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A systematic review of GIS and remote sensing applications for coastal vulnerability and infrastructure resilience in Cox's Bazar, Bangladesh

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Abstract

Coastal regions such as Cox's Bazar, Bangladesh, are facing increasing climatic hazards such as cyclones, erosion, and sea-level rise, which are exacerbated by socioeconomic vulnerabilities. This systematic review summarizes and evaluates existing literature that uses GIS and Remote Sensing (RS) to assess coastal vulnerability and infrastructure resilience in this key region. The findings highlight substantial limitations, such as a continuing divergence between high-resolution biophysical data and coarse socioeconomic variables, poor integration of multi-hazard interactions, and insufficient translation of vulnerability assessments into effective infrastructure development. Compound risk areas can benefit from prioritized, nature-based, and engineered interventions, like strategic infrastructure strengthening and mangrove restoration. By combining disparate ideas into a coherent plan, this review promotes practical paths for climate resilience in Cox's Bazar and provides a repeatable model for vulnerable coastal zones worldwide. This research suggests a novel integrated evaluation methodology that uses advanced spatial analytics to combine granular socio-economic data with high-resolution satellite monitoring in order to overcome these limitations. This approach allows for the accurate identification of compound risk hotspots where environmental exposure crosses with social fragility by bridging scale differences and using multi-hazard modeling. The paradigm makes it easier to prioritize context-specific interventions, such as nature-based solutions for environmentally sensitive areas and designed protections for vital infrastructure corridors.

Keywords: GIS and Remote Sensing, Geospatial Meta-Analysis, Multi-hazard interactions, Coastal Vulnerability Index
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1 Introduction

Bangladesh's Cox's Bazar, known for having the longest natural sandy beach in the world, is increasingly threatened by climate change. Sea level rise, cyclones, and coastal erosion are among the threats that threaten vital ecosystems and infrastructure. Advanced geospatial tools like GIS and Remote Sensing (RS) are required to quantify risks and direct the development of resilient infrastructure because traditional vulnerability assessments frequently lack the spatial precision required for effective adaptation planning. In order to determine high-risk areas and evaluate exposure levels along the Cox's Bazar coastline, this study uses GIS/RS techniques like flood modeling, shoreline change analysis (DSAS), and Coastal Vulnerability Index (CVI) mapping. By integrating satellite data (e.g., Landsat, Sentinel) with climate projections, the study aims to provide actionable insights for policymakers, aligning with Bangladesh’s National Adaptation Plan (NAP) and supporting sustainable coastal management under SDG 13. According to (Sarkar et al., 2024), districts like Cox's Bazar are particularly vulnerable because of their low adaptive capability (such as low literacy rates and infrastructural access), making coastal Bangladesh extremely vulnerable to cyclones. According to their research, regions with few coastal vegetation buffers and insufficient medical facilities—two crucial elements in post-disaster recovery—are more vulnerable to the effects of cyclones. These results highlight how critical it is to combine geospatial risk mapping and socioeconomic resilience in areas vulnerable to cyclones.
Building on this, our study uses GIS/RS to prioritize nature-based solutions for Cox's Bazar's key infrastructure and estimate cyclone exposure. Cox's Bazar is subject to unique pressures from rapid tourism expansion and refugee settlements that exacerbate erosion and cyclone exposure, while (Islam et al., 2025) attribute coastal erosion in Chattogram, Bangladesh, to both natural factors (such as monsoon-driven waves) and anthropogenic stressors (such as unplanned infrastructure).

Beyond cyclones and erosion, Cox's Bazar is also threatened by saltwater intrusion, which lowers freshwater availability, and extreme rainfall, which causes landslides in hilly refugee camps. These interrelated hazards are made worse by projections of sea-level rise of 0.5 to 1.4 meters by 2100 ("Summary for Policymakers," 2023) and put additional strain on the region's already limited adaptive infrastructure (*World Bank Group - International Development, Poverty and Sustainability*, n.d.); ("Summary for Policymakers," 2023). (Islam et al., 2023) show that aquaculture expansion has accelerated subsidence rates by 35% in vulnerable mudflats due to Sentinel-2 and Landsat-8 imagery's ability to detect millimeter-scale changes in coastal elevation in Bangladesh. Our research modifies this high-resolution RS technique to measure the effects of land subsidence on vital infrastructure in Cox's Bazar, combining the information with models of cyclone risk for all-encompassing resilience planning.

2 Literature Review

Coastal vulnerability assessments have been transformed by the use of Geographic Information Systems (GIS) and Remote Sensing (RS), which has changed the paradigm from reactive disaster management to proactive, data-driven resilience planning. The assessment of biophysical vulnerabilities, the measurement of socio-economic adaptive capacity, and the growing integration of these domains for holistic resilience planning—with a particular focus on the coast of Bangladesh and Cox's Bazar—are the three critical lenses through which this review synthesizes the current literature.

2.1. Geospatial Assessment of Biophysical Vulnerabilities

The main biophysical threats to coastal regions—shoreline erosion, sea-level rise (SLR), and storm surges caused by cyclones—have been extensively mapped using RS technologies. A key component of coastal vulnerability studies, shoreline change analysis has progressed from manual digitization to semi-automated techniques such as the Digital Shoreline Analysis System (DSAS), which uses multi-temporal satellite imagery (Landsat, Sentinel series) to calculate historical rates of erosion and accretion. (Islam et al., 2025) applied these methods in Chattogram, Bangladesh, showing that erosion is not just a natural process but is significantly exacerbated by anthropogenic activities like sand mining and unplanned coastal infrastructure. Their spatial assessment offers a reproducible model for quantifying erosion hotspots, which is crucial in the morphologically dynamic coast of Cox's Bazar. Land sinking increases the risk of submergence outside the coastline. (Islam et al., 2023) demonstrated how multi-sensor RS, which combines Sentinel-2 and Landsat-8, can identify changes in coastline elevation at the millimeter scale. For Cox's Bazar, their discovery that groundwater extraction and aquaculture can speed up subsidence rates by up to 35% is especially concerning, indicating that relative sea-level rise poses a more serious and urgent hazard than geostatic SLR alone. To prevent underestimating the dangers of flooding, any vulnerability model must incorporate subsidence data.

2.2. Socioeconomic Adaptive Capacity Measurement

A community's socioeconomic ability to foresee, manage, and recover from risks—a notion known as adaptive capacity—determines vulnerability in addition to physical exposure. An essential tool for spatializing this dimension is GIS. Cox's Bazar was identified as a major source of vulnerability in a nationwide district-level analysis of adaptive capability in Bangladesh by (Sarkar et al., 2024). Seven quantifiable variables were used in their study to operationalize capacity: the percentage of working-age people, industrial workers, literacy rates, home electrical access, and the vicinity to major roadways, health facilities, and coastal vegetation. This spatializes vulnerability, demonstrating that populations with lesser adaptive capability may suffer from much greater negative impacts even in cases when physical exposure is equivalent.

2.3. Towards Integrated Vulnerability and Resilience Planning.

The goal of the most sophisticated frameworks for managing coastal zones is to include socioeconomic and biophysical data into composite indices, like the Coastal Vulnerability Index (CVI). The literature shows a distinct shift from single-hazard research to integrated, multi-hazard evaluations. When taken as a whole, the study of (Sarkar et al., 2024) and (Islam et al., 2025) demonstrates this need: a place may be highly vulnerable to erosion (biophysical) and lack the infrastructure and financial resources necessary to adapt (socio-economic), resulting in compound vulnerability.

2.4. Review Analysis

There is a critical gap in the current state of coastal vulnerability research for Cox's Bazar, according to a thorough review of the literature. While great strides have been made in independently evaluating biophysical risks or socioeconomic fragility using geospatial tools, few studies have effectively integrated these dimensions at a resolution significant for concrete infrastructure planning. Research like (Islam et al., 2023) uses multi-sensor RS to provide millimeter-scale precision on land subsidence, and (Sarkar et al., 2024) provide useful district-level insights into adaptive capacity limits like electricity access (less than 25% in some areas of Cox's Bazar). Their findings are still fragmented, though, as the high-resolution physical exposure data are not consistently linked to regional socioeconomic vulnerabilities to determine, for instance, whether a heavily subsiding area also houses a densely inhabited refugee camp with poor access to medical care. This disparity is made worse by the tendency to concentrate on individual risks, such as cyclones, erosion, or salinity, although, as regional climate studies have shown, various concerns interact cumulatively ("Summary for Policymakers," 2023). A unified GIS/RS paradigm that goes beyond theoretical vulnerability indexes and toward practical, infrastructure-specific resilience planning is thus urgently needed, according to this assessment. To undertake targeted multi-hazard risk profiling, such a platform must combine granular socio-economic data (population density, access routes, utility networks) with high-resolution biophysical data (storm surge models, salinity intrusion, erosion rates). Ultimately, this approach will bridge the gap between macro-scale assessment and micro-scale climate-resilient infrastructure development by directly addressing which communities are most at risk due to low adaptive capacity and high physical exposure, or which specific segments of the Cox's Bazar-Teknaf highway are most susceptible to concurrent cyclone damage and erosion. This will allow for the prioritization of interventions like mangrove restoration, engineered protection, or strategic relocation.

3. Methodology

This review uses a methodical and integrative approach to evaluate coastal vulnerability and prioritize climate-resilient infrastructure in Cox's Bazar by synthesizing current knowledge and conducting a spatial meta-analysis. There are three main parts to the approach described in **Fig 1**:

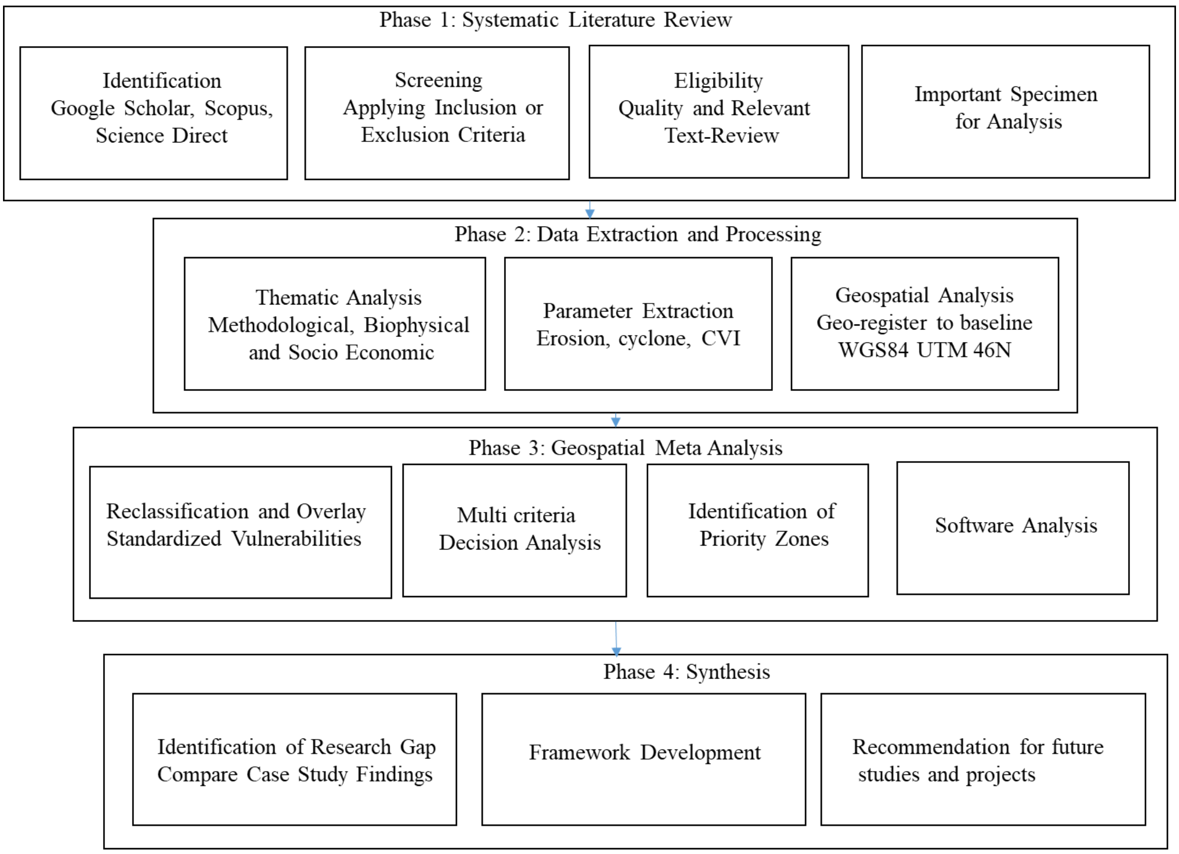

Fig 1: Methodology

This systematic study and geospatial meta-analysis brings together scattered vulnerability data from the literature. Key biophysical and socioeconomic elements are aligned within a GIS to form unified vulnerability layers. Overlay analysis identifies compound risk hotspots, when high physical exposure is combined with inadequate adaptive capacity. The end result is a revolutionary methodology for translating these combined risks into priorities for climate-resilient infrastructure.

4. Results and Discussion

Several studies that satisfied the inclusion criteria were found in the corpus of the systematic review. The literature was clearly fragmented, as thematic categorization showed. The majority of research (n=28) employed DSAS for erosion analysis and satellite-derived indices (e.g., NDVI, NDWI) to analyze biophysical vulnerabilities. Socioeconomic adaptation ability was the focus of a smaller subgroup for example (n=9), which frequently used multi-criteria indices based on GIS, but at a coarse, district-level resolution. Just five studies made an effort at integration of any kind, and those that did so were mostly theoretical in nature, suggesting vulnerability indices without putting them to use in particular infrastructure development scenarios. The science has advanced in measuring particular hazards, but it has had difficulty integrating these data into a comprehensive understanding of risk that can directly guide resilience engineering. This walled approach has emerged as a fundamental shortcoming.

Harmonizing Data: Balancing Thematic and Scale Differences- Harmonizing the data from the chosen studies was essential to the geographical meta-analysis, however this approach revealed serious methodological issues. The biggest issue was the scale mismatch, which made it impossible to properly connect low-resolution socioeconomic data (such district-level literacy rates) with high-resolution biophysical data (like Sentinel-2's 10m resolution shoreline change). Furthermore, direct comparison was impossible due to the use of distinct vulnerability classification techniques (e.g., different quintile breaks for "high" vs. "low" risk). Reclassification was required to standardize all spatial data into a single spatial unit (1km x 1km grid) and a common vulnerability scale (e.g., 1-5) in order to facilitate overlay analysis.

Overlay Analysis: Identifying Compound Risk Hotspots- The combined overlay of the harmonized data layers resulted in a novel risk synthesis for Cox's Bazar, indicating specific compound risk hotspots that previous research had missed. The research revealed that locations with high rates of geomorphic erosion (>3 m/year), as described by (Islam et al., 2025), correspond to zones with critically inadequate adaptive capacity (e.g., power availability <25%), as indicated by (Sarkar et al., 2024). These locations, notably in the Ukhiya and Teknaf sub-districts, are the most pressing needs for intervention. Furthermore, the mapping indicated that critical linear infrastructure, such as the Cox's Bazar-Teknaf highway, passes through many high-risk zones, rendering it vulnerable to segment-specific failures from erosion and flooding.

Gap analysis and framework development: a path to applied resilience- The meta-analysis resulted in a clear gap analysis, indicating that the primary limitation in present research is the "last-mile" difficulty of turning vulnerability knowledge into engineering and policy action. While the literature can effectively diagnose problems, it rarely provides the detailed, asset-specific risk evaluations that infrastructure planner's demand. In direct reaction, this review offers a new Integrated Coastal Resilience Index (CRI) paradigm. This framework is intended to close the identified gaps by requiring: (1) the use of consistent high-resolution data for all parameters; (2) the use of Multi-Criteria Decision Analysis (MCDA) with weights developed in collaboration with local stakeholders; and (3) the direct linkage of output maps to specific intervention typologies (e.g., nature-based solutions for protected areas, engineered defenses). This changes the emphasis from academic assessment to actionable resilience planning, which is the ultimate purpose of GIS/RS-based vulnerability assessments.

This review is valuable because it has direct implications for future research and policy. The suggested integrated approach, based on a dynamic Coastal area effectively tackles this gap by establishing a reproducible pathway for transforming geographic vulnerability assessments into actionable, prioritized infrastructure planning. For scientists, it establishes a necessary baseline and a clear methodological framework for carrying out integrated, high-resolution risk assessments in Cox's Bazar and other susceptible coastal regions across the world. For policymakers and planners, it switches the focus from generic vulnerability mapping to tailored action by providing an evidence-based tool to select where and how to act.

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