npj | climate action

Review

https://doi.org/10.1038/s44168-025-00306-6

Socioeconomic impacts and migration dynamics of riverbank erosion

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Riverbank erosion is a major natural calamity causing destruction to lives, settlements, and the environment. This study analyzes the socioeconomic impacts and migration patterns of communities affected by erosion. It identifies literature and policy gaps, proposing future research directions. After reviewing 62 papers from 2000–2024, the study highlights the neglected vulnerability of erosional migrants, who face significant economic and social challenges. It emphasizes the need for a better understanding of psychological, ecological, and demographic factors.

Riverbank erosion is a natural process caused by human actions and climate change, with serious implications for riverbed environments and surrounding populations[1]. Riverbank erosion is a global concern that affects millions of people. Relocating, property losses, and massive social and economic disruptions are all consequences. Bangladesh and Assam in India face an ongoing issue that leads to displacement and poverty, according to several studies[2–4]. Erosion of riverbanks can be observed around the world in various environments, from deltas in Bangladesh where the Ganges, Brahmaputra, and Meghna rivers meet to vast riverbanks of the Mississippi in America or flood-prone regions such as the Brahmaputra Valley in Assam, India—each area differs in terms of geological, hydrological and socioeconomic influences that impact riverbank erosion rates. Bangladesh is plagued by erosion of riverbanks due to the country's dependence on river systems for food supply, and monsoon rains that occur annually exacerbate the issue, leading to mass relocations, destruction, devastation, or forced emigration[1,4]. The unpredictable activities of the Brahmaputra River in Assam, India, cause severe erosion that ruins millions of lives[3].

The erosion of riverbanks on a global scale has caused serious ecological and economic impacts due to land loss and costly technological measures to curtail riverbank erosion. For example, erosion along the Mississippi River is extensive, causing costly mitigation to minimize damage to infrastructure and ecosystems[5,6]. This behavior is similar to that occurring in European river systems, such as the Tiber and Danube rivers. Both rivers have experienced massive erosion, putting critical infrastructure, cultural heritage sites and local economies at risk[7,8]. Anthropogenic modifications have altered the natural flow and sediment transport dynamics of rivers, such as the Tiber River, which has increased the vulnerability of banks[9]. The Danube River has experienced major engineering interventions that have already altered its morphology and aggravated erosion problems[6,7]. In addition to endangering the physical integrity of riverbanks, these changes affect the livelihoods of communities that depend on these waterways for economic activities.

Riverbank erosion has profound socioeconomic consequences, disproportionately affecting impoverished communities worldwide[1]. Immediate impacts—including forced relocation, livelihood loss, food insecurity, and intensified poverty—are extensively documented[1,4,10–14]. For instance, in Bangladesh, erosion-induced displacement severely disrupts lifestyles, exacerbating housing shortages and unemployment[11,12] whereas quantitative studies in Assam's Brahmaputra Valley directly link high erosion rates to extreme poverty[3,15]. This synergy between environmental degradation and socioeconomic vulnerability traps communities in cycles of deprivation, underscoring the urgency of robust policy interventions and support systems[1,4,16].

However, long-term implications remain understudied. Complex migration patterns, urban infrastructure strain from displaced populations, and psychosocial impacts—such as the loss of cultural heritage and community cohesion—demand deeper analysis[2,3]. Current research emphasizes multidisciplinary solutions integrating engineering measures (e.g., erosion-resistant structures) with social strategies (e.g., livelihood rehabilitation), as highlighted in studies of adaptive techniques and ecosystem resilience[17–20]. A holistic approach bridging environmental and socioeconomic research is vital for developing sustainable frameworks that address both immediate needs and systemic vulnerabilities, ultimately mitigating this escalating global crisis.

Despite these extensive studies, there is still a significant gap in the literature regarding the integration of long-term socioeconomic effects and the migration dynamics of riverbank erosion, especially through a multidisciplinary lens that combines both environmental and social perspectives. Most existing research tends to focus either on immediate impacts or on isolated aspects of the erosion process, without adequately addressing how these processes interact over time to shape migration patterns, community

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Table 1 | Research protocol

Items	Description
Research question	How do socioeconomic impacts and migration dynamics manifest in communities affected by riverbank erosion?
Database	Scopus (primary), and additional articles identified from references during full-text screening.
document type	Only peer-reviewed articles
Language	English
Publication Period	From 1 January 2000 to 31 July 2024
Search terms	Riverbank erosion, socioeconomic impacts, migration dynamics, displacement, adaptive strategies
Search fields	Title, abstract, and keywords
Inclusion criteria	Articles focusing on the socioeconomic impacts of riverbank erosion and related migration dynamics.
Exclusion criteria	Inaccessible full texts, duplicates, non-English articles, and articles not centered on the socioeconomic aspects of riverbank erosion.

adaptation, and resilience. To fill this research gap, a multidisciplinary approach is needed to evaluate both the immediate effects of riverbank erosion and the root causes that influence the susceptibility and adaptability of impacted communities. Therefore, this study addresses the following research questions.

a. What are the socioeconomic impacts of riverbank erosion on affected communities?
b. How does riverbank erosion influence migration dynamics, including patterns and determinants of migration?
c. What are the long-term effects of riverbank erosion on the livelihoods and living conditions of displaced populations?

This research explores the socioeconomic effects of riverbank erosion and the resulting migratory patterns. This research seeks to comprehensively understand the impact of riverbank erosion on vulnerable groups and to suggest effective measures for mitigation and assistance by combining information from various settings. By adopting this comprehensive and integrated approach, this study contributes new insights into the interconnections among environmental change, socioeconomic vulnerability, and human migration, offering practical recommendations for policy and adaptation strategies.

Methodology

Systematic review approach (PRISMA)

This research employs systematic review methods following PRISMA guidelines to explore the socioeconomic effects and patterns of migration caused by riverbank erosion in Bangladesh. We developed a research protocol using PRISMA 2020 principles as our guidelines (Table 1) for research procedures over 24 years, with particular attention given to more recent work, which brings resilient concepts and adaptable methods together to combat riverbank erosion effects.

Search strategy, inclusion, exclusion and study selection for the study process. The study utilized Scopus as its primary database due to its comprehensive coverage of social and environmental research, employing targeted search strings (Table 1) combined with Boolean operators (AND/OR) to optimize results. The search was supplemented by full-text screening, reference tracking, and proximity searches, with English-language and peer-review restrictions applied for quality assurance. Inclusion criteria mandated that studies specifically address the socioeconomic and migration impacts of riverbank erosion in peer-reviewed, English-language publications, while excluding those focused solely on physical or geological aspects.

We employed the PRISMA method for document selection (Fig. 1). A total of 306 research papers were identified from different sources, namely Web of Science (WOS), Scopus, PubMed and Google Scholar. It was screened then, and 61 duplicate papers were excluded. Therefore, 245 studies were then revised through screening titles and abstracts, and 97 papers were excluded due to their irrelevance to the study. Afterwards, we checked the eligibility by screening the full text of 148 studies and found 86 papers were irrelevant, which were excluded from the study. Finally, 62 papers were selected for review in this paper, and the data and information were extracted from those papers. Hence, the noticeable number of published papers comes from the last 10 years.

A systematic document analysis framework (Table 2) guided the in-depth review of the selected literature, ensuring rigorous evaluation through predefined criteria for comprehensive assessment.

This systematic document analysis strategy was used to obtain an accurate evaluation of the selected literature. The first step was to choose words that fit the objectives and research questions and to include everything related to them in the analysis. By providing a term sheet, we had a good structure for working through this type of analysis, and the selection of themes iteratively enabled us to continuously refine topics as we went deeper and more flexibly in the analysis.

Qualitative analysis procedure of selected papers. The study employed thematic analysis to systematically examine the collected literature, beginning with repeated close readings of papers to identify key patterns and nuances relevant to riverbank erosion impacts. Through this immersion process, researchers developed initial codes by methodically categorizing significant textual elements that addressed the research questions. As detailed in Network visualization, this qualitative approach enabled the identification and exploration of emerging themes, providing deeper insights into socioeconomic and migration dynamics. The coding process served as the foundation for subsequent theme development and analysis, ensuring that the findings were grounded in comprehensive data examination.

Theme Identification and reviewing papers. Through iterative analysis, the data extracts were organized into key themes and subthemes, including government responses to riverbank erosion, community adaptation phases, and strategies for socioeconomic resilience and migration management. These themes were rigorously reviewed against the full dataset to ensure that they accurately represented the evidence (Table 3), with each theme carefully defined and labeled to capture its core meaning. This thematic framework then guided the results section, ensuring that the findings were systematically presented and substantiated by the collected data.

Data analysis and bias resolution strategies. Following the PRISMA 2020 guidelines, this study employed thematic synthesis to analyze quantitative and qualitative data on socioeconomic impacts and migration patterns from riverbank erosion systematically, with key trends (e.g., property loss, livelihood disruption) identified through a structured term sheet (Table 3). The analysis incorporated iterative theme refinement and meta-synthesis to triangulate findings, while rigorous bias control measures were implemented: (1) selection bias minimization through strict inclusion/exclusion criteria for peer-reviewed literature; (2) publication

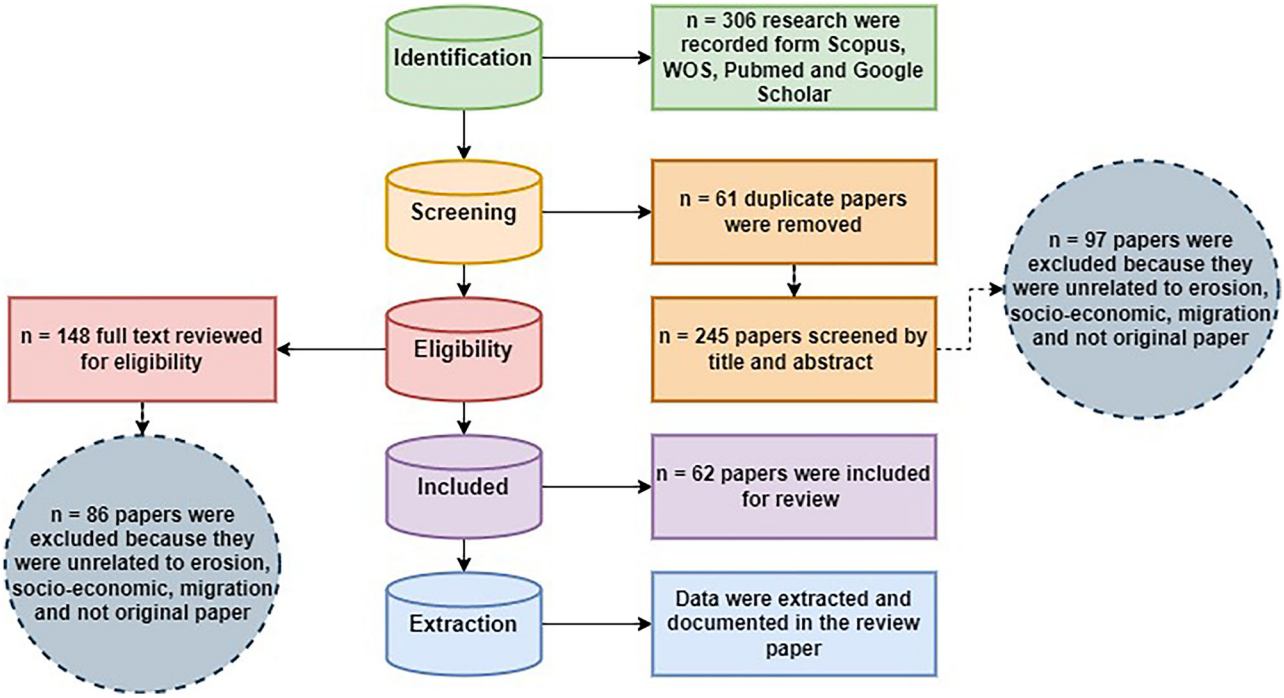

Fig. 1 | Document selection procedure through the PRISMA method.

Table 2 | Criteria of analysis for document review

Criteria	Description
Key phrases selection	The document analysis was initiated by identifying key phrases relevant to research objectives such as 'riverbank erosion', 'socioeconomic impacts', 'migration dynamics', 'displacement' and 'community resilience'.
Term sheet development	A term sheet was developed that specified themes and subthemes to guide the literature analysis. The review was done in reference to this, which brought focus and a structured review of the documents.
Document reading strategy	All selected documents were read with a dual focus: Being able to see the broader narrative and finding sections that the term sheet brings up. The dual approach helped to achieve an all-encompassing knowledge of each document's role in the fulfillment of research objectives.
Theme selection	A thematic analysis was employed. Literature excerpts were categorized in terms of relevant themes from the term sheet. It was iterative, with the opportunity to refine the themes developed as the review progressed, and therefore created a dynamic and responsive analytical framework.

Table 3 | Term sheet for thematic analysis

Theme	Subthemes	Indicators	Sources
Socioeconomic impacts	Economic consequences	- Loss of property and agricultural land - Impact on local economies and employment - Costs associated with relocation and resettlement - Changes in livelihood strategies	17,21–27,60,61
	Social consequences	- Disruption of community and family structures - Health and psychological impacts due to displacement - Effects on education due to migration - Loss of cultural heritage and identity	28,29,33–37,62
Migration dynamics	Migration patterns	- Temporary vs. permanent migration - Rural to urban migration trends - Cross-border migration due to severe erosion - Community-led vs. individual or family migration decisions	38–43,63–66
	Determinants of migration	- Severity and frequency of riverbank erosion events - Socioeconomic status and vulnerability of affected populations - Availability of social networks and support in destination areas - Government policies and interventions affecting migration choices	39,41–44,66
Policy gaps	Riverbank erosion-related policy gaps	- Lack of comprehensive policies addressing both immediate and long-term needs of displaced populations - Insufficient integration of erosion mitigation and adaptation strategies in development planning - Gaps in funding and resource allocation for erosion control and community support - Inadequate engagement with affected communities in policy formulation and implementation	16,47–54,67,68

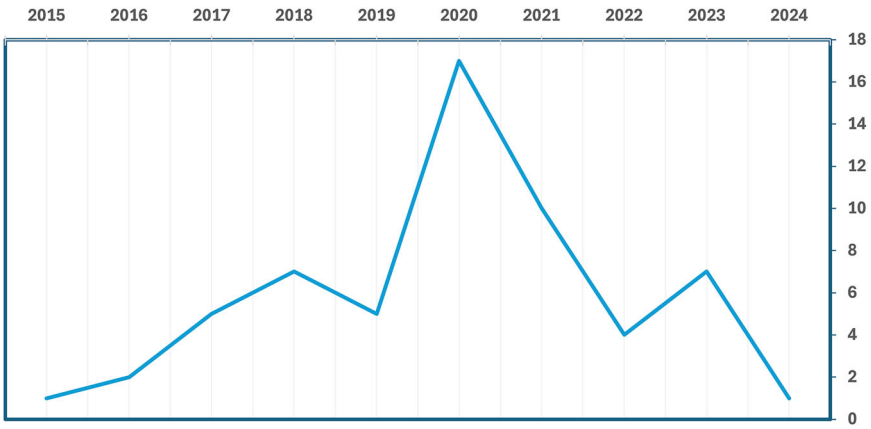

Fig. 2 | Number of publications over the last 10 years.

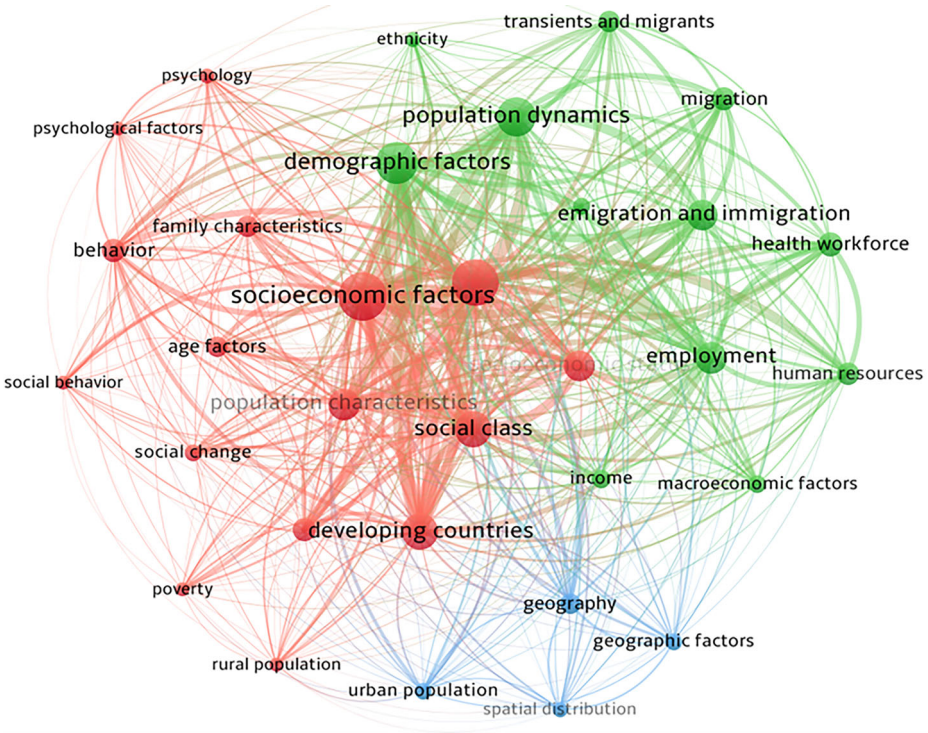

Fig. 3 | Network visualization of co-occurrences from keywords.

bias reduction via incorporation of gray literature and citation chaining; (3) coder bias prevention through dual independent review and validation; and (4) enhanced generalizability through diverse geographical and contextual coverage in the sample. This comprehensive approach ensured methodologically robust and balanced interpretations of erosion dynamics and their consequences.

Results

Distribution of publications over time

The selected documents were published from January 2000 to June 2024. Therefore, the majority of publications were published in the last 10 years (Fig. 2). A gradual increase in publications was noticed from 2015 to 2019, whereas it significantly increased during 2020. However, the number of publications decreases for the years 2022 and 2023. Moreover, the recent publication clearly indicates the need for research on social, economic and migration factors in different manners due to riverbank erosion. Several studies have emphasized adaptation and mitigation strategies for riverbank erosion. Therefore, the suffering of riverside populations comes with not only riverbank erosion but also their socioeconomic status. Hence, different studies also consider the migration of displaced people due to erosional activity. These studies are both qualitative and quantitative. Some of them consider mixed methods to evaluate their objectives.

Network visualization

The VoSviewer tool is used to visualize the interconnections of the concepts of riverbank erosion-induced socioeconomic, psychological, and migration patterns (Fig. 3). The visualization uses a co-occurrence matrix derived from the literature to assess the similarity and frequency of mutual citations among research works. This matrix was illustrated on a two-dimensional map, with items placed closer together indicating stronger relationships. This resulted in the formation of clusters representing related subjects. Through network analysis, key topic clusters were identified, including methods for detecting riverbank erosion, management strategies, health impacts, and patterns of immigration and emigration. The visualization also

Table 4 | Economic losses due to riverbank erosion in Bangladesh

Sectors affected	Geographic location	Methodological estimation	References
Housing, Agriculture, Livelihoods	Lalmonirhat District, Teesta River	Questionnaire Survey, Field Observations, Data Analysis using SPSS	21
Housing, Agriculture, Infrastructure	Charcowa Union, Barisal Sadar Upazila	Field Surveys, Soil Testing, GPS Mapping, Image Analysis	60
Housing, Livelihoods, Agriculture	Bhola District, Coastal Bangladesh	Field Surveys, Interviews, Focus Group Discussions, SPSS Analysis	24
Agriculture, Housing, Infrastructure	Harirampur, Padma River	Field Surveys, Google Earth Image Interpretation, SPSS Analysis	61
Housing, Agriculture, Social Bonds	Nalua Union, Bakerganj	Field Surveys, Google Earth Image Interpretation, SPSS Analysis	25
Housing, Livelihoods, Agriculture	Koyra Upazila, Khulna	Surveys, Key Informant Interviews, Focus Group Discussions	23
Housing, Livelihoods, Agriculture	Harinatpur, Barishal	Field Surveys, Questionnaire Survey, GPS Mapping	26
Housing, Agriculture, Food Security	Gaibandha District, Jamuna River	Field Surveys, Questionnaire Survey, Multinomial Logistic Regression, SPSS Analysis	22
Housing, Agriculture, Livelihoods	Sirajganj District, Brahmaputra River	Participatory Rapid Appraisal (PRA) tools, CRiSTAL software, Rep IV software	27
Agriculture, Housing, Infrastructure, Social Sectors	Mehendiganj Upazila, Barishal District	Field Surveys, Focus Group Discussions, Key Informant Interviews, Descriptive Statistics	17

depicted the most utilized keywords in the studies, with terms such as "socioeconomic," "migration," "immigration and emigration," and factors of adaptation and mitigation strategies indicating high relevance and frequent occurrence in the literature. This analysis highlights the interconnected nature of these topics and their significance in the fields of socioeconomic, migration and sustainable erosion management.

Economic consequences

Bangladesh's vast network of riverbanks is eroding at an alarming rate, a critical environmental and socioeconomic issue affecting millions of people living around rivers. With its Brahmaputra, Teesta, Padma, and Jamuna, Bangladesh struggles with the dynamic, shifting nature of these water bodies. Riverbank erosion is a severe socioeconomic problem as well as an environmental problem that affects the living, housing, facilities and social structures of communities in riverine areas. The problem is exacerbated by annual monsoon floods, which cause severe erosion and loss of land and property, displacement of communities and substantial economic losses (Table 4 and Fig. 4). In this section, we discuss the economic impact of riverbank erosion in Bangladesh, using data from several studies to demonstrate the magnitude and scope of the problem.

Figure 4 shows the spatial visualization of the economic studies, which indicates that a gap in the literature on different rivers prevails. Most of the spatial locations are focused on the Brahmaputra, Jamuna, and Lower Meghna Rivers. However, the Upper Ganga (Padma) is significantly ignored. However, in addition to the three major rivers, other tributaries have received less or no attention regarding economic research projects and their implementation recommendations.

Social consequences

Riverbank erosion in Bangladesh not only has severe economic repercussions but also strongly impacts the social fabric of communities. The country's vast river systems, including the Brahmaputra, Teesta, Padma, and Jamuna, play a dual role as vital resources and agents of destruction. The continuous shifting and eroding of riverbanks have led to significant social and cultural challenges that affect millions of people. Displacement of populations, loss of livelihoods, and disruption of social networks are among the critical issues faced by communities living along these riverbanks. The emotional and psychological toll, compounded by the constant threat of future erosion, adds layers of complexity to their already precarious existence. This section categorizes and discusses the social impact of riverbank erosion on the basis of multiple studies, highlighting the widespread and profound effects on affected populations (Table 5 and Fig. 5).

The spatial pattern of the social consequences is significantly focused on the Sirajganj and Tangail districts, which are banks of the Jamuna River (Fig. 5). These findings reveal that erosional severity mostly prevails in those locations. Moreover, other locations are also focused on the identification of social consequences from erosional perspectives.

Migration patterns

A summary of the migration patterns, settlement dynamics, and migration rates in various riverine and char areas affected by riverbank erosion is presented in Fig. 6 and Table 6. Figure 6 reveals that the major percentage of population migration is in the banks of the Jamuna and Padma. Moreover, these migration percentages vary in different locations, ranging from 60% to >80%.

The dynamics of this migration vary by region (Table 6). In some areas, such as the Jamuna basin, households have relocated >13 times over four decades. In the Lower Meghna region, settlements are often temporary, with most people moving nearby, though permanent resettlement is less common. This pattern of frequent displacement highlights a cycle of vulnerability, where communities are unable to establish long-term stability.

Determinants of migration

Table 7 explores the factors that influence the decision of migration and nonmigration in regions affected by riverbank erosion. It presents a comparison between the causes leading to migration and the reasons for individuals or households choosing not to migrate in various riverine and char areas.

Riverbank erosion is the root cause of migration in most studies. Therefore, we determine the cause of why some people are migrating due to riverbank erosion and why others are not. The cause behind this is riverbank erosion, which is the main determinant of the loss of agricultural land and income sources, poverty, limited employment opportunities, and a lack of livelihood and income opportunities. As in the lower Meghna River Basin, 44% of migration happened to save dwellings. Conversely, factors contributing to nonmigration include a lack of viable alternatives for relocation, a fear of increased impoverishment and a lack of resources in urban settings, deep-rooted connections to communities, and access to natural resources. For example, 89% of the respondents had no alternative land to migrate to other locations.

Key challenges and coping mechanisms for displaced populations

Table 8 provides a comprehensive analysis of the difficulties faced by migrants due to riverbank erosion. These challenges are essential for understanding the complexities and difficulties faced by displaced populations.

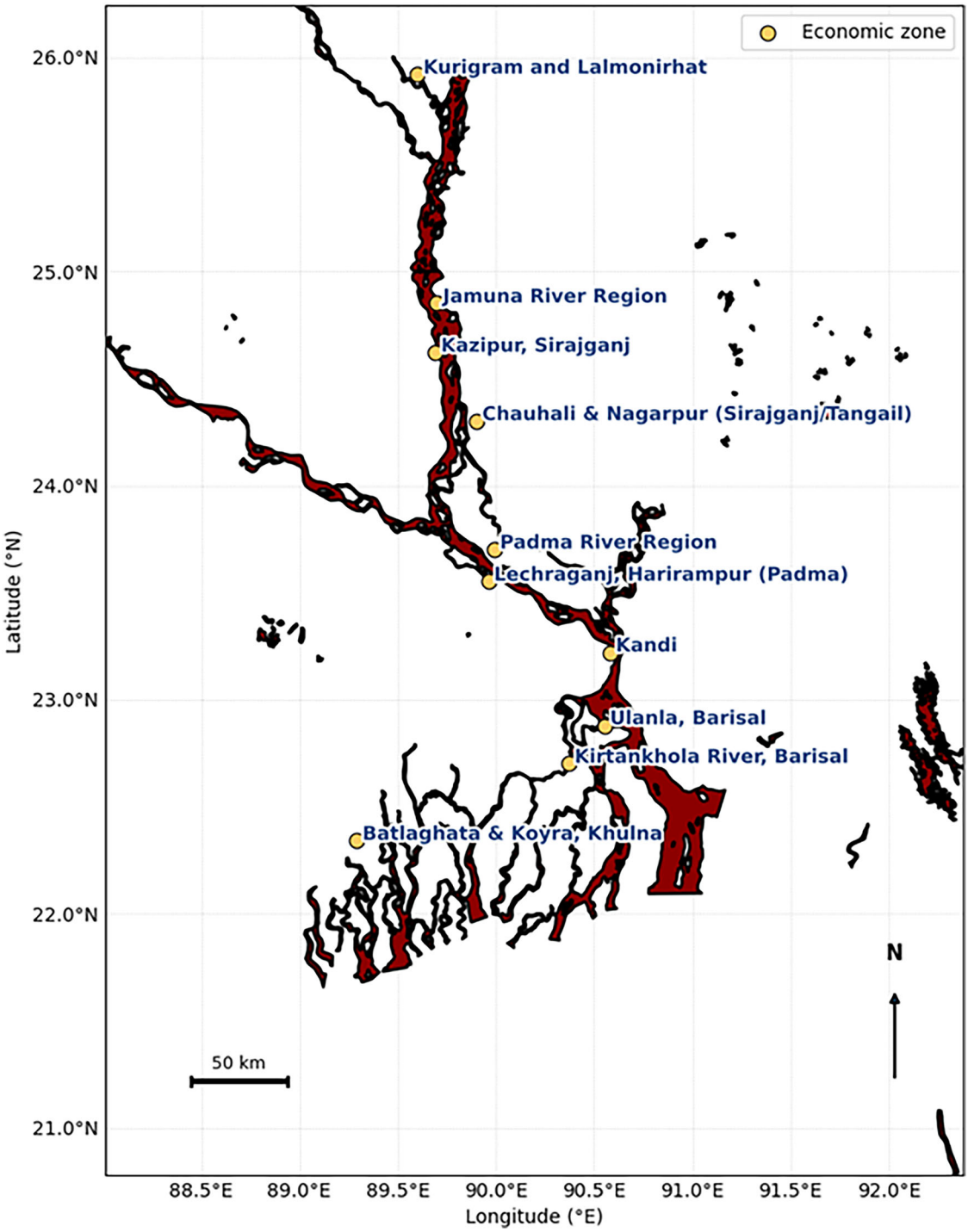

Fig. 4 | Spatial distribution of the economic impact assessment study due to riverbank erosion.

In Table 9, we explore different coping mechanisms from the variety of eroded locations in Bangladesh. These coping strategies are crucial for further study development and policy advancement. Hence, these findings may help displaced populations navigate and adapt to the challenges they encounter.

Riverbank erosion-related policy gaps

Table 10 presents a comprehensive analysis of policy gaps in riverbank erosion management in Bangladesh, derived from an extensive review of literature and field-level experiences. The table highlights critical shortcomings across various dimensions of policy and implementation, shedding light on the challenges hindering effective erosion mitigation strategies. These gaps encompass financial constraints, coordination failures, regulatory inconsistencies, inadequate infrastructure, and knowledge deficiencies, among others. On the other hand, different studies have indicated policy measures, governance challenges and recommendations, which include insufficient aid for environmental refugees, inadequate access to resources, a lack of government intervention, limited access to formal credit, and high vulnerability to displacement (**S1**). Through systematic categorization, each policy gap is elucidated, providing a nuanced understanding of the multifaceted nature of riverbank erosion management challenges in Bangladesh.

Table 5 | Erosional impact on communities and livelihoods

Geographic location	Population affected	Livelihoods impacted	Social and cultural impacts	Sources
Sirajganj, Sharia Kandi	238 households	Agriculture, day laborers	Increased psychological distress, loss of agricultural land	28
Ulanla, Barisal	796 households	Fishing, small businesses	Loss of homes, disruption of social networks, and Increased gender-based vulnerabilities	33
Padma River Region	Thousands	Agriculture, small trades	Displacement, loss of cultural heritage, and increased poverty levels	34
Kurigram and Lalmonirhat	300 households	Smallholder, farmers	Increased risk perception, adoption of diverse adaptation strategies	29
Lechraganj, Harirampur	2653 households	Various	Food Insecurity, adaptation strategies, and Increased vulnerability to natural disasters	62
Kazipur, Sirajganj	619 households	Agriculture, small trades	Frequent displacement, social fragmentation, and dependence on local patrons	35
Chauhali, Sirajganj and Nagarpur, Tangall	330 households	Farming, non-farming	Adoption of new crop varieties, changing planting time, homestead gardening, and migration	55
Jamuna River Region	380 households	Diversifying crops, homestead gardening, and migration	Lack of Information, lack of credit, limited access to institutions	10
Batlaghata and Koyra, Khulna	420 households	Various	Loss of social relationships, health Impacts due to climate change	36
Kirtankhola River, Barisal	6156 of the surveyed population	Various	Migration changes in social structure, Increased vulnerability	37

Discussion

Economic impacts

Riverbank erosion severely disrupts economic stability, and damages housing, agriculture, infrastructure, livelihoods, social cohesion, and food security[21,22]. Housing losses force repeated reconstructions, displacing families and straining finances[21,23], whereas temporary shelters increase vulnerability[24]. Agriculture suffers from land loss, reducing productivity and triggering migration[25,26], however, erosion-resistant farming methods remain understudied. Infrastructure collapse (e.g., roads, bridges) cripples local economies[17,26], demanding resilient designs. Livelihood erosion pushes communities into insecure work, perpetuating poverty[23,26], whereas social fragmentation and food shortages deepen crises[25,27].

Riverbank erosion is an urgent and complex issue that requires holistic approaches to mitigate its economic impact. Efforts should focus on sustainable housing, resilient infrastructure, diversified livelihoods, strengthened community bonds, and food security measures. Policymakers and researchers must collaborate to develop integrated strategies that address both immediate needs and long-term resilience in erosion-prone regions.

Social impacts

Riverbank erosion severely disrupts psychosocial well-being and community structures. Affected populations experience chronic stress, anxiety, and depression due to displacement and livelihood loss[28–32]. Displacement fractures social networks, with women disproportionately affected by increased domestic burdens and economic vulnerability[33,34]. Cultural erosion and community fragmentation are particularly acute in frequently displaced areas such as Kazipur[35].

The intersection of social and health vulnerabilities due to displacement is evident, as erosion-induced migration leads to overcrowded living conditions, limited access to healthcare, and heightened health risks. Research by refs. 36 and 37 revealed the prevalence of diseases and the erosion of informal support systems in displaced populations. Additionally, affected communities often lack access to crucial resources such as information, credit, and institutional support, hindering their resilience and adaptation capabilities[10]. Future research should prioritize sustainable strategies for rebuilding social ties, fostering cultural heritage, improving healthcare delivery, and strengthening institutional support. Policies that integrate mental health, social cohesion, and resource accessibility can address these cascading challenges and enhance community resilience.

Migration dynamics and determinants

Analysis of migration patterns, settlement dynamics and migration rates provides an understanding of the multifaceted nature of displacement arising from riverbank erosion (Table 3.1). Riverbank erosion drives complex migration patterns shaped by geographic, socioeconomic, and environmental factors. Analysis revealed significant regional variations in displacement frequency—from single migrations (71% in Meghna/Lakshmipur) to repeated relocations (2–5 times in Lower Meghna)[11,38]. Settlement types diverge between temporary moves to elevated areas/relatives' homes[28], and permanent resettlement beyond erosion zones[39,40], with displacement rates ranging from 36% in the Meghna estuary to 72.2% in the Padma-Jamuna basins[41,42].

Migration decisions stem from three interlinked determinants:

1. **Push factors**: Direct erosion impacts, including land loss[39], livelihood collapse[11], and housing destruction[38].
2. **Anchoring factors**: Cultural ties to ancestral lands[22] and reliance on local ecosystems[41].
3. **Systemic barriers**: Lack of alternative land[43] and economic constraints preventing relocation

These dynamics underscore the need for context-specific interventions addressing both (i) immediate drivers (through erosion control and livelihood alternatives) and (ii) root causes (via land management and community resilience programs)[14].

Key challenges and coping mechanism

An analysis of key challenges and coping mechanisms in populations affected by riverbank erosion helps characterize how displacement experiences are multifold and how people manage adversity. Table 8 presents the scope of challenges facing the displaced population, from economic hardships and health vulnerabilities to social dislocation. Erosion-induced displacement drives livelihood shifts, often toward insecure urban labor markets[28,39].

Furthermore, the lack of health facilities only increases health vulnerabilities and risks, particularly for women who visit antenatal services, which are essential baselines for systemic issues as they further heighten the vulnerability of displaced people[40]. A lack of social interaction, a shortage of decent accommodations and increased distress are evidence of the large-scale sociocultural effects of riverbank erosion-induced migration[44,45].

Table 9 shows the resourcefulness and resilience of the affected communities through different coping measures. The adaptive capacities of

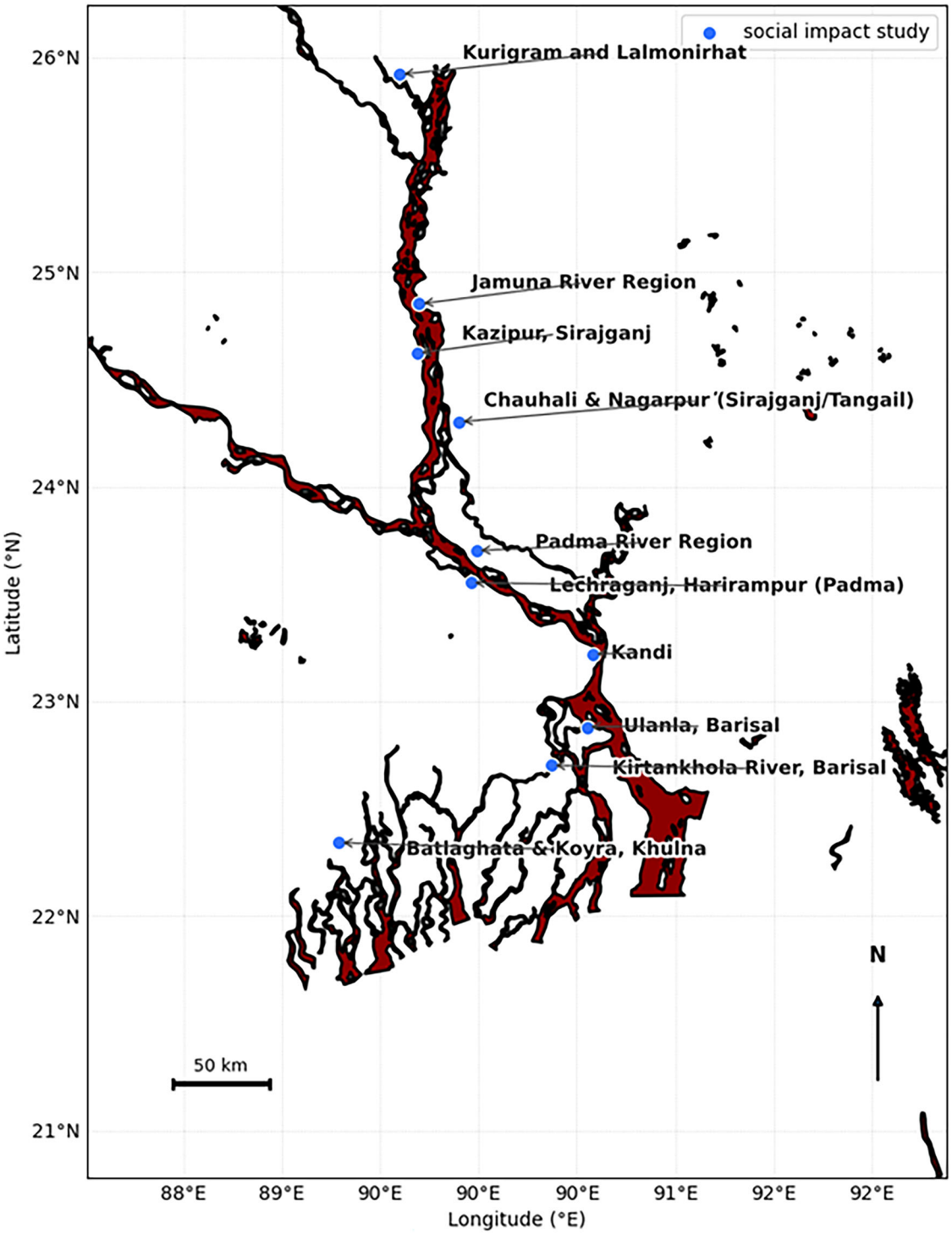

Fig. 5 | Spatial distribution of the social impact assessment study due to riverbank erosion.

displaced populations to adversity are manifested by strategies such as seeking funding from relatives, temporary housing arrangements, and diversifying livelihoods[1,46]. Moreover, community mobilization strategies and the use of cultural and religious beliefs work as important coping mechanisms to offer support, both emotionally and practically, when people are moving from one place to another[28,37].

Appreciation of the multiple interconnections among socioeconomic, environmental and cultural factors can help policymakers and practitioners design interventions suited to the situations of populations at risk. It is possible to promote people's resilience and hence sustainable adaptation of the people affected by riverbank erosion through livelihood improvement interventions, adequate healthcare service provision and a strong social support network. Additionally, addressing the root causes of displacement is crucial in combating environmental destruction and poverty to guarantee the well-being and safety of communities in the long-term.

Policy gaps and recommendations

Riverbank erosion in Bangladesh poses severe environmental and socio-economic challenges of people living near the Brahmaputra, Teesta, Padma, and Jamuna rivers. Therefore, different studies address various research

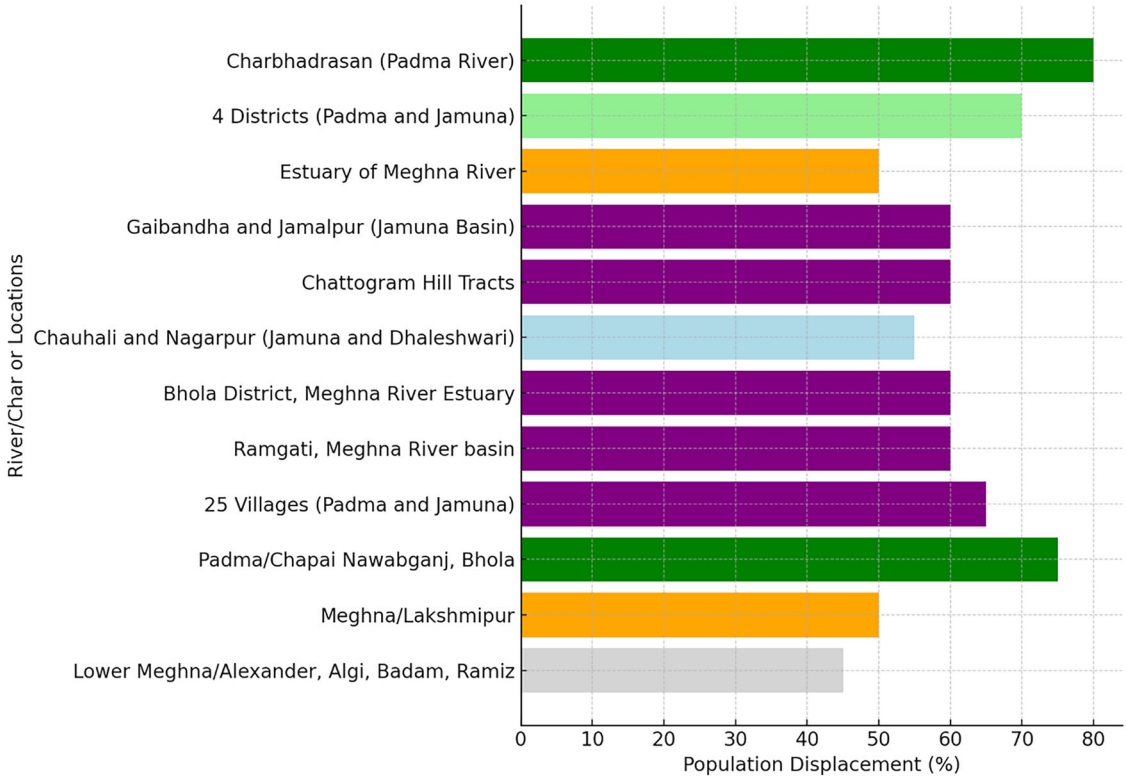

Fig. 6 | Spatial migration percentage focusing on riverine migrants in different rivers of Bangladesh.

Table 6 | Exploring riverbank erosion: migration patterns, settlement dynamics, and migration rates

River/Char or locations	Distance moved	Temporary settlements	Permanent resettlement	Rate of migration	Sources
Lower Meghna/Alexander, Algi, Badam, Ramiz	Nearby	Yes	No indication	2–5 times	38
Meghna /Lakshmipur	>15 km	Yes	No indication	Once (71%) Fourth (>6%)	11
Padma/Chapai Nawabganj, Bhola	Alleviated place nearby	N 0 = o	Most of the respondents	>1	39
25 Different villages from the basin of the Padma and Jamuna	Alleviated place nearby/ relatives	No indication	No indication	>3	63
Ramgati, Meghna River basin	12.65 square miles	No indication	Yes	>1	64
Bhola District, Meghna River Estuary	Nearby embankment comes the road	Yes	Yes (42%)	3–4 times	40
Serajganj and Shariakandi	Nearby	Yes	No indication	Once (5%) Twice (8%) 3–4 times(40%) 5–10 times (36%)	28
Chauhali and Nagarpur Upazila of the Jamuna and Dhaleshwari River	No indication	Yes	Most of the respondents	>1 (one third) >3 times (57%)	14
Chattogram Hill Tracts	Far from the displaced location	No indication	Most of the respondents	Every year	43
Gaibandha and parts of Jamalpur district in the Jammuna River Basin	Within 5 km of the erosional area	Yes	Poor (76%) Moderately poor (70%)	13 times between 1978 and 2018	65
Estuary of Meghna River	Nearby	Yes	No	2–5 times	41
Four different districts in the basin of the Padma and Jamuna rivers	3.3 km	Yes	Yes	4.63 times	42
Charbhadrasan Upazilla in the basin of the Padma River	Far from the displaced location	Yes	Yes	>3 (60.2%) 3–4 (12.8%) 5–6 (12.2%) 7–8 (14.8%)	66

Table 7 | Factors influencing riverbank erosion-driven migration and nonmigration

River/Char	Causes and percentage for migration		Causes and percentage for no migration		Sources
Lower Meghna/ Alexander, Algi, Badam, Ramiz	To save the dwellings from riverbank erosion	44%	Riverbank erosion is an inherent aspect of livelihood, with no viable alternatives for relocation	16%	38
			Fertile Land	n/a	
Meghna River/ Lakshmipur	Losing agricultural land, an income source	n/a	Have no land to establish themselves elsewhere	89%	11
Padma/Chapai Nawabganj, Bhola	To resettle the dwelling elsewhere so that they would not have to suffer erosion again.	12 out of 16	Because of a lack of skills for other jobs, and depending on natural resources like fishing from the river		39
Khulna	Because of losing cattle, land, and income source	n/a	n/a	n/a	44
Fulchari & Saghata upazilas of Gaibandha district	Climate change, alongside its associated disasters such as flooding and erosion, serves as a primary driver as it is a threat to their life, food, water and energy security.	n/a	As the land they are living on is from their ancestors, however, they had to leave their land because of severe erosion in 2017	n/a	22
Serajganj and Shariakandi	Rapid population growth, poverty, and limited industrialization in Bangladesh have increased vulnerability to riverbank erosion.	n/a	The poor face significant economic constraints and marginalization, especially when displaced to urban areas. The fear of increased impoverishment and lack of resources in urban settings might discourage migration.	n/a	28
Chauhali and Nagarpur Upazila of Jamuna and Dhaleshwari River	The cause of migration in vulnerable households is primarily driven by the lack of access to agricultural land and limited employment opportunities.	n/a	n/a	n/a	14
Chattogram Hill Tracts	Lack of livelihood and income opportunity	79% &59%			43
Estuary of Meghna River	Numerous households in the study region have relocated in anticipation of potential loss of their homes to riverbank erosion.	n/a	The displaced populations within the study region exhibit a strong preference to stay locally, driven by deep-rooted connections to their communities and the abundance of natural resources. The proximity to river systems offers them opportunities to rebuild river-dependent livelihoods. Additionally, they have access to fresh, uncontaminated fish and vegetables, free from harmful chemicals like formalin.	n/a	41
Four different districts in the basin of the Padma and Jamuna rivers	Loss of homes and agricultural lands, leading to being forced to migrate and relocate elsewhere	n/a	Strong attachment to their community and land	n/a	42
Charbhadrasan Upazilla in the basin of the Padma River	Lack of occupational opportunity		Due to no of capacity to hold land elsewhere household did not migrate, although they are at risk of erosion.	92.31%	66

'n/a' indicates that no data percentage was found.

Table 8 | Navigating migration challenges: insights into riverbank erosion-induced migration obstacles

Key challenges	Sources
Managing the source of income	39
Fee free public hospital is not providing appropriate health facilities to the women who need women's antenatal care due to riverbank erosion displacements.	63
Due to moving to a new place, social connections were greatly hindered	40,44
85.7% of the 420 households were physically damaged during the displacement period	44
92.9% of the 420 households do not have sufficient money to take treatment	44
The relocated individuals experienced significant challenges, including housing and sanitation issues, food insecurity, health concerns, and various social problems upon resettlement in a new location.	22
The vulnerable communication system in the place where the erosion respondent lived.	22
97% of respondents think building revetment plays a significant role in reducing displacement	64
62.82% of respondents had to change their profession as erosion has taken away their cultivated land. Therefore, due to loss of their own land, some became agricultural labor, some became seasonal labor.	40
Crises of money (81.6%), food (53.6%) and relocating household belongings are a vital challenge.	40
The displaced people are forced to go to urban areas to find a job, where they have faced social and economic disadvantages. Therefore 90% of them have no skill in other jobs except farming activities.	28
Numerous individuals residing in impoverished urban areas expressed their inability to relocate due to insufficient resources, despite enduring continuous exposure to climatic, environmental, and social hazards. Consequently, this predicament has had detrimental effects on their mental well-being	45,69,70
Migration propensity is higher among households characterized by members aged between 20 and 50 years (with an average of 28.6 years) and education levels below primary education (with an average of 2.7 years).	14
75% of the riverside economy depends on agriculture. However erosional activity destroys occupational dependency which generates forced migration	39

Table 8 (continued) | Adapting to change: effective coping strategies for riverbank erosion-induced migrants

Key challenges	Sources
Coastal cyclones are the root cause for the severity of riverbank erosion as it is leading to climate migrants	43
Health consequences like diseases, lack of medical individuals and lack of livelihood infrastructure facilities	43
The scarcity of financial means among those displaced poses a significant obstacle. This financial shortfall restricts the capacity of these households to relocate from regions prone to riverbank erosion.	41
Displaced individuals face significant socioeconomic hardships, including reduced income, education, and access to basic facilities like sanitary toilets and electricity.	42

Table 9 | Adapting to change: effective coping strategies for riverbank erosion-induced migrants

Coping strategies	Sources
Taking loans, getting help from relatives	38
Getting assistance through debt, help from relatives and selling domestic animals and properties	46
>Temporarily living in relative/friend's house and finding another place to live, even by leasing land from others. >Moving to the capital of Dhaka city and joining as a garment worker, janitor, cobbler, or fruit retailer.	1,39
Despite formulating numerous adaptation strategies such as reducing expenses and food consumption, engaging in begging, livestock rearing, and seeking refuge in demesne land to address their livelihood challenges and sustain their lives.	22
Due to the lack of government's proper attention to the community who were at risk of erosion, protested through social media and human chain and eventually they succeeded to attract the government. Finally, the government built the revetment in Ramgati.	37
Taking shelter on the road comes embarkment, and renting houses during the time of erosion	40
People affected by riverbank erosion have developed coping and adaptation strategies. Despite high levels of psychological distress primarily due to socioeconomic deprivation, they tend to rely heavily on religion and cultural beliefs to interpret and respond to natural calamities.	28
Seasonal migration emerges as a significant coping mechanism in response to food shortages due to riverbank erosion	14
Early, during and after the hazard assistance from the government may significantly help to mitigate hazardous events like erosion	71–73
Reconstructing homes close by on the properties of family members, acquaintances, and neighbors, as well as on land owned by the government.	41
Access to community support networks is another key coping strategy for migrants, providing crucial emotional and practical assistance during times of displacement and resettlement.	42
Leasing land for the resettlement of 74.36% households.	74

gaps (**S2**). However, policy gaps hinder effective mitigation and adaptation. Inadequate funding remains a key issue, limiting the development of protective infrastructure, as evidenced by the Flood Action Plan (FAP) 21/22 (1993), which failed to realize embankments due to financial constraints[47]. Stakeholder coordination is also poor, despite the National Plan for Disaster Management (2021–2025) emphasizing community involvement and predictive technologies. This lack of collaboration among academics, communities, NGOs, and administrative bodies reduces mitigation efficiency[48]. Similarly, emergency response measures are flawed, and often exclude displaced landless populations from disaster aid[16].

Additional challenges include inconsistent regulations, fragmented policy frameworks, and significant knowledge gaps regarding river morphology and soil dynamics, leading to ineffective erosion control strategies[49,50]. Poorly maintained infrastructure, such as geobag revetments by the Bangladesh Water Development Board (BWDB), and bureaucratic delays exacerbate the problem, leaving communities vulnerable[47,51–53]. While the Bangladesh Delta Plan 2100 advocates adaptive delta management, it lacks immediate measures to address pressing vulnerabilities[54]. Addressing these issues requires increased funding, improved stakeholder collaboration, actionable emergency policies, robust research, and integrated strategies balancing long-term planning with immediate actions.

Field studies across various regions underscore these policy gaps and governance challenges:

- No specific policy or aid is provided for environmental refugees in Rajshahi and Chapai Nawabganj. Formulating comprehensive management policies and developmental relief are recommended[16].
- Inadequate access to resources, articulation of livelihood vulnerabilities, and absence of targeted policies are found to aggravate livelihood vulnerabilities in Sirajganj and Tangail. It is suggested that resource access should be improved, and the infrastructure should be enhanced[55].
- Sustainable planning guidelines and hazard zoning maps are also needed to mitigate the unsustainable traditional management practices and economic constraints along the Padma River[56].
- In Banshkhali and Rangunia, the lack of government intervention and limited access to formal credit is advised to be managed through the integration of indigenous knowledge into formal policy[57].
- There is no comprehensive national policy for internally displaced persons (IDPs) to govern Shebagram Village in Laxmipur District. Here, we propose developing a policy based on UNHCR Guiding Principles and establishing climate change commission[58].

Collectively, these studies advocate the establishment of comprehensive riverbank erosion management policies, improved synchronization of protection works, and resource access. Additionally, the importance of integrating community-based adaptation programs, strengthening the institutional framework, and secure sustainable funding is emphasized[38,43,59].

Finally, addressing the diverse policy gaps in riverbank erosion management needs to be handled as a whole package. This includes:

- Allocating sufficient funding for timely and effective erosion control measures.
- Enhancing coordination among stakeholders to unify efforts and resources.
- Development of coherent regulatory frameworks for consistent policy implementation.
- Establishing targeted emergency response guidelines for displaced populations.
- Investing in research and infrastructure to inform evidence-based practices.
- Adaptive management plans that balance long-term strategies with immediate actions should be implemented.

Table 10 | Charting uncharted territories: unveiling policy gaps in riverbank erosion management

Policy gap	Description	Reference
Limited Funding	Insufficient financial resources are allocated toward riverbank erosion management and mitigation. For instance, Flood Action Plan (FAP) 21/22 concluded in 1993 that the timely and complete development of the embankment of the river cannot be done due to lack of financial resources.	47
Coordination Plan for execution	National Plan for Disaster Management (21–25) express the scenery of community engagement and technological advancement such as riverbank erosion prediction. Therefore, the coordination between academic scholars, community, administrative support and local and international NGO engagement is not focused.	48
Lack of Guideline for emergency response	In 2007 Ministry of Food and Disaster Management issued CI sheets for all kinds of disasters. In addition, the victims must own land to get benefits from the listed CI sheet. However, unlike other disasters like floods, droughts, etc, erosion causes the displacement of populations who do not own land. So that reason they fail to get relief.	16
Inconsistent Regulations	Regulatory frameworks for riverbank erosion control lack coherence and uniform implementation.	49
Limited Scope of Getting Aid	Field-level experience has shown that riverbank erosion created displacement. The displaced people in most cases moves to different district or locations where no aid assistance they gets.	16
Knowledge Gap	Insufficient designs stem from a deficiency in thorough research encompassing morphological comprehension, hydrodynamic forces, and soil characteristics	50
Bank Protection Infrastructure Limitations	Since 2000 Bangladesh Water Development Board (BWDB) has taken technological and geobags revetments initiatives. However, in Bangladesh, riverbank protection is lacking without adequate adaptation and maintenance efforts. Revetments experience shallower scour depths compared to protruding structures like spurs or "hard points," making them less prone to failure. However, toe protection aprons have limited effectiveness, requiring stable soil, single-layer deployment, and wider dimensions to mitigate flow slides during rapid scouring	51–53,67
Inadequate Infrastructure	The existing riverbank protection infrastructure lacks resilience and is often poorly maintained.	68
Immediate Project Implementation	Government of Bangladesh has taken a minimum two years for the approval of riverbank protection initiative. Therefore, to reduce the losses and to hold the design significance of the riverbank protection a quick approval from the government is crucial.	47
Uncertainty of Delta Plan 2100	The absence of riverbank protection persists despite the implementation of the Bangladesh Delta Plan 2100, which emphasizes country-wide water management through Adaptive Delta Management. This approach acknowledges uncertainties and advocates for experiential learning rather than relying solely on predetermined plans.	54

Thus, bridging these gaps provides Bangladesh with a favorable opportunity to reduce the socioeconomic consequences of riverbank erosion and the ensuing migration dynamics, to contribute to the resilience and well-being of affected people.

Proposed policy framework

This review presents a proposed policy framework for riverbank erosion management and displaced populations in Bangladesh in response to the important need to address the multifaceted issues resulting from this environmental phenomenon (Fig. 7). A detailed situational analysis highlights the scale of displacement and land loss resulting from riverbank erosion and the resulting adverse socioeconomic impacts, such as livelihood loss, homelessness, and marginalization. These findings clearly stress the need for comprehensive policy interventions that not only alleviate the suffering of affected communities but also protect their well-being.

The policy objectives are defined to include not only mitigation of the effects of riverbank erosion, but also the adoption of sustainable riverbank management strategies. These strategies are implemented in strategic policy areas, which include preventive measures and land management, early warning and disaster preparedness, housing and resettlement, relief and rehabilitation, and livelihood restoration. Policy institutions are defined at the government agency level, NGOs, and community organization level, paying particular attention to constituting a dedicated, multidisciplinary task force in charge of riverbank erosion management and displaced populations' welfare. Furthermore, community involvement and awareness are stressed toward ownership and cooperation in erosion control undertakings, and sufficient monitoring and evaluation methods are recommended to appraise policy efficacy and modify responses over time. The financial implications and support needed to promote adequate budgetary resources and international cooperation in policy initiatives are also addressed. The ultimate action plan of the proposed framework is focused on bringing together the required cohesive action from all the stakeholders to alleviate the adverse effects of riverbank erosion and strengthen the capacity of the affected communities to cope with these impacts.

The erosion of riverbanks in Bangladesh has emerged as a major socioeconomic problem that calls for multi-facet treatment that integrates technology, community participation, and a combination of innovative policies. Satellite imaging or ICT sensors are modern monitoring systems that can deliver near-real-time data to react rapidly. The environment becomes more resilient when erosion-resistant infrastructures and methods of bioengineering, including hydroseeding, are incorporated. Capacity building and educational initiatives help local communities; innovations in socioeconomics, such as promoting community involvement and increasing economic diversification, reduce the risk of vulnerability. Moreover, strengthened legal frameworks, as well as international cooperation, are essential to ensure that sustainability is long-term and lowers erosion risk.

Conclusion

Riverbank erosion is a major and frequently neglected catastrophe that progressively increases the vulnerability of countless individuals. Its consequences are not always immediately apparent, permitting it to quietly disrupt lives and cause hardship. In contrast to more commonly recognized disasters such as floods, cyclones, or storms, riverbank erosion has slowly begun to attract attention within scientific circles. This article aims to offer a comprehensive review of various studies on the vulnerability associated with riverbank erosion conducted between 2000 and 2024. Studies conducted during this timeframe indicate that the vulnerabilities resulting from riverbank erosion have increased in severity over the years. Researchers have identified new facets of vulnerability, leading to a better understanding of the problem. The rising populations in Bangladesh, along with ongoing environmental degradation, have significantly exacerbated these vulnerabilities. Major concerns include the displacement of people, family relocations, loss of assets and properties, shifts in occupational patterns, economic loss, and detrimental effects on the environment. Initially, the research methods used to study riverbank erosion were quite basic. Over time, however, they have evolved into more advanced and precise techniques, owing to the development of remote sensing (RS) and geographic information systems (GIS). These technological advancements have significantly improved the scientific study of riverbank erosion. Despite this

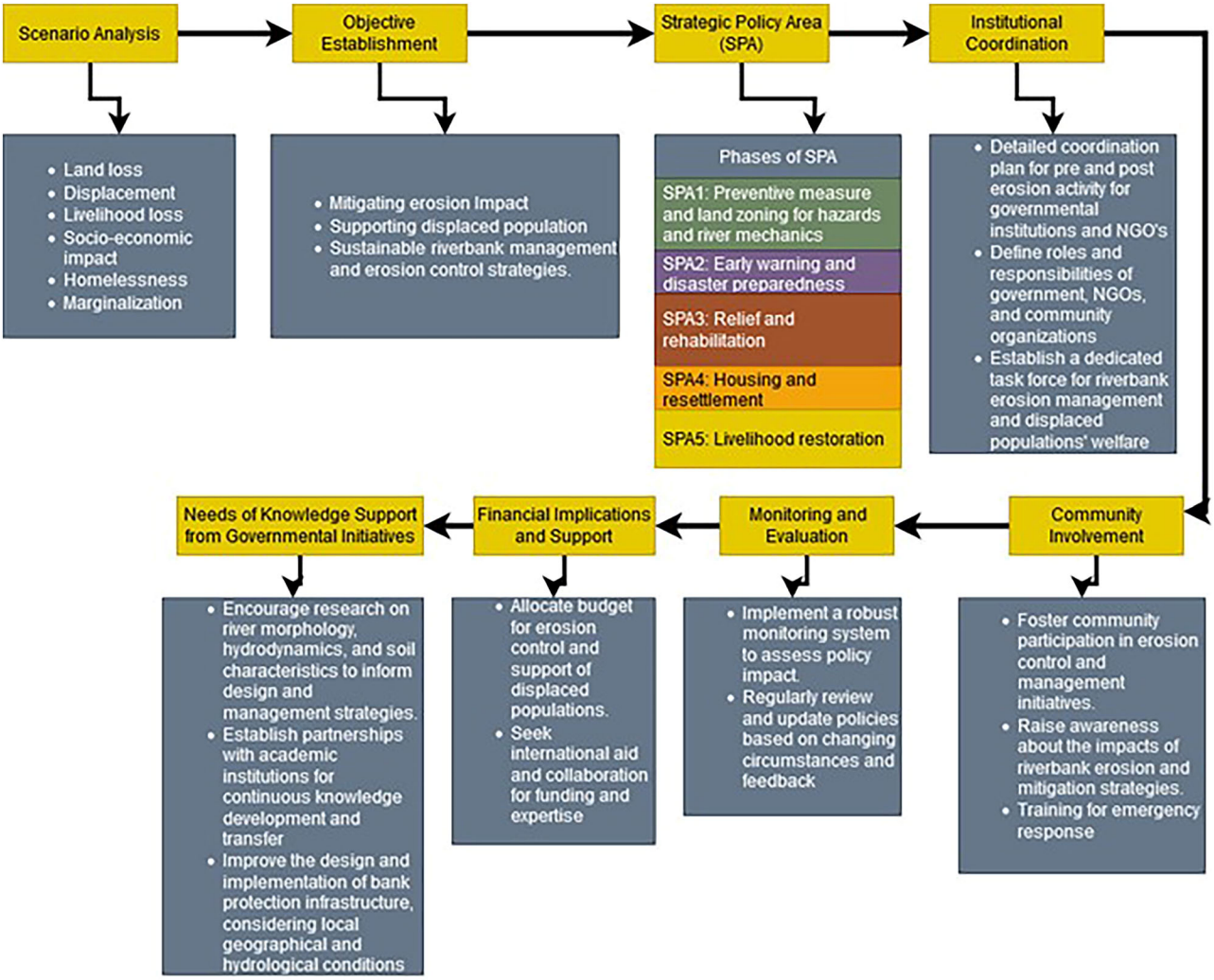

Fig. 7 | Navigating change: a strategic blueprint for riverbank erosion management.

progress, several challenges still need to be overcome to achieve a thorough understanding of the phenomenon. It is essential to share the findings and insights from these studies with the communities affected by riverbank erosion. Disseminating this knowledge can empower them to reduce their vulnerability and strive for a more secure and sustainable future.

This study's scope was limited by its focus on English-language peer-reviewed studies and, thus, may omit relevant research conducted in other languages or formats (gray literature). Furthermore, secondary data and thematic analysis can create subjectivity as well as miss local knowledge, which might provide insight. Finally, the lack of field studies with empirical evidence inhibits our ability to comprehend subtle ground-level effects associated with erosion of riverbanks; future research must address these gaps by including multilingual sources, diverse methods, and field-based validations.

We identify several significant aspects that could also be considered for analyzing and mitigating erosional consequences. First, defining vulnerability and creating a specific vulnerability index are crucial for accurately assessing and addressing riverbank erosion. Second, studying the impacts on agriculture and the economy, including changes in cropping patterns and financial losses, is essential for developing mitigation strategies. Third, research should focus on diverse target groups and conduct comparative studies to understand how different populations cope with vulnerability. Fourth, developing insurance and risk-sharing mechanisms can provide financial safety nets for those affected by erosion. Fifth, smart engineering solutions, such as automated levees and AI-driven analytics, can enhance dynamic responses to erosion. Sixth, issuing green bonds and sustainability investments can fund large-scale erosion control projects and promote economic growth. Seventh, conducting ecological studies will help develop nature-based solutions to strengthen riverbank resilience and biodiversity. Finally, exploring deep learning methodologies can improve the accuracy of erosion predictions and support effective mitigation strategies.

Data availability

The authors confirm that all data generated or analyzed during this study are included in this published article.

Received: 25 March 2025; Accepted: 15 October 2025;
Published online: 06 November 2025

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Acknowledgements

This work was supported by the General Research Fund (GRF) of the Research Grants Council of the Hong Kong Special Administrative Region, China (project no. 12608425).

Author contributions

M.N.R. conceived and designed the review, developed the research protocol and methodology, created figures and tables, supervised the literature search, performed the initial thematic analysis, and wrote the first draft of the manuscript. S.A.S.M.S. contributed to literature screening, data extraction, and assisted in the qualitative data analysis and interpretation of findings. M.N.I.S. supported data synthesis, created figures and tables, and provided content for the policy and recommendations sections. K.L. contributed to the critical review and editing of the manuscript, conceptulaization and initial draft preparation, provided guidance on the structure and argumentation, and oversaw the overall progression of the project. All authors contributed to the manuscript's revision and approved the final version for submission.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44168-025-00306-6.

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