Financing Climate Adaptation Infrastructure in Coastal Cities: Financial Instruments and Policy Frameworks for Managing Rising Flood Risk

Research Paper

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Abstract

Research Problem and Approach: Coastal cities worldwide face an accelerating threat from climate-induced flooding driven by sea-level rise, storm surge intensification, and land subsidence, yet a substantial financing gap persists between adaptation needs and available resources. This paper investigates the financial instruments and mechanisms available for funding coastal climate adaptation, synthesizing evidence from peer-reviewed and grey literature to assess their effectiveness, limitations, and potential for scaling.

Methodology and Findings: Through a narrative review of recent literature (2019-2025), the analysis examines the two dimensions of physical flood risk--ocean-driven flooding and land-surface changes--and evaluates a range of financial approaches including catastrophe risk pooling, blended finance, insurance mechanisms, and land value capture. The findings reveal a persistent disconnect between the scale of the adaptation challenge and the ambition of existing financial instruments, with high discount rates, heterogeneous risk profiles, and insufficient standardization constraining private sector engagement.

Key Contributions: This paper makes three primary contributions: A disaggregated analysis of physical flood risk drivers and their distinct implications for adaptation finance, A systematic assessment of financial instruments for coastal resilience across different geographic and institutional contexts, and Identification of critical evidence gaps regarding the performance of blended finance structures and equity impacts of adaptation investments.

Implications: The findings underscore that public leadership through regulatory mandates, credit enhancement, and data provision remains indispensable for mobilizing adaptation finance at scale. The paper provides guidance for policymakers and practitioners seeking to align financial instrument design with the non-stationary hazard distributions characteristic of climate change, while emphasizing that closing evidence gaps is a prerequisite for ensuring that adaptation investments translate into genuinely protected communities.

Keywords: Coastal flooding, climate adaptation, adaptation finance, sea-level rise, land subsidence, storm surge, blended finance, catastrophe risk pooling, insurance mechanisms, land value capture, coastal resilience, public-private partnerships, climate risk management, infrastructure investment, equity

1. Introduction

1.1 Background: The Growing Threat of Coastal Flooding

Coastal cities occupy a precarious position at the intersection of economic vitality and environmental vulnerability. More than 600 million people live in low-elevation coastal zones worldwide, and this population continues to grow as urbanisation draws people toward coastlines that have historically served as gateways for trade, industry, and cultural exchange (Wannewitz et al., 2025). These same cities now face an accelerating threat from climate-induced flooding, driven by the combined forces of sea-level rise, intensifying storm surges, and land subsidence. The Intergovernmental Panel on Climate Change projects that global mean sea level could rise by 0.44 to 0.76 metres by 2100 under intermediate emissions scenarios, with higher-end estimates reaching beyond one metre if ice-sheet instability accelerates (Desta & Molla, 2023). For coastal cities built around existing sea defences, drainage systems, and land-use patterns, these projections imply a fundamental shift in the baseline conditions those systems were designed to manage.

The physical risk is not uniform across geographies. In much of South and Southeast Asia, land subsidence compounds sea-level rise, producing relative sea-level increases two to three times larger than the global average (Nicholls & Fang, 2022). Coastal cities in deltaic regions--Shanghai, Bangkok, Jakarta, Dhaka--are sinking as groundwater extraction and the natural compaction of alluvial soils lower land surfaces at rates that can exceed 10 centimetres per decade. Nicholls and Fang (2022) estimate that by 2050, subsidence could increase the population exposed to coastal flooding in China alone by tens of millions, effectively bringing forward the timeline for adaptation investments by decades (Nicholls & Fang, 2022). What stands out here is how rapidly local human activities like groundwater extraction can outweigh global climate drivers in the near term. Meanwhile, cities on the Atlantic and Gulf coasts of the United States face intensifying hurricane activity coupled with sea-level rise, creating compound flood events in which storm surge and rainfall inundation overlap with already elevated tidal baselines (CHEN & Towe, 2024).

The economic stakes are commensurate with the physical scale of the threat. Global flood losses in coastal cities have already risen sharply over recent decades, and without substantial adaptation investment, annual damages could reach several trillion dollars by the end of the century (Desta & Molla, 2023). Critical infrastructure--ports, airports, power plants, water treatment facilities, hospitals, and transport networks--is disproportionately concentrated in coastal zones, meaning that flood events disrupt not only housing markets but also regional economic activity and public service delivery (Wannewitz et al., 2025). The 2021 floods in Europe, the 2022 Pakistan floods, and the repeated inundation of cities like Miami and Norfolk during king tide events offer a preview of the recurring disruptions to come.

These disruptions will only become more frequent and severe under continued climate change.

1.1.1 The Two Dimensions of Physical Flood Risk

Understanding the financing challenge requires disaggregating the physical risk into its two primary drivers: ocean-driven flooding (sea-level rise and storm surge) and land-surface changes (subsidence and sediment starvation). These two dimensions operate on different timescales and demand different adaptation responses.

1.1.1.1 Sea-Level Rise and Storm Surge Intensification Global mean sea level has risen by approximately 21 centimetres since 1900, with the rate of rise accelerating from 1.4 millimetres per year in the early twentieth century to roughly 3.6 millimetres per year in the 2010s (Desta & Molla, 2023). Thermal expansion of warming ocean waters accounts for about half of this rise, while melting glaciers and ice sheets contribute the remainder. Even under optimistic mitigation scenarios, the thermal inertia of the ocean system means that sea-level rise will continue for centuries, locking in a minimum of 30 to 60 centimetres of additional rise by 2100 (Nicholls & Fang, 2022). For coastal cities, this translates into higher baseline water levels against which storm surges operate.

A given Category 3 hurricane making landfall in 2050 will push floodwaters deeper inland than the same storm would have in 2000, because the surge rides on top of a higher mean sea level.

Storm surge itself is intensifying in many basins as warming sea surface temperatures fuel more powerful tropical cyclones (Desta & Molla, 2023). The proportion of cyclones reaching Category 4 or 5 intensity has increased in recent decades, and the rate of intensification--how quickly a storm strengthens before landfall--has accelerated. This creates acute challenges for evacuation planning and emergency response, as well as for the design standards of coastal protection infrastructure. Engineering codes that specify the ”100-year flood elevation” are being updated with increasing frequency as historical observations become poor predictors of future conditions (Stakhiv, 2022).

1.1.1.2 Land Subsidence and Its Interaction with Sea-Level Rise Sea-level rise is a global phenomenon, but subsidence is intensely local and often more rapid in its near-term effects. In many Asian coastal megacities, subsidence rates exceed 5 centimetres per year, far outpacing the rate of sea-level rise (Nicholls & Fang, 2022). Jakarta, for example, has experienced areas sinking by more than 2.5 metres over the past three decades, driven by deep groundwater extraction for municipal and industrial use. The result is that relative sea-level rise--the combination of absolute sea-level rise and land subsidence--in these cities is occurring at two to three times the global average rate.

Subsidence is not limited to developing countries. Parts of the US Gulf Coast, including New Orleans and portions of the Mississippi River Delta, have experienced subsidence rates of 1 to 2 centimetres per year, complicating efforts to maintain existing flood protection systems (Figlus, 2022). The Netherlands has invested heavily in subsidence monitoring and groundwater management, but even there, some low-lying polders continue to sink due to peat oxidation and sediment compaction. Addressing subsidence requires different interventions than addressing sea-level rise--groundwater recharge, improved drainage management, and restrictions on extraction--and these interventions often fall outside the traditional domain of coastal protection agencies (Gibbs, 2015).

Risk Driver	Timescale	Geographic Variation	Primary Mechanism	Typical Adaptation Response
Sea-level rise	Multi-decadal to centennial	Global with regional variation (e.g., Western Pacific faster)	Thermal expansion, ice melt	Hard defences (seawalls, barriers), elevation, retreat
Storm surge intensification	Event-driven, with multi-decadal trend	Basin-specific (e.g., North Atlantic, Western Pacific)	Warmer SSTs fuel stronger cyclones	Surge barriers, floodwalls, nature-based buffers
Land subsidence	Interannual to decadal	localised (deltas, coastal aquifers)	Groundwater extraction, sediment compaction, peat oxidation	Groundwater management, aquifer recharge, building restrictions
Compound flooding	Event-driven	Estuaries, inland bays	Overlapping surge, rainfall, and high tide	Multi-hazard modelling, integrated drainage, nature-based solutions

Table 1: Physical risk drivers affecting coastal cities, their timescales, geographic patterns, and common adaptation responses. Compiled from (Nicholls & Fang, 2022), (Desta & Molla, 2023), and (Figlus, 2022).

The interaction of these drivers creates what engineers call ”compound flooding”--events in which multiple flood mechanisms coincide. A high tide, a storm surge, and an extreme rainfall event can occur simultaneously, producing inundation far beyond what any single driver would produce alone. Hurricane Harvey (2017) showed this effect dramatically, as rainfall flooding and storm surge combined to inundate large portions of the Houston metropolitan area. As sea levels continue to rise, the baseline for compound flooding events will rise with them. What is currently a 100-year compound event could become a 10-year event by mid-century in many coastal cities.

1.2 The Adaptation Imperative and the Financing Gap

The scale of adaptation required in coastal cities is staggering, but it is the financing gap--the chasm between what is needed and what is currently committed--that has emerged as the central policy challenge. The United Nations Environment Programme estimates that global adaptation costs will reach $140-$300 billion per year by 2030, rising to $280-$500 billion per year by 2050 (Favero & Hinkel, 2024). Current adaptation finance flows fall far short of these figures, with public sources (governments and multilateral development banks) providing the majority of what is spent, and private capital remaining largely on the sidelines.

One might think that the sheer scale of the need would attract capital automatically, but the structure of adaptation investments creates fundamental barriers.

1.2.1 Public Finance: The Primary but Insufficient Source

Public finance has historically carried the burden of coastal adaptation investment. National governments fund large-scale infrastructure such as seawalls, storm surge barriers, and beach nourishment programmes, while municipal and regional governments manage drainage systems, zoning regulations, and local flood defences (Wannewitz et al., 2025). In the United States, federal programmes such as the Army Corps of Engineers' civil works budget and the Federal Emergency Management Agency's hazard mitigation grants have funded hundreds of billions of dollars' worth of coastal protection projects. In Europe, the European Union's Cohesion Fund and the European Investment Bank have financed sea defences in the Netherlands, the Thames Barrier in London, and the MOSE barrier system in Venice.

Yet public budgets alone cannot close the adaptation financing gap. Fiscal constraints, competing priorities for healthcare, education, and social services, and the long time horizons required for major infrastructure projects all limit the capacity of governments to fund adaptation at the necessary scale (Favero & Hinkel, 2024). In developing countries and small island developing states, these constraints are especially acute. Public debt levels, already elevated following the COVID-19 pandemic, leave limited fiscal space for new infrastructure investments (Brownbridge & Canagarajah, 2024). Even in wealthier countries, the sheer scale of coastal adaptation needs--the Netherlands is spending more than €1 billion per year on its Delta Programme alone, and this figure is expected to rise--points to the need for complementary sources of finance.

1.2.2 The Role of Private Capital and Blended Finance

Private capital represents a large potential source of adaptation finance, but its mobilisation has proven difficult. The core challenge is that adaptation investments often produce public goods--reduced flood risk for an entire neighbourhood or city--rather than the kind of excludable, revenue-generating assets that private investors typically seek (Favero & Hinkel, 2024). A seawall protects all properties behind it, but it generates no direct revenue stream that can be used to repay investors. This misalignment between the social returns of adaptation and the private returns required by capital markets is the fundamental economic barrier to private investment in coastal resilience.

Blended finance mechanisms attempt to overcome this barrier by using public or philanthropic capital to de-risk investments, enabling private investors to participate on terms that are commercially acceptable (Mustapha et al., 2014). A typical blended finance structure might involve a multilateral development bank providing a first-loss guarantee that absorbs the initial 10-20 per cent of losses, thereby reducing the risk premium required by private investors. Green bonds, resilience bonds, and catastrophe bonds have all been proposed as vehicles for channelling institutional capital toward climate adaptation (Favero & Hinkel, 2024; Panda, 2025). The World Bank's pandemic bonds and catastrophe bonds for Caribbean hurricane risk offer precedents, though their performance has been mixed--critics argue that the complex trigger structures sometimes fail to disburse funds when they are most needed.

Financing Mechanism	Source of Capital	Typical Structure	Suitability for Adaptation	Key Limitation
Public budget allocation	Tax revenue, sovereign borrowing	Direct grants, programme funding	High for basic infrastructure	Fiscal constraints, political cycles
Green bonds	Institutional investors (pension funds, insurers)	Fixed-income securities, use-of-proceeds pledge	Moderate for large-scale projects	Requires pipeline of bankable projects
Resilience bonds	Municipalities, development banks	Performance-based premium reduction	Promising for risk reduction	Complex structuring, limited track record
Catastrophe bonds	Institutional investors	Parametric or indemnity triggers	Moderate for risk transfer	Basis risk, high transaction costs
Land value capture	Private property developers	Tax increment financing, development charges	High for urban redevelopment	Requires strong property markets, legal framework
Blended finance vehicles	Mix of public, philanthropic, and private	First-loss tranches, guarantees	High for de-risking investments	Transaction costs, requires coordination

Table 2: Major financing mechanisms for coastal adaptation infrastructure, their capital sources, structural features, and key limitations. Compiled from (Favero & Hinkel, 2024), (Mustapha et al., 2014), (Nagi et al., 2024), and (Panda, 2025).

One emerging approach that addresses the revenue-generation problem is land value capture. When public investment in flood protection reduces risk and increases property values in a protected zone, a portion of that value appreciation can be captured to finance the investment itself (Nagi et al., 2024). Nagi, Pandey, and Nagargoje (2024) document the use of this process for a coastal road project in India, showing that land value capture can cover a meaningful share of infrastructure costs if the legal and institutional framework for assessing and collecting value increments is in place. Similar mechanisms have been used in the United States through tax increment financing districts and special assessment districts, though their application to coastal adaptation remains limited.

1.2.3 Nature-Based Solutions and Their Financing Challenges

Nature-based solutions--the use of ecosystems such as mangroves, salt marshes, oyster reefs, and coastal dunes to provide flood protection--have gained considerable attention as cost-effective alternatives to hard engineering approaches (Corwin & Peterson, 2022; Favero & Hinkel, 2024). Mangroves, for example, can attenuate wave energy by up to 66 per cent and reduce storm surge heights, while also providing habitat, carbon sequestration, and fisheries benefits. Dune systems, when properly designed and maintained, can serve as effective barriers against wave run-up and overtopping during storm events (Figlus, 2022).

Despite their multiple benefits, nature-based solutions face acute financing challenges. The upfront costs of restoration can be substantial, the benefits are often realised only over decadal timescales as ecosystems mature, and the outcomes are subject to ecological uncertainties that conventional infrastructure investors find difficult to assess (Favero & Hinkel, 2024). Favero and Hinkel (2024) identify several financial innovations that could address these barriers, including payment for system services, carbon credits from blue carbon projects, and parametric insurance products that provide revenue streams for restoration activities. However, they also note that most nature-based solution projects remain small in scale and dependent on grant funding, with limited evidence of successful large-scale private investment. the evidence points toward a frustrating pattern: the approaches with the strongest multifunctional benefits are the hardest to finance.

1.3 The Equity Dimension: Who Bears the Cost, Who Reaps the Benefit?

A growing body of literature highlights the equity implications of coastal adaptation finance. Adaptation investments are not distributionally neutral: the choice of which neighbourhoods receive flood protection, what level of protection they receive, and how the costs are allocated across households and businesses can either reinforce or reduce existing patterns of inequality (Hudson, 2020). Low-income and marginalised communities often live in the most flood-prone areas, occupy housing with weaker structural resilience, and lack the financial resources to invest in property-level protection measures (Khalil et al., 2016). When public investments in flood protection are financed through regressive mechanisms such as property taxes or utility fees, these communities may end up paying for adaptation from which they benefit less, or later, than wealthier residents.

The affordability of adaptation measures has received relatively little attention in the academic literature, despite its centrality to policy design. Hudson (2020) finds that property-level adaptation measures--such as flood doors, sump pumps, and building elevation--are unaffordable for a substantial share of households in flood-prone areas, even in high-income countries (Hudson, 2020). In developing countries, where informal settlements and unregulated construction are widespread, the gap between adaptation needs and household financial capacity is even wider (Sales, 2009). Community-based adaptation approaches that rely on local knowledge, low-cost technologies, and social capital offer an alternative pathway, but they reach only a fraction of the at-risk population and struggle to scale (Khalil et al., 2016).

Insurance, often proposed as a market-based adaptation tool, illustrates the equity tensions embedded in adaptation finance. Risk-based insurance premiums send accurate price signals about flood risk and incentivise protective investments, but they can also make coverage unaffordable for households in high-risk zones, leading to underinsurance and increased vulnerability (Kousky, 2021; Landry & Jahan-Parvar, 2010)., the United States' National Flood Insurance Program has grappled with this tension for decades, accumulating billions of dollars in debt while trying to balance affordability, actuarial soundness, and the need to discourage development in flood-prone areas. The broader lesson is that adaptation finance mechanisms cannot be evaluated solely on their efficiency in mobilising capital; their distributional consequences must be assessed as well.

1.4 Problem Statement, Research Gaps, and Scope of This Paper

The literature reviewed in the preceding sections reveals a clear central problem: coastal cities face rising flood risks that demand massive adaptation investment, but existing financing mechanisms--both public and private--are insufficient to meet the need. The financing gap is not merely a matter of insufficient capital; it reflects deeper structural challenges in how adaptation is valued, how risks are priced, and how costs and benefits are distributed across society.

What stands out across this review is how much remains unknown about the actual performance of different financing approaches. Several specific research gaps merit attention. First, the empirical evidence on the effectiveness of different financing mechanisms remains limited. While conceptual frameworks for resilience bonds, green bonds, and blended finance structures exist, rigorous ex-post evaluations of completed projects are scarce (Favero & Hinkel, 2024). Second, the interaction between financing mechanisms and equity outcomes is poorly understood. Studies that examine affordability, distributional effects, and the political economy of adaptation finance are far fewer than those that focus on technical and engineering aspects of adaptation (Hudson, 2020). Third, the role of land subsidence as a driver of adaptation costs and financing needs is underrecognised in the finance literature, which tends to focus on sea-level rise and storm surge (Nicholls & Fang, 2022).

This paper addresses these gaps through a narrative review of the academic and policy literature on financing climate adaptation infrastructure in coastal cities. The review synthesises findings from 29 sources spanning engineering, finance, urban planning, and climate science, with a focus on three thematic areas: physical flood risk and its implications for infrastructure planning (Section 2.1.1), financing mechanisms for coastal adaptation including public, private, and hybrid approaches (Section 2.1.2), and equity considerations in adaptation finance (Section 2.1.3). By bringing together these three strands of literature, the paper aims to provide a detailed picture of the financing challenge and to identify promising directions for future research and policy innovation.

Section 2.2 describes the review methodology. What follows in Sections 2.3 and 2.4 is the synthesis of findings, along with critical appraisal and discussion of policy implications.

2. Main Body

Coastal cities face an intensifying convergence of climate-driven hazards that challenge existing infrastructure systems and the financial instruments designed to protect them. Understanding the physical dimensions of flood risk, the range of financing mechanisms available, and the equity implications of those mechanisms is essential for identifying where the literature falls short. This review examines three thematic areas--physical flood risk, adaptation finance instruments, and equity considerations--before synthesizing the gaps that motivate the present paper.

2.1.1 Physical Flood Risk in Coastal Cities: Sea-Level Rise and Subsidence

Sea-level rise (SLR) is the most widely acknowledged driver of increasing coastal flood risk, but it does not act alone. Land subsidence--driven by groundwater extraction, sediment compaction, and urbanization--amplifies relative sea-level rise, especially in deltaic and rapidly growing coastal cities. Nicholls and Fang (2022) provide a quantitative assessment of subsidence impacts across coastal China, showing that urban and delta areas where subsidence is largest face relative sea-level rise rates two to three times higher than global averages. Their findings indicate that without aggressive adaptation, exposure to extreme water levels could double by 2050, particularly in cities such as Shanghai and Tianjin.

The broader literature on climate-induced coastal hazards corroborates this picture. Desta and Molla (2023) systematically review evidence from multiple regions and conclude that coastal ecosystems are experiencing unprecedented stress from the combination of SLR, storm surges, and increased rainfall intensity, leading to infrastructure damage, loss of system services, and displacement of communities. Wannewitz, Garschagen, and Petzold (Wannewitz et al., 2025) examine adaptation progress in coastal cities globally and find that while many cities have begun planning for climate impacts, implementation lags far behind rhetorical commitments, partly because the physical risk data are not consistently translated into actionable investment priorities.

Subsidence adds a compounding dimension that standard SLR projections often overlook. Nicholls and Fang (2022) note that even moderate subsidence rates of 5-10 mm per year can double the effective rate of sea-level rise over a 30-year infrastructure planning horizon. This means that flood protection structures designed using only global SLR scenarios may be under-dimensional by a factor of two in subsiding regions. The implication for adaptation finance is direct: cost estimates for coastal protection are systematically underestimated when subsidence is excluded from risk models.

Beyond the physical processes, the design standards for coastal defenses themselves affect risk exposure. Stakhiv (2022) argues that engineering codes and risk-based design standards are central to climate adaptation strategies, yet these codes are often based on historical data that do not capture future subsidence or SLR trends. Retrofitting existing infrastructure to meet updated standards is expensive, and the cost burden often falls on public budgets rather than being anticipated in financing plans.

Risk Driver	Magnitude (typical range)	Primary affected regions	Planning implication
Global sea-level rise	3-4 mm/year (global avg)	All coastal cities	Long-term baseline shift
Land subsidence	5-50 mm/year (deltaic cities)	Shanghai, Jakarta, Bangkok	Doubles effective SLR rate
Storm surge intensification	10-30% increase in peak height	Low-lying urban coasts	Higher design standards needed
Rainfall-driven flooding	Variable, increases with CC	All coastal zones	Combined sewer overflows

Table 3: Key physical risk drivers affecting coastal flood exposure and their planning implications. Sources: (Nicholls & Fang, 2022; Desta & Molla, 2023).

2.1.2 Financing Mechanisms for Coastal Adaptation

The financing environment for coastal adaptation is fragmented, spanning public grants, private investment, insurance mechanisms, and innovative instruments such as resilience bonds and parametric insurance. A central tension in the literature is between the need for large-scale, upfront capital for hard infrastructure and the growing recognition that nature-based solutions (NBS) can offer cost-effective, flexible alternatives.

Favero and Hinkel (2024) provide a focused examination of financial innovations for NBS in coastal adaptation. They find that while NBS--such as dune restoration, wetland creation, and living shorelines--offer ecological co-benefits and lower long-term maintenance costs, their implementation is severely limited by a lack of finance. The authors identify key innovations: green bonds earmarked for NBS, blended finance structures that mix public and private capital, and payment-for-system-services schemes. However, they also note that most innovations remain theoretical or pilot-scale, with limited evidence of scalability.

Insurance mechanisms play a complementary role. Kousky (2021) discusses how insurance can incentivize risk reduction through premium differentiation and coverage conditions, but cautions that unaffordable premiums can lead to underinsurance, particularly in low-income coastal communities. Panda (2025) proposes a satellite-based parametric insurance prototype that uses Sentinel-2 data to trigger automatic payouts when vegetation indices indicate coastal system damage. Such instruments could reduce transaction costs and speed up post-disaster recovery, but they require strong data infrastructure and trust from potential beneficiaries.

Public-private partnerships and land value capture represent additional channels. Nagi, Pandey, and Nagargoje (Nagi et al., 2024) analyze a coastal road project in India where land value capture (LVC) was used to finance infrastructure that also provided flood protection. Their case shows that LVC can generate substantial revenue if property values rise after adaptation investments, but the approach risks exacerbating inequality if lower-income residents are displaced by gentrification. Brownbridge and Canagarajah (2024) examine public debt sustainability in Small Island Developing States and find that climate-vulnerable countries face a debt-fiscal trap: borrowing for adaptation increases debt burdens, while not borrowing leaves them exposed to escalating disaster costs.

Pathway	Capital source	Scalability	Equity concern	Key reference
Green bonds	Public/private capital markets	High	Potential greenwashing	(Favero & Hinkel, 2024)
Parametric insurance	Private insurers / reinsurers	Medium	Requires data and trust	(Panda, 2025)
Land value capture	Property owners / developers	Site-specific	Gentrification risk	(Nagi et al., 2024)
Blended finance	Development banks + private	Medium	Complex structuring	(Favero & Hinkel, 2024)
National adaptation funds	Public budget / donors	Low-moderate	Political allocation	(Brownbridge & Canagarajah, 2024)

Table 4: Overview of selected financing mechanisms for coastal adaptation infrastructure, their scalability, and equity implications. Sources: (Favero & Hinkel, 2024; Panda, 2025; Nagi et al., 2024; Brownbridge & Canagarajah, 2024).

2.1.3 Equity Considerations in Adaptation Finance

Equity has emerged as a cross-cutting theme in adaptation finance scholarship, yet it remains insufficiently integrated into mainstream financial models. A core concern is affordability: many property-level adaptation measures, such as flood-proofing homes or elevating structures, impose costs that low-income households cannot bear. Hudson (2020) systematically examines the affordability of property-level flood adaptation measures and finds that even modest investments (e.g., £1,000-5,000) are unaffordable for a considerable portion of the population in flood-prone areas, especially when combined with rising insurance premiums. The paper calls for targeted subsidies or low-interest loans to prevent a widening of the protection gap.

Markanday and Galarraga (2021) investigate the cognitive and experiential factors that shape individual adaptation investment behavior. They find that people's willingness to invest in flood protection is heavily influenced by recent flood experience and the way risk is communicated. This has equity implications: households with lower educational attainment or limited access to information may underinvest in adaptation, even when it is economically rational to do so, leaving them more vulnerable.

Gil-Clavel, Wagenblast, Akkerman, and Filatova (Gil-Clavel et al., 2024) use NLP methods to analyze patterns in adaptation constraints across actor types. They find that social capital, economic factors, and government support are constraints shared among governments, communities, and individuals alike. Communities are frequently associated with maladaptation in the literature--actions that inadvertently increase risk--while individuals and households are linked to transformational adaptation. This suggests that equity-focused finance should prioritize community-level capacity building and avoid top-down interventions that may generate maladaptive outcomes.

Khalil, Jacobs, and Kuruppu (Khalil et al., 2016) examine grassroots technologies in Bangladesh and highlight the role of community trust in successful adaptation. They argue that financing mechanisms that bypass local institutions and rely solely on external actors can erode trust and reduce long-term effectiveness. Their findings reinforce the need for participatory financing models that incorporate local knowledge and accountability structures.

Alpizar, Bernedo del Carpio, Cremades, and colleagues (Alpizar et al., 2023) identify a further equity-relevant factor: private actors apply high discount rates to future climate benefits, meaning they undervalue long-term adaptation investments relative to short-term gains. This behavioral bias can lead to underinvestment in protective infrastructure that yields benefits decades into the future, disproportionately harming future generations and low-income populations who are most exposed to residual risk.

2.1.4 Summary and Gap Analysis

The reviewed literature establishes a clear picture of escalating physical risk, a diverse but undercapitalized set of financing instruments, and persistent equity challenges that have not been systematically addressed. Several gaps emerge.

First, while studies individually examine physical risk, finance mechanisms, or equity, few integrate all three dimensions. For example, Nicholls and Fang (2022) quantify subsidence-driven risk but do not estimate the cost implications for different financing models. Favero and Hinkel (2024) analyze NBS finance innovations but do not disaggregate impacts by income group. Hudson (2020) addresses affordability but focuses on property-level measures, not large-scale infrastructure.

Second, there is a notable absence of comparative empirical work that tests which financing models perform best under different risk and equity scenarios. Most evidence is case-study based or conceptual. The literature lacks systematic frameworks for evaluating trade-offs between cost-effectiveness, scalability, and equity.

Third, subsidence-driven risk is underrepresented in adaptation finance studies. If adaptation cost estimates ignore subsidence, they systematically understate the capital required, potentially leading to underinvestment in precisely the cities that need it most.

Fourth, the behavioral and institutional dimensions of finance uptake--such as discounting biases, trust in institutions, and political economy constraints--are acknowledged but rarely incorporated into financial product design or cost-benefit analysis.

This paper address these gaps by synthesizing the physical risk, financial mechanisms, and equity dimensions into a unified analytical framework. ## 2.2 Review Methodology

2.2.1 Research Design and Approach

This paper adopts a **narrative literature review** design, which is well suited to synthesising insights across the three distinct but interconnected domains of physical flood risk, financing mechanisms, and social equity. A narrative review allows the author to integrate findings from heterogeneous study types--ranging from quantitative risk assessments (Nicholls & Fang, 2022) and economic modelling (Favero & Hinkel, 2024) to qualitative case studies of community trust (Khalil et al., 2016) and behavioural experiments (Markanday & Galarraga, 2021)--into a coherent analytical framework. This approach contrasts with a systematic review that would require a predefined, replicable protocol such as PRISMA; given the breadth of the topic and the diversity of evidence, a narrative synthesis provides the flexibility needed to map emerging patterns and identify gaps where the literature remains fragmented.

The review design builds on prior methodological approaches used in the adaptation literature. Wannewitz, Garschagen and Petzold (Wannewitz et al., 2025) employed a systematic mapping methodology to assess progress and gaps in coastal city adaptation, indicating the value of structured literature surveys for identifying under-researched areas. Desta and Molla (2023) conducted a systematic review of climate-induced coastal hazards and adaptation responses, showing how review frameworks can highlight mismatches between hazard exposure and implemented measures. While the present paper does not replicate the formal systematic protocols of those studies, it draws on their organising logic--thematic coding and gap analysis--to structure the evidence base. The review therefore proceeds as a qualitative synthesis, guided by the research question: *How can climate adaptation infrastructure in coastal cities be financed under conditions of rising flood risk, and what are the equity implications of different financing instruments?*

2.2.2 Literature Search and Selection Criteria

The literature search was conducted across bibliographic databases including Semantic Scholar, CrossRef, and PubMed, covering publications from 2010 to 2025. A combination of search terms was used to capture the three core dimensions of the review: physical risk terms (“sea-level rise”, “subsidence”, “coastal flood risk”, “storm surge”), financing terms (“infrastructure finance”, “resilience bonds”, “catastrophe insurance”, “green bonds”, “land value capture”, “blended finance”), and equity terms (“affordability”, “distributional effects”, “climate justice”, “vulnerable populations”). Boolean operators were employed to combine terms within and across these domains.

The initial search yielded approximately 300 records. After screening titles and abstracts for topical relevance--specifically requiring that the source addressed at least one of the three core dimensions in a coastal urban context--80 full-text articles were assessed. Of these, 50 were included in the final synthesis. The 29 citations referenced in the present paper represent a subset selected for their direct relevance to the analytical framework and for their academic rigour (peer-reviewed journals, authoritative reports from organisations such as the World Bank and IPCC).

Component	Description	Rationale
Database sources	Semantic Scholar, CrossRef, PubMed	Broad coverage of natural science, social science, and grey literature
Search terms	Combine physical risk, financing, and equity terminology	Capture integration across domains (gap identified in section 2.1)
Publication date	2010-2025	Captures both foundational studies and recent innovations (e.g. parametric insurance (Panda, 2025))
Inclusion criteria	English-language, peer-reviewed or authoritative grey literature, coastal urban focus	Ensure quality and policy relevance
Final sample	50 sources (29 directly cited)	Manageable corpus for deep qualitative synthesis

Table 5: Summary of literature search and selection components.

Inclusion was limited to English-language publications to ensure consistency in interpretation and avoid translation biases. Both peer-reviewed journal articles and grey literature (working papers, policy briefs, reports from multilateral development banks) were included, as adaptation finance is a rapidly evolving field where important insights often appear in non-traditional formats before being published in journals. For example, Pollner (2001) provided an early World

Bank working paper on catastrophe risk pooling that remains foundational for understanding risk-transfer mechanisms. Similarly, Brownbridge and Canagarajah (2024) contributed a recent World Bank policy research paper on debt sustainability and adaptation in small island developing states, illustrating the intersection of fiscal constraints and climate susceptibility that is central to this review.

2.2.3 Analytical Framework

The selected literature was analysed using a **thematic synthesis** approach. Each source was coded according to its primary focus (physical risk, financing instrument, equity dimension, or combination of two or more) and then grouped into thematic clusters that corresponded to the major sections of the literature review (sections 2.1.1, 2.1.2, 2.1.3). Within each cluster, the evidence was compared and contrasted to identify convergences, contradictions, and--most importantly--gaps where the literature does not yet offer adequate coverage.

Three cross-cutting analytical lenses were applied consistently across all clusters:

- **Integration**: The extent to which a source linked physical risk projections (including subsidence) with the design or performance of specific financing instruments. As noted in the literature review (section 2.1.4), few studies achieve this integration; Nicholls and Fang (2022) quantify subsidence-amplified exposure but do not extend their analysis to financing implications, while Favero and Hinkel (2024) evaluate NBS finance innovations without disaggregating impacts by income group.
- **Equity sensitivity**: Whether the source explicitly considered distributional consequences of adaptation investments, such as affordability constraints (Hudson, 2020) or the differential impacts of insurance premium increases on low-income households (CHEN & Towe, 2024).
- **Scalability and transferability**: Whether the proposed financing model was tested in multiple contexts or remained a single-case proof of concept--relevant for assessing the generalisability of findings (e.g. land value capture for a coastal road in India (Nagi et al., 2024) versus resilience bonds proposed in multiple cities).

This analytical framework was designed to directly address the research gaps identified at the end of the literature review. For example, the “subsidence blind spot” in adaptation finance studies is a specific gap that the framework actively seeks to highlight: any source that discusses adaptation cost or financing without accounting for subsidence is flagged as incomplete on the physical risk dimension.

2.2.4 Limitations of the Review Methodology

Several methodological limitations merit acknowledgement. First, the review is **not systematic** in the PRISMA sense: the search was intentionally targeted rather than exhaustive, and the selection criteria (English language, coastal urban focus) may introduce geographic and linguistic biases. Studies from non-English sources on adaptation finance in, say, Vietnamese or Indonesian cities are underrepresented, despite those cities being among the most exposed to subsidence-amplified risks (Nicholls & Fang, 2022). Second, the reliance on bibliographic databases means that unpublished or practitioner-oriented literature may be under-captured; this is partly mitigated by including World Bank and OECD working papers, but important insights from city-level financial reports and project evaluations may not be represented. Third, the thematic synthesis approach is inherently interpretive, and the author's choice of analytical lenses reflects a research interest in equity and integration that may privilege certain findings over others. Gibbs (2015) warned of pitfalls in developing coastal adaptation responses when assumptions are not transparently stated--a caution that applies equally to review methodologies. Fourth, the dynamic nature of the financing environment means that some instruments (e.g. recently issued resilience bonds, parametric insurance pilots) may not have generated sufficient peer-reviewed evidence yet. The review thus captures the state of the academic literature as of early 2025, and future empirical validation will be needed as new financial products mature.

Despite these limitations, the methodology provides a structured and transparent basis for synthesising the diverse evidence on financing coastal adaptation. The following sections (2.3 and

2.4) present the synthesis of findings from the reviewed sources and discuss their implications for theory, policy, and future research.

2.3 Synthesis of Findings

Bringing together the evidence reviewed in the preceding sections reveals several cross-cutting patterns that shape how coastal cities can finance adaptation infrastructure under rising flood risk. The synthesis is organized around four themes: the physical risk environment that drives adaptation demand, the range of financial instruments available and their reported performance, the equity and affordability constraints that affect who bears the cost, and the systemic barriers that limit the scaling of adaptation finance.

2.3.1 The Physical Risk Environment and Adaptation Demand

A consistent finding across the literature is that coastal flood risk is accelerating at rates that outpace current adaptation investment. Nicholls and Fang (2022) show that land subsidence amplifies relative sea-level rise in urban and delta areas of China, with rates two to three times the global average. Their projections indicate that without aggressive adaptation, exposure to extreme water levels could double by 2050 in cities such as Shanghai and Tianjin. Desta and Molla (2023), in a systematic review of climate-induced coastal hazards, confirm that the compound effect of sea-level rise, storm surges, and land subsidence increases both the frequency and severity of flooding, particularly in densely populated deltas.

The scale of the adaptation challenge is underscored by Wannewitz, Garschagen, and Petzold (Wannewitz et al., 2025), who assess progress and gaps in coastal adaptation globally. Their analysis finds that while many coastal cities have begun planning, implementation lags behind the growing risk. This disconnect between physical exposure and adaptive action creates an urgent demand for financing mechanisms that can bridge the gap. Sales (2009), studying Cavite City in the Philippines, reinforces this point, showing that local communities face high risk factor but limited access to capital for infrastructure upgrades.

2.3.2 Financial Instruments and Their Reported Effectiveness

The literature documents a diverse array of financing mechanisms, each with distinct strengths and limitations. Favero and Hinkel (2024) provide a detailed assessment of innovations in financing nature-based solutions (NBS) for coastal adaptation. They find that while NBS offer cost-effectiveness and ecological co-benefits, their uptake is constrained by a lack of standardised financial products and measurable risk-reduction metrics. Green-gray infrastructure, as described by Corwin and Peterson (2022), represents a hybrid approach that combines engineered structures with ecological elements, but the authors note that site-specific design requirements limit replicability.

Parametric insurance has emerged as a promising instrument for rapid post-disaster liquidity. Panda (2025) prototypes a satellite-based parametric insurance scheme for coastal cities, showing that index-based triggers can reduce transaction costs and payout delays compared to traditional indemnity insurance. However, Kousky (2021) cautions that insurance alone cannot address adaptation deficits; it works best when paired with risk-reduction investments. Land value capture, exemplified by the coastal road project in India analysed by Nagi, Pandey, and Nagargoje (Nagi et al., 2024), offers a driver to channel appreciation in land values toward infrastructure finance, but its applicability is limited to areas with strong property markets and governance capacity.

Blended finance--which combines concessional public funds with private capital--is frequently cited as a tool to de-risk adaptation projects. Mustapha, Prizzon, and Gavas (Mustapha et al., 2014) note that blended structures can mobilise private investment for infrastructure in developing countries, yet they also identify challenges in measuring additionality and ensuring alignment with adaptation priorities. Brownbridge and Canagarajah (2024) raise a further concern: heavy reliance on public debt for adaptation can strain fiscal sustainability, particularly in small island developing states where climate exposure is high and revenue bases are narrow.

Table 1 summarises the key financial instruments identified in the literature, their reported advantages, and the constraints that limit their deployment.

Financial Instrument	Reported Advantages	Key Constraints	Source
Nature-based solutions (NBS) finance	Cost-effectiveness, ecological co-benefits	Lack of standardised products, measurement metrics	(Favero & Hinkel, 2024)
Parametric insurance	Fast payout, low transaction costs	Requires reliable index data, limited risk coverage	(Panda, 2025)
Land value capture	Links infrastructure value to revenue	Needs strong property market, governance capacity	(Nagi et al., 2024)
Blended finance	De-risks private investment, mobilises capital	Complexity in measuring additionality	(Mustapha et al., 2014)
Green-gray infrastructure	Hybrid resilience, adaptable design	Site-specific, needs cross-sector coordination	(Corwin & Peterson, 2022)

Table 6: Summary of financing mechanisms for coastal adaptation infrastructure, based on reviewed studies.

2.3.3 Equity and Affordability Constraints

A recurring theme in the literature is that adaptation finance is not distributed equally across income groups or geographies. Hudson (2020) examines the affordability of property-level adaptation measures and finds that low-income households in flood-prone areas are often priced out of even basic protections, such as flood doors or sump pumps. This affordability gap means that private finance mechanisms--such as insurance or resilience loans--may actually reinforce existing inequalities.

Khalil, Jacobs, and Kuruppu (Khalil et al., 2016) explore grassroots technologies in coastal settlements of Bangladesh and show that community trust and local knowledge are critical for the uptake of adaptation finance. Without culturally appropriate delivery channels, even well-designed instruments may fail to reach vulnerable populations. Markanday and Galarraga (2021) add a behavioural dimension, showing that individual risk perception and prior flood experience considerably influence willingness to invest in adaptation measures. This suggests that financing mechanisms must be coupled with risk communication to be effective.

Alpizar et al. (Alpizar et al., 2023) document that private actors often apply high discount rates to future climate benefits, making adaptation investments appear unattractive compared to short-term alternatives. This temporal misalignment is particularly acute for long-lived infrastructure such as seawalls or stormwater systems. Gil-Clavel, Wagenblast, Akkerman, and Filatova (Gil-Clavel et al., 2024) consolidate these insights, identifying patterns of adaptation constraints across different actor groups: governments face fiscal and capacity constraints, communities face social and trust barriers, while individuals and households face affordability and perception constraints.

Table 2 distils the principal equity-related barriers identified in the reviewed studies.

Barrier Category	Key Finding	Examples from Literature
Affordability	Low-income households excluded from property-level adaptation	(Hudson, 2020)
Trust and culture	Community trust essential for uptake of finance instruments	(Khalil et al., 2016)
Risk perception	Experience and framing influence investment behaviour	(Markanday & Galarraga, 2021)
Discount rates	Private actors undervalue long-term adaptation benefits	(Alpizar et al., 2023)
Multi-actor constraints	Different barriers for governments, communities, individuals	(Gil-Clavel et al., 2024)

Table 7: Equity and affordability constraints affecting coastal adaptation finance.

2.3.4 Barriers to Scaling and Gaps in the Evidence

Several cross-cutting barriers limit the broader deployment of adaptation finance. Gibbs (2015) warns of pitfalls in coastal adaptation planning when assumptions about future risk, cost, and institutional capacity are not made transparent. Without explicit assumptions, financial models can overestimate returns or underestimate residual risk, undermining investor confidence. Stakhiv (2022) highlights the centrality of engineering codes and risk-based design standards: financing mechanisms depend on consistent, predictable technical standards, yet many coastal cities lack up-to-date building codes that reflect climate projections.

A notable gap in the literature concerns the empirical validation of financial instruments for adaptation. Although Favero and Hinkel (2024) identify several innovations in NBS finance, they note that few have been rigorously evaluated for cost-effectiveness or risk reduction in real-world settings. Similarly, parametric insurance prototypes, as described by Panda (2025), have not been tested at scale. Liziński, Bukowski, and Wróblewska (Liziński et al., 2015) compare valuation methods for flood protection projects and find that benefit-cost analyses often omit distributional impacts and non-monetised co-benefits, skewing investment decisions.

Finally, the literature consistently points to a need for better integration across disciplines. Ayyub (2019) argues for practical resilience metrics that can be embedded in financial contracts, while Whittaker (2023) identifies through bibliometric analysis that urban climate adaptation finance remains a fragmented field, with limited exchange between engineering, economics, and social science communities. This synthesis confirms that bridging those disciplinary divides is essential for translating financial innovation into on-the-ground resilience in coastal cities.

2.4 Discussion

The findings from the literature synthesized in section 2.3 reveal notable insights that both align with and extend the theoretical frameworks discussed in section 2.1. As noted in the literature review (section 2.1), coastal adaptation finance has been examined primarily through three separate lenses: physical flood risk, financing mechanisms, and equity considerations. What the synthesis in section 2.3 makes clear is that these dimensions are not merely related--they are mutually constitutive. A financing dynamic designed without accounting for subsidence-amplified risk, for example, will systematically undervalue the protection needs of deltaic cities, while one that ignores household affordability will reproduce existing inequalities regardless of its technical sophistication.

2.4.1 Bridging the Risk-Finance-Equity Disconnect

The most striking pattern emerging from the literature is the persistent fragmentation between physical risk assessment and financial instrument design. Section 2.1 described how Nicholls and Fang (2022) indicated that subsidence in coastal China amplifies relative sea-level rise rates two to three times above global averages. Yet as Favero and Hinkel (2024) observe, few financing innovations for nature-based solutions have been stress-tested against such spatially heterogeneous risk profiles. The implication is that current financial models--whether green bonds, blended finance, or insurance pools--are operating with an incomplete picture of the hazard they are meant to address. Ayyub (2019) argues for practical resilience metrics that could be embedded in financial contracts, but the synthesis in section 2.3 confirms that such metrics remain underdeveloped in practice. The research gap identified in section 2.1--the lack of integration between subsidence data and financing models--has not yet been adequately addressed by the literature, though the works of Favero and Hinkel (2024) and Panda (2025) represent initial steps toward parametric insurance prototypes that could incorporate dynamic risk indicators.

A related disconnect concerns the temporal mismatch between risk trajectories and financial planning horizons. Alpizar et al. (Alpizar et al., 2023) highlight that private actors apply high discount rates to long-term adaptation investments, effectively undervaluing benefits that materialise decades into the future.1 in the context of behavioural barriers, is corroborated by the synthesis in section 2.3 which shows that benefit-cost analyses for flood protection often omit distributional impacts and non-monetised co-benefits (Liziński et al., 2015). The theoretical framework from section 2.1 suggested that discounting behaviour could undermine adaptation policy; the evidence from (Alpizar et al., 2023) and (Liziński et al., 2015) now provides concrete empirical support for that concern. What the literature does not yet offer is a systematic comparison of how different financial instruments (e.g. catastrophe bonds vs. Resilience bonds vs. Concessional loans) perform under the discount-rate assumptions of different actor types--a gap that future empirical validation should address.

2.4.2 Affordability, Equity, and the Limits of Financial Innovation

The literature reviewed in section 2.1 raised equity concerns about adaptation finance, particularly the risk that market-based mechanisms could exclude low-income households and communities. Hudson's (Hudson, 2020) finding that property-level adaptation measures are unaffordable for 40-70% of households in flood-prone regions directly validates those concerns. This is not merely a distributional issue; it has structural implications for the viability of adaptation finance. If a meaningful portion of the population cannot invest in protective measures, the aggregate risk profile of the coastal city remains high, undermining the risk-pooling logic that underpins insurance-based mechanisms. The synthesis in section 2.3 also highlighted the role of community trust, as shown by Khalil, Jacobs, and Kuruppu (Khalil et al., 2016) in the context of grassroots technologies in Bangladesh. Trust mediates the uptake of any financial product, and where communities are sceptical of external interventions--a pattern observed in multiple coastal settings--even well-designed instruments may fail to achieve scale.

Table 1 below summarises the key disconnects identified across the literature and their implications for adaptation finance.

Theme	Key Finding from Literature	Implication for Policy	Citation
Risk-finance gap	Subsidence amplifies SLR, but financing models ignore spatial heterogeneity	Financial instruments must embed dynamic risk metrics	(Nicholls & Fang, 2022; Favero & Hinkel, 2024)

Theme	Key Finding from Literature	Implication for Policy	Citation
Temporal mismatch	Private actors apply high discount rates to long-term investments	Public guarantees or concessional terms needed for long-duration bonds	(Alpizar et al., 2023; Liziński et al., 2015)
Affordability barrier	40-70% of households cannot afford property-level adaptation	Subsidies or microfinance required to reach vulnerable groups	(Hudson, 2020)
Trust deficit	Community trust essential for uptake of interventions	Participatory design and local partnerships are prerequisites	(Khalil et al., 2016)
Fragmented discipline	Limited exchange between engineering, economics, social science	Interdisciplinary research teams and integrated assessment frameworks	(Whittaker, 2023)

Table 8: Summary of key disconnects found in the literature and their implications for coastal adaptation finance.

As the table illustrates, the barriers to effective adaptation finance are not merely technical but institutional and social. The literature reviewed in section 2.1 identified engineering codes as a cornerstone of risk-based design (Stakhiv, 2022), yet the synthesis in section 2.3 shows that many coastal cities lack updated codes that reflect climate projections. Without such codes, financial instruments cannot anchor their risk assessments to consistent standards. Similarly, the bibliometric analysis by Whittaker (2023) confirms that urban climate adaptation finance remains a fragmented field, with limited cross-disciplinary exchange. The theoretical expectation from section 2.1--that integrated approaches are needed--is fully borne out, but the literature also shows that the institutional conditions for integration are often absent.

2.4.3 Limitations and Future Research Directions

The findings from the literature must be interpreted with several caveats. First, many of the financing mechanisms discussed in section 2.1 and 2.3 have not been empirically validated at scale. Favero and Hinkel (2024) note that innovations in nature-based solution finance lack rigorous cost-effectiveness evaluations, and Panda's (Panda, 2025) parametric insurance prototype remains a proof of concept. The absence of large-scale implementation data means that conclusions about scalability are necessarily provisional. Second, the geographic coverage of the literature is uneven: while East Asia and South Asia are well represented through studies on China (Nicholls & Fang, 2022) and Bangladesh (Khalil et al., 2016), other regions such as West Africa and Latin America are underrepresented, limiting the generalisability of findings.

What the literature does strongly suggest is that future research should focus on hybrid financing models that combine public, private, and community-based mechanisms in ways that address multiple constraints simultaneously. For instance, a blended finance structure that bundles concessional loans with parametric insurance could reduce the discount-rate burden while ensuring affordability. Such models need to be tested through pilot projects with built-in monitoring and evaluation frameworks. Future work should develop resilience metrics that can be legally embedded in financial contracts, as Ayyub (2019) advocates, and integrate these metrics with spatially explicit risk assessments that account for subsidence (Nicholls & Fang, 2022). The fragmentation highlighted by Whittaker (2023) calls for interdisciplinary research teams that bring together engineers, economists, and social scientists from the outset of any study. Only through such integration can the literature move from identifying barriers to providing actionable solutions for financing coastal adaptation in cities facing rising flood risk.

3. Conclusion

The literature examined in this paper reveals a complex and evolving environment for financing climate adaptation infrastructure in coastal cities facing rising flood risk. Three overarching insights emerge from the synthesis, each carrying distinct implications for research, policy, and practice.

3.1 Summary of Findings

3.1.1 Physical Risk and Financing Mechanisms

The physical dimensions of flood risk are increasingly well characterized. Subsidence amplifies relative sea-level rise by two to three times global averages in deltaic urban areas, with cities such as Shanghai and Tianjin facing exposure levels that could double by 2050 without aggressive intervention (Nicholls & Fang, 2022). Coastal ecosystems are under compounding stress from storm surges, rainfall intensification, and sea-level rise (Desta & Molla, 2023). Against this backdrop, adaptation planning has gained traction globally, yet implementation lags behind stated commitments (Wannewitz et al., 2025).

The financing mechanisms reviewed span public budgets, insurance instruments, blended finance, and nature-based solutions. Key innovations such as parametric insurance prototypes and land value capture frameworks show promise (Panda, 2025; Nagi et al., 2024), but their scalability remains unproven at the portfolio level. Favero and Hinkel (2024) document a persistent finance gap for nature-based solutions, while Corwin and Peterson (2022) illustrate how green-gray infrastructure blends can bridge technical and financial constraints. The literature suggests that no single instrument is sufficient; a layered approach combining risk transfer, concessional capital, and user fees is likely necessary.

3.1.2 Equity and Implementation Gaps

A recurring theme across the evidence is the equity dimension of adaptation finance. Hudson (2020) shows that property-level adaptation measures are often unaffordable for low-income households, raising concerns about regressive outcomes when risk signals are transmitted through insurance premiums or mandatory costs. The affordability gap is especially acute in developing-country coastal settlements, where community trust and grassroots technologies play a mediating role (Khalil et al., 2016).

Several authors caution that without explicit equity safeguards, adaptation financing can deepen existing vulnerabilities (Gibbs, 2015; Sales, 2009).

Theme	Key Finding	Source
Physical risk	Subsidence amplifies SLR 2-3× in delta cities	(Nicholls & Fang, 2022)
Financing gap	NBS face chronic underinvestment despite innovation	(Favero & Hinkel, 2024)
Equity	Property-level measures often unaffordable for poor	(Hudson, 2020)
Implementation	Planning widespread but execution lags	(Wannewitz et al., 2025)
Community role	Trust and local tech mediate adaptation success	(Khalil et al., 2016)

Table 9: Summary of core findings across the three review themes.

3.2 Implications for Policy and Practice

The evidence points toward several actionable directions. A starting point is that adaptation finance must move beyond project-by-project allocations toward systemic frameworks that integrate risk assessment, cost-benefit analysis, and equity criteria. Engineering standards and risk-based design codes need updating to reflect projected conditions rather than historical baselines (Stakhiv, 2022). Another critical area is blended finance structures--combining public guarantees with private capital--which require standardized metrics to attract institutional investors while ensuring that adaptation benefits reach vulnerable populations (Mustapha et al., 2014). And insurance mechanisms must be designed with affordability in mind, potentially through subsidy layering or index-based triggers that lower premium costs (Panda, 2025; Landry & Jahan-Parvar, 2010). the more telling finding is the disconnect between the scale of the problem and the ambition of financial instruments. While catastrophe risk pooling has been applied in small island states (Pollner, 2001), its applicability to large coastal cities with heterogeneous risk profiles remains an open question. Similarly, high discount rates used by private actors undermine the long-term perspective that adaptation demands (Alpizar et al., 2023). These patterns suggest that public leadership--through regulatory mandates, credit enhancement, and data provision--is indispensable.

3.3 Limitations and Future Research Directions

This paper is based on a narrative review of the peer-reviewed and grey literature, and several limitations should be acknowledged. The selection of sources prioritizes recent contributions (2019-2025) and may underrepresent older but still relevant work on insurance pooling and infrastructure finance. The geographic coverage is uneven, with a bias toward East Asia, Europe, and North America; coastal cities in South Asia and West Africa are less represented in the available evidence.

On top of that, quantitative comparisons across studies are constrained by heterogeneous methodologies, risk metrics, and time horizons.

Three lines of inquiry stand out for future research. One is empirical studies that track the actual deployment and performance of blended finance instruments for coastal adaptation--these are scarce and urgently needed. Alongside that, equity impact assessments--both ex-ante and ex-post--should become standard components of adaptation finance evaluations. And the interplay between physical risk dynamics (subsidence, SLR, storm surge) and financial instrument design deserves systematic modeling that accounts for non-stationary hazard distributions. Without such evidence, the risk of maladaptation--investing in infrastructure that is either under- or over-designed relative to future conditions--remains high. Closing these gaps is not merely an academic exercise; it is a prerequisite for ensuring that the billions of dollars committed to coastal resilience translate into genuinely protected communities.

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