Plausible hybrid-infrastructure alternatives for enhancing climate resilience of coastal communities -a case of megacity of Mumbai, India

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Abstract

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Marginalized vulnerable coastal communities living along the urban coasts are continuously under the dual threat of natural hazards and the adverse impact of infrastructure development, which results in the increase of cumulative risk for these communities. Further, the irreversible impacts of climate change have also exacerbated the risks associated with aging infrastructure and vulnerable coastal communities. Therefore, strengthening the climate resilience of such communities stands as a duly acknowledged priority for developing nations. One of the possible solutions to strengthen climate resilience is through the development and implementation of sustainable hybrid infrastructure alternatives. In this work, we characterized the data-driven Coastal Infrastructure Resilience Index (CIRI) to assess the performance of existing coastal infrastructure along the coast of Mumbai City in India. This study thoroughly utilized the potential of high-resolution remote-sensing imagery and socio-economic parameters from SEDAC data to derive CIRI. The robustness of the CIRI is improved with integrated value function and expert knowledge. As both grey infrastructure, such as seawalls, levees, and bulkheads and green infrastructure, such as salt marshes, mangroves, beaches, dunes, oysters and coral reefs have limited resilience in a multi-hazard environment, we identified the major hotspots of concerns through CIRI to propose the plausible hybrid (green-grey) infrastructure alternatives (green-grey) using Adaptive Gradient Framework for Mumbai's coastal context. Adapting Hybrid infrastructure alternatives empowers coastal communities with heightened climate benefits and co-benefits. The major findings of this study contribute as a science-policy instrument to localize the Sustainable Development Goals 11(11.5, 11. b), 13, and 14.2 of the United Nations.

Keyword- Integrated Coastal Management, Adaptation, risk-informed, Urban coastal areas, decision-analysis

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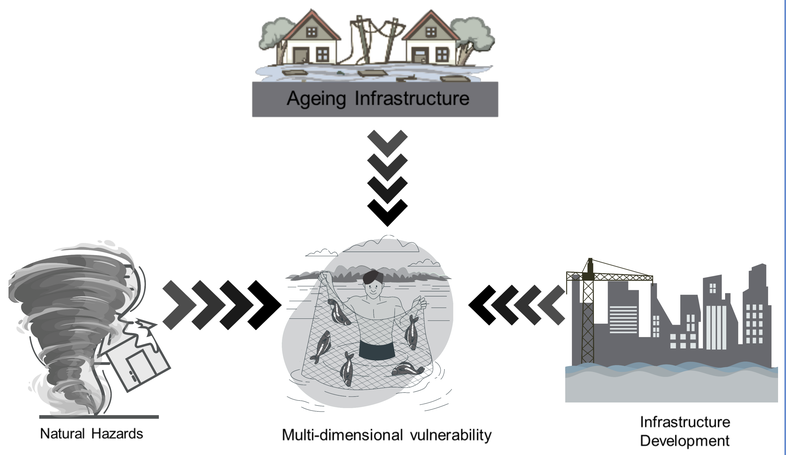
1. Introduction

- Coastal ecosystems are the **most threatened ecosystems** in the world due to anthropogenic impact .
- In case of megacity of Mumbai, **unplanned urbanization, overburdened drainage, poor waste management** destroys habitats, pollute surroundings, erode buffer zones, disrupt natural processes, and amplify vulnerability to climate change, culminating in **coastal degradation**.



2. Objectives

- To Assess Resilience of existing coastal Infrastructure in multi- hazard environment along the coasts of Mumbai through data driven multi-criteria index - **CIRI**
- To identify optimal hotspots to propose **plausible hybrid infrastructure alternatives -** combination of grey-green infrastructure

3. Study Area

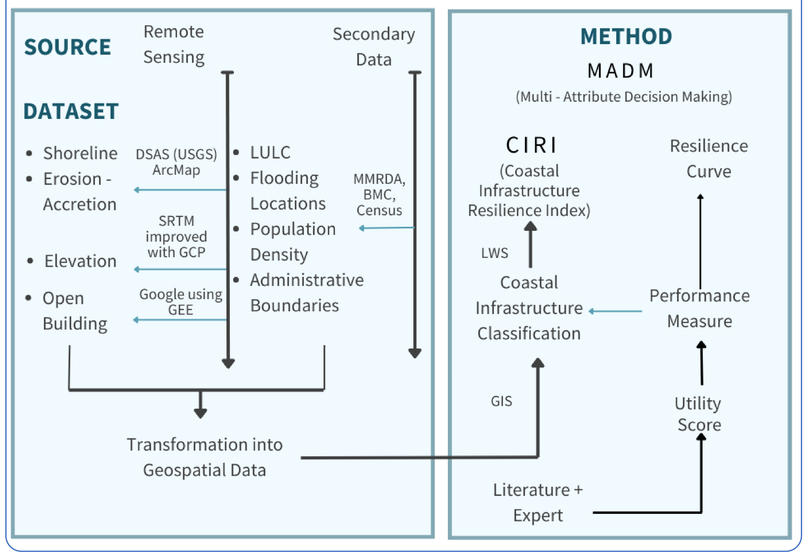
- Mumbai is an island megacity facing Arabian sea along the west coast of India built on reclaimed land
- Largest population exposed to coastal flooding – estimated at 2,787,000 currently, and projected to increase to more than 11 million people exposed by 2070.
- Complex urban coastal area where all the classic geomorphological features and urban signatures are present

4. Hybrid Infrastructure

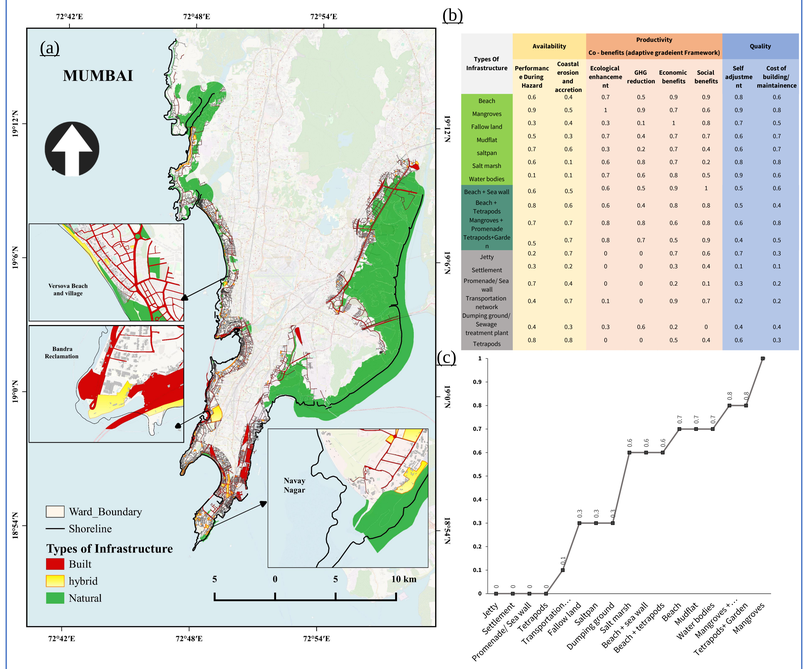
	Green/ Natural Infrastructure	Hybrid Infrastructure	Grey/ Built Infrastructure
Strength	• Co-benefits + coastal protection • Grows **stronger with time** as it gets established • Cost- effective in long run • Provide ecosystem services	• Capitalizes on best characteristics of built and natural • Provide a greater level of confidence than natural approaches alone • Appropriate for highly urbanized coastal cities	• Decades of Experience • Ready to withstand a storm event as soon as they are constructed • When space is limited (e.g., in an urban setting) or areas containing high value assets
Weakness	• Can take a **long time for ecosystems** to get established to provide the necessary level of coastal protection • Substantial amount of space to implement in urbanized areas	• **Does not provide all the same benefits** as green infrastructure • Crafting an effective response mix requires navigating technical challenges alongside nuanced political and value-based decisions .	• Does not adapt with changing climate • Negative impacts on the ecosystem • Lull communities into thinking they are safe from all disasters • Weakens with time & has built-in lifetime require continuous maintenance

Figure 2 Strength and weakness of various coastal infrastructure

5. Methodological Framework



6. Infrastructure Classification and Performance Measure



Types Of Infrastructure	Availability		Productivity				Quality	
			Co - benefits (adaptive gradeient Framework)					
	Performance During Hazard	Coastal erosion and accretion	Ecological enhancement	GHG reduction	Economic benefits	Social benefits	Self adjustment	Cost of building/ maintainence
Beach	0.6	0.4	0.7	0.5	0.9	0.9	0.8	0.6
Mangroves	0.9	0.5	1	0.9	0.7	0.6	0.9	0.8
Fallow land	0.3	0.4	0.3	0.1	1	0.8	0.7	0.5
Mudflat	0.5	0.3	0.7	0.4	0.7	0.7	0.6	0.7
saltpan	0.7	0.6	0.3	0.2	0.7	0.4	0.6	0.7
Salt marsh	0.6	0.1	0.6	0.8	0.7	0.2	0.8	0.8
Water bodies	0.1	0.1	0.7	0.6	0.8	0.5	0.9	0.6
Beach + Sea wall	0.6	0.5	0.6	0.5	0.9	1	0.5	0.6
Beach + Tetrapods	0.8	0.6	0.6	0.4	0.8	0.8	0.5	0.4
Mangroves + Promenade	0.7	0.7	0.8	0.8	0.6	0.8	0.6	0.8
Tetrapods+Garden	0.5	0.7	0.8	0.7	0.5	0.9	0.4	0.5
Jetty	0.2	0.7	0	0	0.7	0.6	0.7	0.3
Settlement	0.3	0.2	0	0	0.3	0.4	0.1	0.1
Promenade/ Sea wall	0.7	0.4	0	0	0.2	0.1	0.3	0.2
Transportation network	0.4	0.7	0.1	0	0.9	0.7	0.2	0.2
Dumping ground/ Sewage treatment plant	0.4	0.3	0.3	0.6	0.2	0	0.4	0.4
Tetrapods	0.8	0.8	0	0	0.5	0.4	0.6	0.3

Figure 3 (a) Coastal infrastructure classification of Mumbai, India (b) Utility scores of natural, hybrid and grey infrastructure based on availability, productivity and quality. (c) Utility Function for coastal features

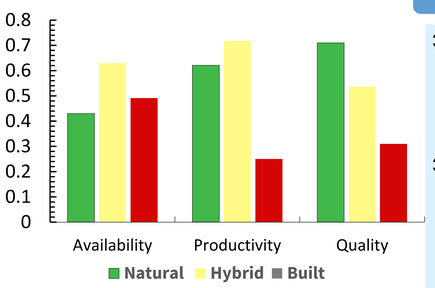


Figure 4 Performance Measure of various coastal Infrastructure

7. Way Forward

- Creating data driven mulitti-criteria index with expert system analysis for multi-hazard environment.
- To identify optimal hotspots to propose **plausible hybrid infrastructure alternatives** based on adaptive gradient framework.
- Developing Science Policy Instrument for Coastal Planners