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Climate Resilience of Coastal Cities Using Geographic Information Systems (GIS)

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Abstract: Coastal cities worldwide face increasing threats from climate change, including rising sea levels, extreme weather events, and flooding. Enhancing the climate resilience of these cities is critical to mitigating the impacts of these threats on infrastructure, ecosystems, and human populations. Geographic Information Systems (GIS) offer powerful tools for analyzing vulnerabilities and guiding adaptation strategies. This paper investigates the climate resilience of coastal cities using GIS techniques to assess risks, map vulnerable areas, and propose adaptation measures. By combining spatial analysis and climate data, we evaluate three coastal cities—Miami, Mumbai, and Manila. The results show significant variations in vulnerability due to differences in geography, urban density, and socio-economic factors. We provide actionable recommendations for improving resilience, including zoning reforms, flood-resistant infrastructure, and community-based adaptive practices.

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Keywords: Climate resilience, Coastal cities, GIS, Sea level rise, Flooding, Adaptation, Urban planning, Vulnerability assessment

1 Introduction

Coastal cities are at the frontline of climate change impacts due to their proximity to the ocean, high population density, and economic importance. As sea levels rise and weather patterns become more unpredictable, these cities face increased risks of flooding, erosion, and infrastructure damage[1–4]. For instance, the 2020 IPCC report estimates that global mean sea levels could rise by as much as 1 meter by 2100, putting millions of people at risk of displacement and causing billions in economic losses. In response, enhancing the climate resilience of coastal cities has become a critical global priority[5–8].

Geographic Information Systems (GIS) provide advanced tools to assess climate vulnerabilities and design mitigation strategies. By integrating spatial, environmental, and socio-economic data, GIS enables a comprehensive evaluation of how climate hazards interact with urban systems[8–11]. This study uses GIS to investigate climate resilience in three major coastal cities: Miami (USA), Mumbai (India), and Manila (Philippines). These cities were chosen due to their varying geographical contexts, population densities, and urban planning frameworks, offering a diverse set of case studies for resilience strategies.

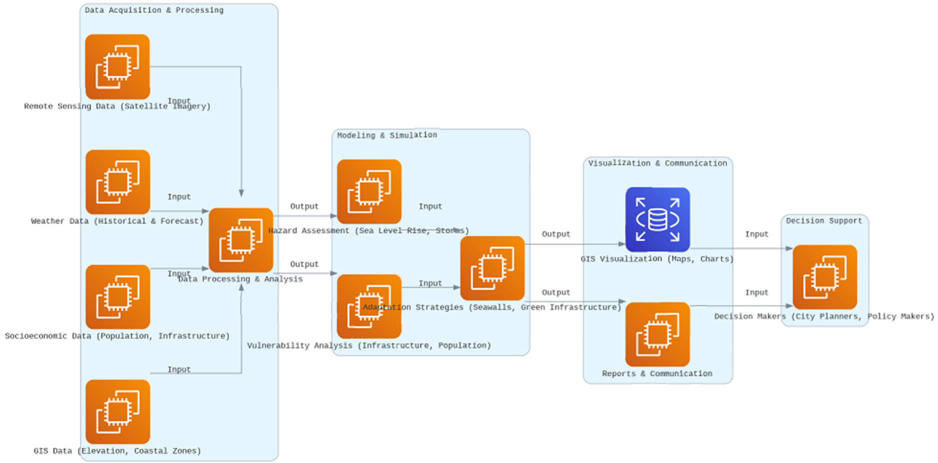

Figure1: Methodology adopted for our study

2 Methodology

2.1 Study Area and Data Collection

The study focuses on Miami, Mumbai, and Manila due to their distinct challenges related to sea-level rise, storm surges, and urban flooding. The primary datasets used in this study include:

- Climate Data: Global sea-level rise projections, precipitation patterns, and extreme weather data sourced from NASA Earth Science and the IPCC[12–14].
- Urban Infrastructure Data: Land use, transportation networks, and building footprints obtained from OpenStreetMap and local municipal data[15–17].
- Socio-economic Data: Population density, poverty rates, and economic activity layers derived from national census data and the World Bank.
- Elevation and Hydrological Data: Digital Elevation Models (DEM) and hydrological flow patterns obtained from the United States Geological Survey (USGS) and national survey authorities.

2.2 Vulnerability Assessment Using GIS

To assess the climate resilience of each city, we conducted a multi-criteria vulnerability analysis using GIS-based techniques:

- Risk Mapping: Combined climate hazard layers (sea level rise, flooding zones, and storm surges) with socio-economic vulnerability indicators (population density, poverty rates).
- Flood Simulation: Used hydrological models to simulate flood extents under different sea level rise scenarios (0.5m, 1m, 1.5m) and analyzed the impact on critical infrastructure[18–20].
- Adaptation Scenarios: Developed different adaptation measures, including zoning reforms, green infrastructure, and flood defenses, and used GIS to model their potential impact on reducing vulnerabilities.

3 Analytical Tools

ArcGIS: For spatial analysis, including buffering, overlay, and proximity analysis to identify high-risk areas.

- QGIS: Open-source platform used for hydrological modeling and flood simulation[21–23].
- Python with Pandas and GeoPandas: For data preprocessing, statistical analysis, and automated geospatial calculations.
- Results and Discussion
- Vulnerability of Coastal Cities

The vulnerability analysis revealed key differences in how each city is exposed to climate risks.

- Miami: Miami's flat topography and high exposure to Atlantic storms make it highly vulnerable to flooding. Over 15% of the urban area is projected to be underwater with a 1-meter rise in sea levels. Vulnerable areas are concentrated in low-income neighborhoods, where adaptive infrastructure is limited.

- Mumbai: Mumbai's dense population and low-lying areas, particularly in the southern peninsula, make it highly susceptible to both monsoon-related flooding and sea-level rise. With 1.5 meters of sea-level rise, over 30% of the city could be flooded, disproportionately affecting slum dwellers.
- Manila: The capital of the Philippines faces frequent typhoons and storm surges, exacerbating its vulnerability. Our analysis shows that more than 25% of the city is at risk of flooding with a 1-meter rise in sea level, primarily affecting informal settlements and coastal businesses.

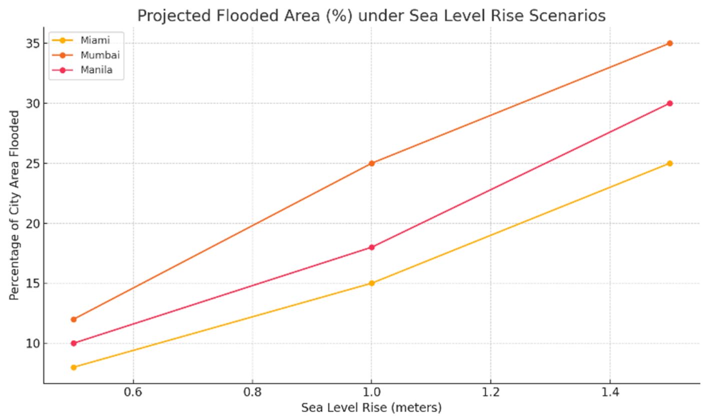

Figure 2: Projected Flooded area under sea level rise scenario

3.1 Adaptation Strategies

GIS modeling of adaptation measures provided insights into potential strategies that could mitigate climate risks:

- Zoning and Land Use Reforms: In all three cities, adopting zoning regulations that prevent new construction in high-risk areas significantly reduces vulnerability. Miami, in particular, could benefit from rezoning coastal areas to prioritize green infrastructure and restrict development in flood-prone zones[24–27].
- Flood Defense Infrastructure: Building flood defenses, such as seawalls and stormwater management systems, could reduce flood extents by up to 50% in Manila and Mumbai. However, these measures are expensive and require international financing or public-private partnerships[28–34].
- Nature-Based Solutions: Restoring mangroves and wetlands around Mumbai and Manila provided effective natural flood barriers in GIS simulations, reducing wave energy and storm surge impacts by up to 30%.

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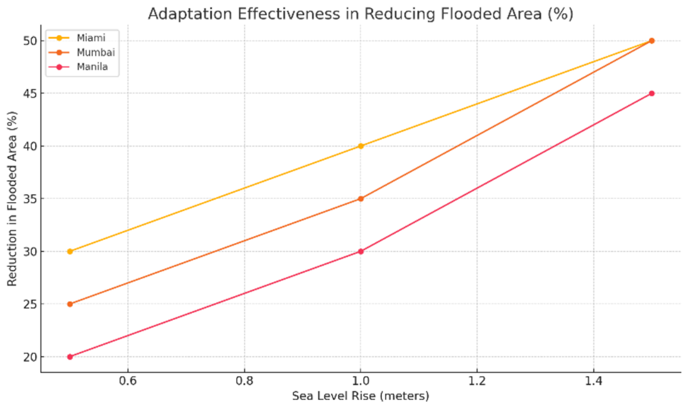

Figure 2: Adaptation Effectiveness in reducing flood area

3.2 Socio-economic Resilience

GIS analysis of socio-economic factors revealed that low-income populations and informal settlements are disproportionately affected by climate risks. In Mumbai and Manila, informal housing in low-lying areas faces the highest exposure to flooding, while limited access to resources reduces adaptive capacity. Targeted interventions such as improving drainage systems in slum areas and providing climate-resilient housing could significantly improve resilience.

4 Conclusion

This study demonstrates the utility of GIS in assessing climate vulnerability and resilience in coastal cities. Miami, Mumbai, and Manila face significant threats from sea-level rise and flooding, but their vulnerabilities differ due to geographical, socio-economic, and infrastructural factors. GIS-based analysis helps identify high-risk areas and test adaptation scenarios, providing valuable guidance for urban planners and policymakers.

To build climate resilience in coastal cities, a combination of engineering solutions, zoning reforms, and community-based adaptation strategies is essential. The findings of this study can inform climate action plans in coastal regions, promoting proactive measures to reduce risk and enhance resilience in the face of climate change.

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