices and the percentage of residents with college education.

However, the phenomenon of post-disaster gentrification is not universally consistent. Other research has documented contrasting scenarios where natural disasters have led to stagnation in wealth or even exacerbated poverty conditions in affected neighborhoods. For example, referring back to van Holm and Wyczalkowski (2019), not all New Orleans neighborhoods predisposed to gentrification in 2000 followed this path by 2015. Neighborhoods such as the Lower Ninth Ward and Hollygrove, despite suffering severe damages, remained economically depressed and did not experience gentrification, according to the study. Zhang (2012) examined the impact of Hurricane Andrew on five cities in Miami-Dade County using parcel-level data from 1991 (one year before the hurricane) to 2000 (eight years after). He employed a discrete-time hazard model to predict the transition of parcels from residential to abandoned, using block-level socio-economic characteristics and the proximity to other abandoned parcels as independent variables, while also controlling for damage level and building age. The study reveals that, independent of damage and age, the odds of a property becoming vacant were 67% lower in middle-class neighborhoods compared to poorer ones. Moreover, the analysis showed that proximity to an abandoned parcel significantly increased the likelihood of a property becoming abandoned. These findings suggest that in some of the communities with high poverty rates, the damage caused by Hurricane Andrew, instead of attracting new, wealthier residents, further depressed socioeconomic conditions.

The investigative journalism piece In Arms' Way (Lubben et al., 2022) further illustrates how repeated natural hazards can compound socio-economic challenges in vulnerable communities. The article reports the struggles of residents in flood-prone areas, who face significant financial losses when attempting to relocate. For example, a resident of Smithfield, Virginia (US), after enduring multiple floods, was forced to sell her home for only $39,000 and subsequently obtained a new mortgage, to buy a $136,000 new house in a safer area. Another case from Freeport, Illinois, involves a homeowner who attempted repairs on her home, valued at just $7,000. Local building codes required that renovations exceeding 50% of the property's assessed value meet flood protection standards, and even minor repairs would have surpassed this threshold, necessitating costly upgrades that were financially unfeasible. This scenario, referred to as a 'poverty trap' (Black et al., 2013), demonstrates how natural hazards can sometimes deepen poverty within affected communities.

In summary, both scientific research and investigative journalism document dual outcomes in communities exposed to natural hazards. In some cases, affected communities attract wealthier residents after experiencing a destructive event, leading to gentrification and socioeconomic uplift. In others, these events exacerbate existing poverty, trapping residents in worsening conditions. Based on the reviewed studies, the likelihood of either scenario appears to depend more on factors unrelated to the hazard itself, such as the inherent attractiveness of the affected location. This conclusion aligns with the previous section, where we discussed the role of community characteristics in attracting and retaining residents (Cross, 2014). This conclusion is also supported by Elliott and Pais (2010), who compared the effects of Hurricane Andrew on two communities: Miami, a densely urbanized area, and southwestern Louisiana, a more rural region. The study found that in Miami, long-term recovery displaced socially vulnerable populations from the hardest-hit areas, whereas in southwestern Louisiana, recovery processes concentrated these vulnerable groups within the hardest-hit zones. Therefore, we can conclude that in generally more attractive communities, natural hazards can displace poorer residents, creating opportunities for wealthier individuals to move in. Conversely, in stagnating or economically depressed areas, the destruction caused by natural hazards can further reduce attractiveness, deepening pre-existing poverty. Finally, there is a lack of scientific literature examining socio-economic changes in response to chronic, low-intensity events like tidal flooding.

4.3 The Housing Market

A large body of literature, primarily from the field of economics, examines how natural hazards affect housing prices. Although housing prices are not a socio-demographic characteristic per se, they can shape a community's socioeconomic composition. For instance, if housing prices decline in high-exposure areas relative to safer ones, lower-income households may be drawn to these areas, increasing the concentration of vulnerable populations in hazard-prone neighborhoods. This pattern, for example, has been observed in Los Angeles, California (US), where minority households (Black and non-Black Hispanic) are more likely than non-Hispanic Whites to reside in areas exposed to fluvial flooding (Sanders et al., 2023). The literature identifies three main ways in which natural hazards may influence housing prices. First, destructive events can temporarily raise prices by reducing overall housing supply (Figure 5 *a*). Second, after an intense, rare event, prices in more exposed areas suffer a sudden discount relative to less exposed ones. This discount appears to be temporary, gradually vanishing over time (Figure 5 *b*). Third, in the case of chronic hazards like SLR and tidal flooding, more exposed areas tend to appreciate less, leading to persistent and increasing price differentials (Figure 5 *c*). However, despite these discounts, some homebuyers may underestimate future risks, inflating prices beyond their fundamental value and increasing the risk of price bubbles. The following section reviews studies that explain these mechanisms.

Natural hazards can temporarily reduce housing supply, leading to short-term price increases (Figure 5 *a*). According to the law of supply and demand, a drop in available housing raises prices until the damaged stock is restored. Studies examining average housing prices at the community level, without distinguishing between exposure levels, support this trend. For instance, Graff Zivin et al. (2023) analyzed residential sales in Florida following a hurricane and found that average prices temporarily rise, typically for 2–3 years. They also observed that mortgage applicants during this period tend to be wealthier, potentially contributing to gentrification in affected areas. Murphy and Strobl (2010) compared post-hurricane housing prices with projected prices had the hurricane not occurred, finding similar results. They reported that house prices typically rise by 3–4% three years after a hurricane, though this effect gradually fades over time. Staer and LaCour-Little (2016) also documented rising housing prices in Christchurch, New Zealand, following the 2011 earthquake. Similarly, Vigdor (2008) reported sharp increases in both sale prices and rents in New Orleans immediately after Hurricane Katrina. Although Graff Zivin et al. (2023) accounted for a home's proximity to a hurricane's path, future hurricanes are spatially unpredictable. Within the same geographic region, proximity to a past hurricane does not necessarily indicate higher future exposure, as future hurricanes can follow unpredictable trajectories. Murphy and Strobl (2010), Staer and LaCour-Little (2016), and Vigdor (2008) analyzed price changes at the city level without differentiating between properties with different exposure levels. Therefore, these studies confirm overall price increases in affected communities, but they do not clarify how hazards impact more versus less exposed areas.

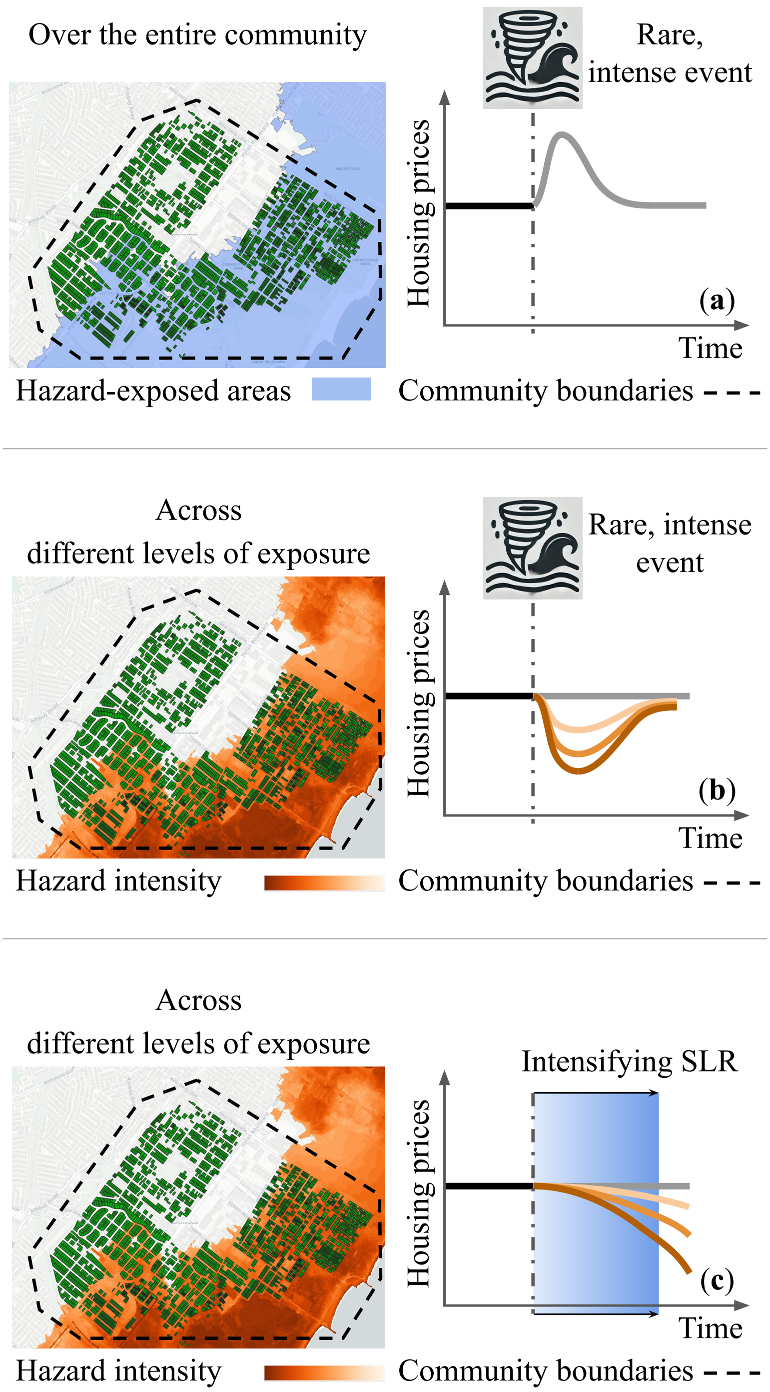

Figure 5. Effects of natural hazards on housing prices. (a) After a destructive hazard, overall housing prices rise due to supply shortages, then return to baseline as housing stock recovers. (b) More exposed homes decline in relative value compared to less exposed ones, but prices realign over time if the event is a single, intense occurrence. (c) For recurrent, lower-intensity hazards (e.g., sea level rise and tidal flooding), the price gap between more and less exposed homes persists and grows over time.

When controlling for different exposure levels, natural hazards tend to reduce housing prices in the most exposed areas relative to less exposed ones (Figure 5 *b*). Relative price discounts in high-exposure zones have been observed after various hazards, including flooding (Ortega & Taşpınar, 2018; Bin & Polasky, 2004), earthquakes (Jung & Smith, 2022; Shi & Naylor, 2023), wildfires (Adachi & Li, 2023; Koo & Liang, 2022), and tornadoes (Cho et al., 2022). For instance, Ortega and Taşpınar (2018) found that non-damaged properties within Hurricane Sandy's flooded zones in New York City experienced an 8% price discount compared to similar properties just outside the inundated area. This finding suggests a market adjustment to the increased perceived risk of future flooding. A similar effect has been observed after the public release of updated risk ratings, such as the inclusion of properties in flood hazard areas following a flood map update. Gibson and Mullins (2020) compared property prices in New York City before and after FEMA's 2013 flood map revision. They found that properties newly designated as flood-prone appreciated about 12% less over four years than similar properties outside the updated maps. Donovan et al. (2007) reported a comparable trend in Colorado Springs, where home prices declined after the local fire department publicly rated the wildfire risk of 35,000 houses. These findings suggest that both direct hazard events and official risk designations increase risk perception among homebuyers, reducing demand and lowering property values in high-exposure areas.

However, housing price responses to natural hazards vary across communities, as factors beyond hazard exposure also influence demand. The reviewed literature identifies three key factors that interact with natural hazards in shaping housing prices: proximity to urban centers, natural amenities, and risk disclosure policies. For example, Cheung et al. (2016) examined housing price declines in Oklahoma following seismic shocks. They found that price drops correlate with earthquake intensity but are less pronounced in urban areas than in rural ones. Urban housing remains more attractive due to factors discussed in the previous section, such as greater economic opportunities. Even in areas experiencing strong earthquakes, these advantages help sustain demand, mitigating price declines. Natural amenities can also offset the negative effects of hazard exposure on housing prices. In Los Angeles, Sanders et al. (2023) found that minority households (Black and non-Black Hispanic) are more likely than non-Hispanic Whites to reside in areas exposed to fluvial flooding. However, non-Hispanic Whites are more concentrated in coastal areas, despite their higher exposure to coastal flooding. This suggests that the amenity value of coastal proximity outweighs flood risk for some buyers. Similarly, Bin and Kruse (2006) and Bin et al. (2008) analyzed property sales in Carteret County, North Carolina (US). They found that floodplain properties are generally discounted compared to similar homes outside flood zones, but mainly for inland flooding. In contrast, coastal properties command higher prices despite their increased exposure to coastal flooding, confirming the role of natural amenities in shaping housing demand. The third factor influencing housing demand is the strength of risk disclosure laws. Research shows that stricter disclosure requirements lead to greater price discounts for properties in officially designated high-exposure areas, such as FEMA's Special Flood Hazard Areas (SFHAs). For example, Gourevitch et al. (2023) analyzed price discounts for SFHA-designated properties across the US coastline, controlling for state flood disclosure laws and local climate concern. They found that SFHA inclusion reduces property values by 2.5% to 9.7%, with stricter disclosure laws and greater climate awareness associated with larger discounts. Similarly, Pope (2008) compared housing prices before and after the implementation of the 1996 Residential Property Disclosure Act, which mandated disclosure of flood risk in North Carolina (US). Before the law, there was no significant price difference between SFHA and non-SFHA properties, but after its passage, SFHA properties experienced a 4% relative price discount. Ma et al. (2023) found a similar effect for wildfire risk disclosure in California (US), observing that properties in areas where wildfire risk must be disclosed sell for approximately 4.3% less than comparable properties in unregulated areas. These findings suggest that formal risk disclosure increases buyer awareness, reducing demand and lowering prices in high-risk zones.

In some cases, the initial drop in housing prices following an intense hazard event diminishes over time and may eventually disappear. For example, Bin and Landry (2013) found that housing prices in Pitt County, North Carolina (US), dropped in floodplains after Hurricanes Fran (1996) and Floyd (1999) but returned to pre-disaster levels within six years. Similar trends have been documented for other hazards, including fluvial flooding (Atreya et al., 2013), earthquakes (Yasuda et al., 2019), and tornadoes (Cho et al., 2022). The disappearance of price differentials over time suggests that risk perception adjusts, either due to belief updates among long-term residents or the arrival of new buyers unfamiliar with past hazards. Bakkensen and Barrage (2022) used an agent-based model to show that even a small share of homebuyers with overly optimistic risk perceptions can drive up prices, reducing the gap between exposed and non-exposed areas.

As previously discussed, among natural hazards, flooding is one of the most spatially predictable. While hurricanes can follow various paths after landfall, flood exposure is largely determined by topography and proximity to water bodies. Due to this predictability, some studies examined housing price differentials within SFHA, focusing on the effects of SLR and tidal flooding (Figure 5 *c*). For example, Keys and Mulder (2020) analyzed home sales in Florida's coastal areas from 2001 to 2020, excluding tracts affected by major hurricanes to isolate the effects of SLR. The number of sales in high-exposure areas began declining in 2013, dropping 16–20% relative to low-exposure areas by 2018. Home prices remained stable until 2016 but then fell 5–10% below trend by 2020. This lead-lag pattern, where sales decline before prices, resembles trends observed in the 2008 housing recession. The study attributed these shifts primarily to reduced demand in high-SLR areas, likely due to growing climate risk awareness among buyers. Other studies on SLR report similar findings. Keenan et al. (2018) and McAlpine and Porter (2018) examined the relationship between housing prices and exposure to SLR in Miami-Dade County, Florida. Keenan et al. (2018) found that properties at higher elevations appreciated more over time than similar properties in low-lying areas, even after controlling for housing characteristics and location. This trend suggests that tidal flooding may influence homebuyer preferences, reducing demand for properties more exposed to SLR. McAlpine and Porter (2018) analyzed the relationship between housing prices and tidal flooding, controlling for proximity to the shore. They found that properties with greater exposure to tidal flooding appreciated, on average, $3 less per square foot per year than those in lower-risk areas. This effect applies to both houses that are directly flooded and to homes near frequently flooded roads, indicating that broader infrastructure disruptions also influence property values. Lastly, Bernstein et al. (2019) examined housing prices in coastal areas across the US, focusing on properties within 400 meters of the shore. They found that homes exposed to SLR sell for about 7% less than comparable unexposed properties at the same distance from the beach. Since they found no correlation between SLR exposure and rental rates, this discount likely reflects homebuyers' long-term concerns about future sea levels.

Despite observed price differentials, the literature suggests that expected future losses in flood-exposed areas in the US are still not fully reflected in housing prices. Gourevitch et al. (2023) compared current housing prices in flood-prone areas with their fundamental values, which account for expected flood damages and insurance costs. They estimated total overvaluation in flood-exposed areas at $121–$237 billion, depending on the assumed appreciation rate. This overvaluation increases the risk of a housing bubble, which, if it bursts, could harm homeowners and destabilize the broader economy.

In conclusion, the interaction between natural hazards and housing prices leads to three key outcomes. First, at a broad spatial scale, destructive hazards reduce housing supply, temporarily driving up prices for unaffected properties. Though these increases vanish once rebuilding is complete, they can have lasting effects by raising the average wealth of residents and potentially triggering gentrification. Second, at a more localized level, properties in high-exposure areas tend to be discounted relative to those in less exposed areas. After an intense hazard event or updated risk mapping, these discounts appear suddenly but often fade over time, likely due to shifting risk perceptions. In contrast, with chronic hazards like SLR and tidal flooding, price discounts in more exposed areas tend to persist and grow. These long-term discounts can have significant economic consequences. Gourevitch et al. (2023) highlight several risks associated with declining housing prices in hazard-prone areas. First, lower prices may attract low-income households, concentrating vulnerable populations in areas where the hazard is more frequent and intense. Additionally, declining property values erode homeowners' equity and heighten community-wide social vulnerability, especially for households whose homes are their primary financial asset. Falling prices can also raise mortgage default risks. If property values drop below mortgage balances, homeowners may be more likely to default, potentially destabilizing local housing markets. If prices fall below construction costs, rebuilding after a disaster may become financially unfeasible, leading to prolonged blight and non-recovery. Finally, declining property values reduce local tax revenues, limiting funding for hazard adaptation and community resilience efforts.

5 Mathematical Modeling of Post-Hazard Recovery and Long-Term Changes

Here, we review simulation-based models that examine the impacts of natural hazards on long-term relocation. We classify the models into three categories based on their primary focus and methodological approach (Figure 6). The first category includes models that simulate recovery following a single destructive event, while accounting for permanent out-relocation of current residents. These models integrate engineering-based damage assessments with socio-economic factors influencing relocation decisions, such as place attachment and households' financial capacity. Their primary objective is to estimate which residents are more likely to permanently out-relocate during the recovery process. The second category consists of models that simulate longer time frames and recurring hazards. These models incorporate behavioral economics to simulate flows of residents into, out of, and within communities, accounting for risk perception, heterogeneous preferences, and financial constraints. Their main goal is to assess long-term demographic and economic changes in hazard-exposed communities, such as changes in population size and economic segregation. The third category comprises models that simulate relocation flows across multiple locations, such as all counties in the United States. These models build on ongoing relocation patterns and estimate how slow-onset hazards, such as SLR, could alter these trends over time.

Before describing in detail models of hazard-induced relocation, we briefly overview models that focus on post-hazard recovery, which simulate how communities restore infrastructure, housing, and services after a disruptive event. As discussed in earlier sections, the recovery process can shape long-term relocation patterns. Therefore, even though these models do not explicitly simulate relocation, they remain relevant to this review. Most models on recovery build on engineering techniques and the disaster risk analysis literature (Cheng et al., 2024; Ceferino et al., 2018; Arora & Ceferino, 2023; Negri et al., n.d.; Houng & Ceferino, 2025; Xu & Noh, 2021). Miles et al. (2019) classified recovery models into three categories: lifeline restoration, housing reconstruction, and community-wide recovery. They also identified various modeling approaches, including system dynamics, agent-based modeling, and network models. For example, infrastructure-focused models simulate the restoration of essential services such as hospitals, transportation and utilities (Alisjahbana et al., 2023; Ramachandran et al., 2015; Davidson et al., 2017). Similarly, housing recovery models use Markov chains and agent-based approaches to predict rebuilding timelines and neighborhood recovery patterns (Dhulipala et al., 2021; Nejat & Damnjanovic, 2012). At the community level, models such as ResilUS (Miles & Chang, 2011) integrate multiple recovery sectors, illustrating how interdependencies between households, businesses, and infrastructure can shape recovery trajectories. Addi-

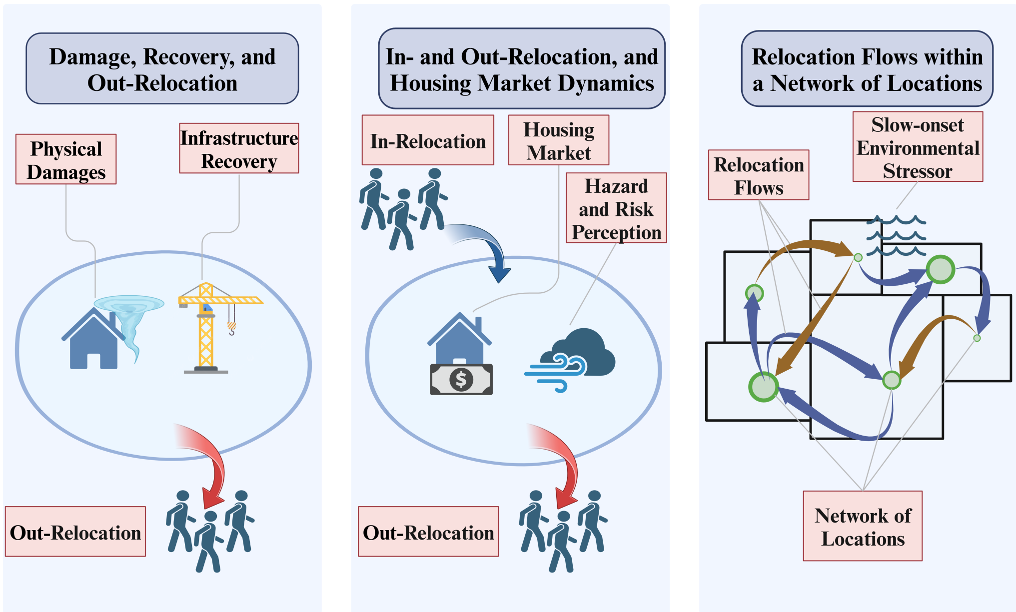

Figure 6. Schematic representation of the three categories of simulation-based models on hazard-induced relocation. The figure highlights the primary aspects each category emphasizes, including physical damage and recovery with out-relocation (Category 1), economic drivers of in- and out-relocation (Category 2), and large-scale relocation flows shaped by slow-onset hazards (Category 3). Created in BioRender. Malakun, A. (2025) https://BioRender.com/1z4sd7q

tionally, Sutley and Hamideh (2020) introduced a fourth dimension—household recovery—modeling transitions of households through different housing stages, such as emergency shelter, temporary shelter, temporary housing, and permanent housing. These models provide valuable insights into the pace and extent of recovery, which can influence both in- and out-relocation.

5.1 Models on Recovery and Permanent Out-Relocation

Paul et al. (2024) reviewed models that examine permanent out-relocation induced by natural hazards. They classified each model based on the out-relocation drivers they consider, such as the extent of housing damage, place attachment, and socio-demographic characteristics. Most models use an agent-based approach to simulate household decisions following a destructive natural hazard. For example, Costa et al. (2022) developed an agent-based model to simulate homeowners' decisions to either repair their damaged dwelling or permanently out-relocate after a major earthquake in San Francisco. Their model considers three factors influencing this decision: place attachment, the time required to initiate repairs, and the financial extent of damages. The study found that place attachment, quantified using US Census Bureau surveys on neighborhood and home satisfaction, plays a significant role in decision-making, and that excluding this factor may significantly underestimate out-relocation. Other studies extend these models beyond homeowners to include out-relocation decisions of renters (Mongold et al., 2021; H. Burton et al., 2019). Bhattacharya and Kato (2021) included in their model the effects of community characteristics (e.g., presence of essential services and economic opportunities) and post-hazard policies on permanent out-relocation decisions. All these models primarily focus on the out-relocation of current residents after a destructive hazard event. They provide valuable insights into which households are more likely to permanently relocate and which communities face higher risks of disruption. However, as discussed in previous sections, natural hazards can drive both out- and in-relocation, meaning these models cannot fully predict long-term, net population changes.

5.2 Models on Socio-Economic and Demographic Changes

Most of these models simulate hazard-exposed communities over multiple decades, capturing the effects of recurring extreme events, such as storm surge flooding, or gradual environmental changes, such as SLR. They employ agent-based modeling to examine long-term socio-economic changes within these communities. Researchers use these models to explain empirical observations, such as temporary declines in housing prices after major disasters, and to project future outcomes like economic segregation. Most reviewed models in this category focus on flooding, which is spatially more predictable than other hazards. In flood-prone areas, households can be located either inside or outside a floodplain while remaining within the same commuting zone. This spatial predictability influences local dynamics between exposed and non-exposed areas, which are reflected in housing market trends. For instance, studies show that after a flood, houses within the floodplain tend to appreciate less than comparable houses just outside it. A group of models simulates socio-economic shifts in flood-prone areas by focusing on the housing market. They simulate the behavior of home buyers and sellers, with agents driven by their preferences (e.g., proximity to water and risk perception) and constraints (like income and budget). The hazard impacts the market by increasing perceived future losses and the financial burden from property taxes and insurance premiums. For example, Bakkensen and Barrage (2022) and de Koning and Filatova (2020) developed agent-based models to simulate flood-exposed housing markets. In these models, agents are attracted to coastal properties for the amenity of living close to water, but are also deterred by the perceived risk of future flood losses. Risk perceptions and preferences are heterogeneous across agents and evolve over time, with risk awareness increasing after a flood event. The models successfully reproduce observed depreciation of flood-exposed properties following a flood and the gradual price rebound as risk perception adjusts. They also show that even a small fraction of agents with overly optimistic expectations of future losses can artificially inflate property values. These inflated values may then lead to sudden equity losses as the effects of SLR become more apparent and risk perception intensifies among a broader pool of prospective homebuyers. Additionally, they highlight the risk of economic segregation: as home prices drop below a certain threshold, less affluent households become unable to sell their homes, remaining trapped in hazard-exposed areas.

McNamara et al. (2024) built on previous models (Brad Murray et al., 2013; McNamara & Keeler, 2013) to investigate housing market dynamics in a coastal community exposed to SLR, focusing on the effects of community-level, in-place adaptation measures such as beach nourishment. In their model, beach nourishment enhances the attractiveness of coastal properties, but it also increases property taxes, making homes less affordable. Additionally, SLR accelerates beach erosion, necessitating more frequent adaptation efforts over time. The study explored various scenarios by adjusting government subsidies for beach nourishment and the price differences between coastal and inland properties. They found that reduced government subsidies initially attract more affluent residents who can support nourishment efforts through higher property taxes. However, if inland property values also decline, the widespread depreciation leads to property acquisition by absentee landlords, resulting in an influx of low-income renters.

Similarly, Karanci et al. (2016) and Karanci et al. (2018) presented an agent-based model simulating the interaction between housing market dynamics, community-level adaptation measures, and flood damage in a coastal town. Applied to Nags Head, North Carolina (US), the model runs over 50 years, incorporating recurring minor floods and a single major event at year 25. Results reveal a threshold effect: when the major event's intensity remains below a critical level, the community recovers and resumes its prior growth trajectory. However, if the hazard intensity surpasses this threshold, a negative feedback loop emerges: flood damages lead to increased out-relocation, reducing property tax revenues and slowing adaptation efforts. This, in turn, heightens risk perception and exacerbates future damages, reinforcing further out-relocation and stagnation. Similarly, Tonn and Guikema (2018) developed an agent-based model in which agents can collectively decide to implement seawalls protecting the entire community. They showed how reduced perceived risk can trigger the levee effect, attracting more residents to flood-prone areas and increasing their exposure to low-probability, high-impact events.

Modeling the housing market to investigate socio-economic changes in hazard-exposed communities has also been applied to hazards beyond flooding. For example, Grinberger and Felsenstein (2016) developed an agent-based model to simulate the long-term welfare impacts of a hypothetical earthquake in Jerusalem, focusing on how physical damages influence housing market dynamics and socio-economic inequalities. Their model shows how wealthier residents may gain a competitive advantage in the housing market after a destructive event, displacing low-income populations and leading to the gentrification of some neighborhoods. This model accounts for the effects of physical damage on reducing housing supply, but it does not explicitly simulate the reconstruction process.

5.3 Models on Relocation Networks

Models in this category simulate relocation patterns among a network of locations, such as all the counties composing the US. They estimate flows of migrants between locations and analyze how slow-onset environmental stressors (e.g., SLR), influence ongoing relocation trends. For example, Davis et al. (2018) and De Lellis et al. (2021) built on the radiation model (Simini et al., 2012; Boldini et al., 2024), a spatial interaction model that predicts relocation flows based on population distribution across locations. Davis et al. (2018) modified the standard radiation model by reducing the attractiveness of flood-prone areas as destinations in the relocation network. De Lellis et al. (2021) introduced dynamic out-relocation rates that increase in locations affected by SLR. Both articles apply their models to case studies in Bangladesh, predicting cascading relocation effects also in areas not directly affected by SLR. Robinson et al. (2020) took a different approach, using machine learning to model relocation in the US. They trained two separate models: one based on historical IRS county-to-county relocation data, and another based on relocation patterns following Hurricanes Katrina and Rita (2005–2006 IRS data). They then applied these models to simulate how future SLR could influence relocation patterns across the US. Their model predicts the intensification of existing relocation patterns towards urban areas, and indirect effects in receiving locations caused by population pressures.

5.4 Comparison of Different Models

We identify five key components of hazard-induced relocation that different models incorporate to varying degrees: physical damage and recovery of infrastructure and services, permanent out-relocation of affected residents, in-relocation of new residents, behavioral economics and housing market dynamics, and relocation flows across a network of locations (Figure 6). Each model category emphasizes specific components while overlooking others. For example, models in the first category primarily simulate physical damage and recovery, and incorporate factors influencing out-relocation, such as place attachment, but overlook in-relocation and housing market dynamics. Models in the second category simulate in- and out-relocation driven by economic considerations, often without explicitly modeling physical damage. Models in the third category consider both origins and destinations of relocation, but cannot incorporate household-level characteristics or building-specific damages without becoming computationally infeasible. These differences often reflect the disciplinary origins of the models. Models in the first category stem primarily from the engineering literature and build on research on hazard characteristics, physical damage assessment, and infrastructure recovery. Models in the second category originate from the economic literature and draw on studies of housing market dynamics, behavioral economics, and coupled human-natural systems. Models in the third category are refinements of the gravity model, which applies principles derived from physics to human relocation patterns.

Integrating all components into a single model remains a significant challenge, but a more comprehensive approach is needed to better capture the complex interactions between hazard impacts and relocation. Currently, no model fully integrates physical damage, recovery, out-relocation, in-relocation, and housing market dynamics. The only exception is the model by Karanci et al. (2016), which attempts to incorporate all these aspects. However, this model relies on strong assumptions about how housing demand evolves over time, particularly in relation to in-relocation of new residents. Modeling in-relocation is especially challenging, as its relationship with natural hazards is complex and remains under-explored. Another important gap is the role of social connections in relocation decisions. As previously discussed, strong social ties——such as relationships with family, neighbors, and community organizations——can reduce the likelihood of permanent out-relocation. Despite their recognized importance, none of the reviewed models account for this factor, highlighting an opportunity for future research.

6 Conclusions

In this literature review, we examined the effects of natural hazards on human communities, with a specific focus on permanent relocation patterns. We addressed two key questions: (1) what factors influence relocation patterns in hazard-exposed communities, and (2) what are the effects of relocation on the socio-economic and demographic characteristics of these communities. To answer these questions, we reviewed three types of studies: theoretical frameworks that explain the mechanisms driving relocation, empirical analyses that identify patterns and trends using data, and simulation-based models that explore the dynamics of relocation and community change through mathematical simulations. We kept our focus mostly on developed economies, particularly non-agriculture-dependent communities, as covering both developed and developing economies in depth would have made our review too broad.

In addressing the first question, we found that the effects of natural hazards on relocation patterns are influenced by a combination of multiple factors, encompassing household and community characteristics, and policies and government interventions. Household characteristics include wealth, risk perception, and place attachment, while community characteristics encompass the availability of jobs, essential services, and social networks. Policies and government intervention include the implementation of in-place hazard adaptation measures and post-event financial stimuli. The interactions between natural hazards and these factors can be complex, sometimes triggering cascading effects within communities. For instance, a severe hazard event may displace a large number of residents, reducing the demand for essential services like schools and grocery stores. The closure of these services can discourage displaced residents from returning and prompt additional out-relocation, creating a self-reinforcing cycle of population loss and community decline. In some cases, the very characteristics that attract in-relocation also increase a community's exposure to natural hazards. For example, forests provide natural amenities in wildland-urban interface areas but also heighten wildfire risk, while proximity to waterfronts attracts residents despite the threat of flooding. In such contexts, the same factor can simultaneously draw new residents seeking environmental benefits and drive others out to avoid risk.

In-place adaptation measures can also influence relocation outcomes. For instance, when building codes require costly adaptations, such as home elevation in flood-prone areas, some homeowners may be forced to out-relocate due to financial constraints. Conversely, measures like seawalls can reduce perceived risk, attracting new residents to hazard-exposed areas and increasing exposure to rare, high-impact events that exceed the design limits of these protections. Hazards characteristics, such as intensity, frequency, and spatial predictability, also shape relocation patterns. For example, more spatially predictable hazards, like coastal flooding (e.g., delimited through flood zones), can lead to uneven relocation patterns within the same commuting zone, with high-exposure areas experiencing slower growth compared to less exposed ones. In contrast, hazards with low spatial predictability, such as tornadoes, do not exhibit such patterns. Given the complex interactions between natural hazards and other factors, we cannot accept the simplistic hypothesis that exposure to natural hazards automatically causes permanent out-relocation. Instead, communities with different socio-economic, environmental, and institutional characteristics can experience vastly different relocation outcomes, even when exposed to the same hazard.

In addressing the second question, we found that socio-economic and demographic changes in hazard-exposed communities result from the combined effects of in- and out-relocation. The reviewed literature highlights two key dimensions of these changes: shifts in population size due to net relocation and alterations in the socio-economic composition of the resident population. The literature documents mixed findings regarding changes in population size. Some studies have attempted to correlate the frequency and intensity of natural hazards with population trends across large geographic scales, such as the entire US. These broad statistical analyses suggest that natural hazards generally do not disrupt pre-existing population trends. For example, analyses of US counties indicate that population changes are largely driven by trends from the preceding decade, with natural hazards showing no statistically significant effect. A notable case aligning with this conclusion is New Orleans, where the population had been declining steadily for four decades before Hurricane Katrina. Although the city regained a portion of its displaced population post-disaster, it eventually returned to its pre-hurricane downward trajectory. However, such large-scale studies have limitations: they often do not distinguish between different hazard types, which can produce varying effects. Moreover, they rely on coarse geographic units that may hide more localized mobility patterns. For instance, analyses at the census tract level revealed that tracts exposed to coastal flooding tend to experience slower growth compared to less exposed tracts within the same commuting zone. Moreover, while large-scale studies often downplay the impact of natural hazards on population trends, more focused research on specific hazards, such as SLR, reveals different patterns. In the case of SLR, the gradual loss of land seems to have a greater long-term impact on population size than rare, high-intensity events. The literature particularly highlights the risk of complete community abandonment in island communities, where residents have limited or no options to retreat inland.

Beyond changes in population size, natural hazards can also lead to significant socio-economic shifts within affected communities. The literature describes two contrasting outcomes. In some cases, destruction from intense hazard events displaces less affluent residents, creating opportunities for wealthier individuals to move in. This pattern was observed in several New Orleans neighborhoods after Hurricane Katrina, where new residents in heavily damaged areas were more affluent and better educated than those they replaced. In other cases, natural hazards exacerbate existing poverty, trapping vulnerable residents in high-risk areas as property values decline and relocation becomes financially unfeasible. The likelihood of one outcome over the other often depends on the community's overall attractiveness. In communities with desirable characteristics, such as access to jobs or natural amenities, hazards may accelerate gentrification by displacing vulnerable populations and attracting wealthier newcomers. Conversely, in communities already facing stagnation or decline, natural hazards can deepen existing vulnerabilities. In some cases, even in communities previously facing decline, post-hazard economic stimuli are leveraged by local stakeholders to promote development, increase attractiveness, and create incentives for gentrification.

These socio-economic changes are often reflected in housing market dynamics. Natural hazards can abruptly reduce housing supply, driving up prices across affected communities. Rising prices may enable wealthier homebuyers to dominate the market, contributing to gentrification in some neighborhoods. However, when comparing areas more or less exposed within the same community, studies often found that more exposed areas experience a relative decline in property values, especially after severe events or updates to risk maps. This price decline can attract lower-income households, leading to a concentration of vulnerable populations in high-exposure zones. In the case of chronic hazards, such as SLR and tidal flooding, empirical observations found a persistent and growing price discount for properties with higher exposure. Yet, despite these localized price drops, properties in flood-prone areas across the US remain, on average, overvalued, as future annual expected losses are not fully reflected in current market prices. This overvaluation raises concerns about potential housing market bubbles, which, in case of burst, could erode household wealth on a large scale and destabilize the broader economy.

Lastly, we reviewed simulation-based models that explore the effects of natural hazards on human communities. As discussed earlier, these effects are shaped by a complex interplay of individual behaviors and broader community characteristics. Given this complexity, developing comprehensive models that account for all relevant factors is challenging. As a result, existing models typically focus on specific subsets of factors, addressing particular aspects of hazard-induced relocation and socio-economic change. We classified the reviewed models into three categories based on their primary focus. Models in the first category focus on physical damages and infrastructure recovery, and simulate permanent out-relocation of certain households based on characteristics like place attachment and wealth. The second category focuses on socio-economic changes, simulating both in- and out-relocation, and housing market dynamics. Finally, the third category consists of relocation models that simulate flows of residents between origin and destination areas, incorporating the effects of slow-onset environmental drivers such as SLR.

These models serve various purposes. Some are used to validate assumptions about empirically observed phenomena. For example, some models have demonstrated how differences in risk perception and preferences for coastal living can explain the overvaluation of coastal properties relative to their fundamental risk-adjusted value. Other models are employed to predict future outcomes, such as identifying neighborhoods that are most at risk of permanent out-relocation based on resident characteristics and hazard exposure. Most of the reviewed models incorporate stochastic components to account for the inherent uncertainties in predicting natural hazards and human behavior. Agent-based modeling is the most common approach, as it starts from diverse individual behaviors to investigate aggregate-level outcomes. For instance, agent-based models are particularly effective in studying housing market dynamics, where heterogeneous, individual preferences of homebuyers and sellers shape broader socio-economic trends.

Lastly, we identified research gaps in the existing literature and propose avenues for future investigation. First, more studies should examine socio-economic and demographic changes in hazard-exposed communities, focusing on the long term (one to two decades) and using finer geographic units. Our review shows that if geographic units are too coarse certain localized effects remain undetected. For instance, in the US, Census tracts appear to capture localized trends that are not observable at the county level. Beyond geographic scale, future studies should also differentiate between hazard types. We showed that different hazards—such as tornadoes, storm surges, and tidal flooding—can produce disparate relocation outcomes, and treating them as a single category may confound the results. For example, in areas exposed to spatially predictable hazards like coastal flooding, residents can reduce their exposure by relocating a short distance, an option not available for less predictable hazards like tornadoes. Future analysis should also expand the range of independent and control variables. For example, reviewed studies examined whether pre-event population trends, population density, or the presence of schools influenced post-event population trends across similarly impacted communities. Building on this approach, future research could assess the role of additional factors, such as presence of grocery stores, job opportunities, industry composition, and socio-economic indicators like unemployment levels. Moreover, beyond population size, future research should further examine socio-economic shifts in hazard-exposed communities, including changes in income, age distribution, and education. Despite their role in shaping gentrification and economic segregation, these factors remain underexplored.

Second, most studies focus on destructive events, while chronic, low-intensity hazards remain understudied. For example, tidal flooding is becoming more frequent due to SLR, yet little research examines how it affects long-term socio-economic and demographic trends. One relevant question could be whether Census tracts exposed to tidal flooding are attracting lower-income households, leading to poverty traps. As sea levels continue to rise, understanding these patterns will become more and more important for developing effective adaptation strategies. Emerging evidence suggests that properties in areas exposed to tidal flooding are already losing value. Some studies warn that values could decline even more abruptly in the future, leading to sudden wealth losses, trapping homeowners, and deepening economic and social vulnerabilities.

Third, more household-level research is needed to understand relocation decision-making. Existing studies have identified several factors influencing out-relocation after a destructive event, but their relative importance remains unclear. For example, social networks—such as ties to family, friends, and communities—are often mentioned as key factors influencing relocation, yet few studies have attempted to quantify their impact on relocation decisions. Additionally, research has largely focused on those who leave hazard-exposed areas, while little is known about those who move in. The motivations and characteristics of residents relocating into hazard-exposed areas remain unexamined, despite their potential impact on housing markets and community resilience. For example, studies suggest that people's risk perception is strongly shaped by prior hazard experience. If new residents lack such experience, they may underestimate risks, leading to distorted housing prices, increased development, and lower preparedness in high-exposure areas. This, in turn, could raise long-term costs for governments tasked with disaster recovery.

Lastly, future research should enhance simulation-based models to better capture the complex interactions between natural hazards and relocation patterns. Existing models focus on distinct aspects of hazard-induced relocation, such as physical damage and infrastructure recovery, out-relocation, in-relocation, housing market dynamics, and relocation flows across regions. However, no model integrates all these components. Integrating physical damage, recovery, in- and out-relocation, and housing market dynamics into a single model represents an interesting opportunity to advance the field. In doing so, the main challenge lies in modeling in-relocation, as the characteristics and motivations of residents moving into hazard-exposed areas remain underexplored. Another opportunity for model improvement is incorporating social networks effects into households' relocation decisions. However, as for in-relocation, social network effects remain insufficiently studied and further empirical research is required to model them mathematically.

Open Research Section

The only dataset used in this study is the U.S. Census Bureau's resident population data for Orleans Parish, LA, retrieved from the Federal Reserve Bank of St. Louis (FRED) (U.S. Census Bureau, n.d.). All other information is based on previously published sources cited in the text.

Acknowledgments

The authors acknowledge financial support from the National Science Foundation (Grants No. CMMI-2332144 and No. CMMI-2332145). They also thank Abigail Victoria Malakun for her assistance in preparing the figures, as part of her final research project in fulfillment of her Civil Engineering degree at UC Berkeley.

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