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Designing Seaweed-Based Environmental Strategies for Coastal Erosion Mitigation in Sri Lanka

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Abstract – *Coastal erosion poses a severe threat to Sri Lanka's coastal ecosystems and communities, demanding sustainable, nature-based alternatives to conventional hard-engineered defenses. This paper explores the environmental potential of seaweed as a Nature-Based Solution (NbS) to mitigate coastal erosion while strengthening local livelihoods. Adopting a qualitative case study approach in Hikkaduwa, the study combines visual analysis, stakeholder interviews, and literature synthesis to assess seaweed's ecological feasibility. The findings highlight two dominant local species; Sargassum illicifolium and Eucheuma sp., as ecologically viable erosion buffers capable of stabilizing sediments and dissipating wave energy. Google Earth analysis between 2011 and 2023 indicates a coastline retreat of approximately 18 meters, revealing the urgency for sustainable interventions. Seaweed-based systems, drawing parallels with mangroves and seagrasses, demonstrate potential to reduce wave energy by 20–40% and trap sediments effectively. Beyond environmental protection, seaweed cultivation fosters economic empowerment, particularly among coastal women, through bio-composite development and aquaculture enterprises. The study concludes that integrating seaweed into coastal management frameworks promotes ecological resilience, socioeconomic inclusion, and long-term adaptive capacity. Future research should include hydrodynamic modeling, sedimentation rate analysis, and longitudinal ecological monitoring to quantify environmental performance and scalability.*

Keywords: *Seaweed, Coastal erosion, Nature-based solutions, Ecological resilience, Sri Lanka*

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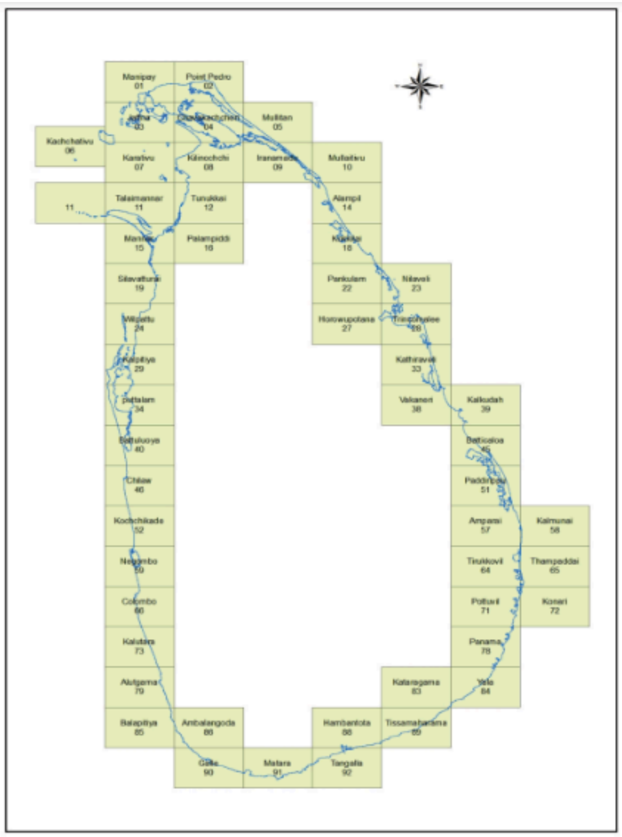
I. Introduction

A. Study Background

Sri Lanka's 1,340 km-long coastline faces escalating erosion due to unregulated coastal development, sand mining, and rising sea levels. The southern coastal belt, particularly Hikkaduwa, exhibits severe shoreline retreat that threatens biodiversity, infrastructure, and livelihoods dependent on fishing and tourism. NbS, or Nature-Based Solutions, are ecologically based approaches to coastal defense, focusing on stabilizing coastlines using mangroves, coral reefs, and seagrasses. However, Sri Lanka's application of NbS remains limited, prompting research on seaweed's potential as an erosion-mitigating NbS, enhancing environmental protection and socioeconomic resilience.

Figure 1
Coastal Line of SL. Source - Disaster Management Center



B. Research Objectives

- Assess seaweed's potential as a sustainable material for coastal erosion control in Sri Lanka.
- Evaluate the socioeconomic impacts of erosion on vulnerable coastal communities.
- Investigate current and emerging seaweed-based applications in sustainable design and erosion management.

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- Examine the ecological compatibility of seaweed solutions with local ecosystems and species.
- Propose a holistic management strategy that balances environmental conservation with community welfare.

C. Research Questions

1. What challenges does coastal erosion pose to Sri Lanka's coastal communities, and how does it affect their livelihoods and environment?
2. What makes seaweed a viable solution for coastal erosion management, and how does it compare to traditional methods in effectiveness and sustainability?
3. How can seaweed-based interventions balance ecological preservation and economic resilience for Sri Lanka's coastal communities?

D. Scope of Research

This study adopts an interpretivist-constructivist approach to explore seaweed as a sustainable material for coastal erosion control in Sri Lanka. Visual documentation and stakeholder interviews were utilized in a study to evaluate the effectiveness and economic feasibility of seaweed-based interventions in addressing erosion.

E. Ethical Considerations and Data Protection Law

Ethical considerations and data protection were prioritized to ensure research integrity. Participants' privacy and dignity were protected through informed consent and confidentiality in interviews and visual documentation (Lee, Zankl, & Chang, 2016, p. 2). These measures upheld respect, social responsibility, and adherence to legal and ethical standards in engagements with coastal communities and experts.

II. Literature Review

Coastal erosion, driven by natural forces like monsoonal waves and sea-level rise, as well as human activities such as coral and sand mining, destabilizes shorelines and increases flood risks. While traditional Nature-based Solutions (NbS) like mangroves, coral reefs, and saltmarshes effectively reduce wave energy and enhance ecosystems, they require specific conditions and long maturation periods. In contrast, seaweed systems demonstrate rapid growth and adaptability. With over 300 seaweed species in Sri Lanka; mainly green, brown, and red algae, species like *Sargassum illicifolium* and *Eucheuma* sp. stand out for their structural strength, nutrient uptake, and resilience. NARA studies confirm their potential to stabilize sediments, enrich biodiversity, and function effectively within coastal ecosystems.

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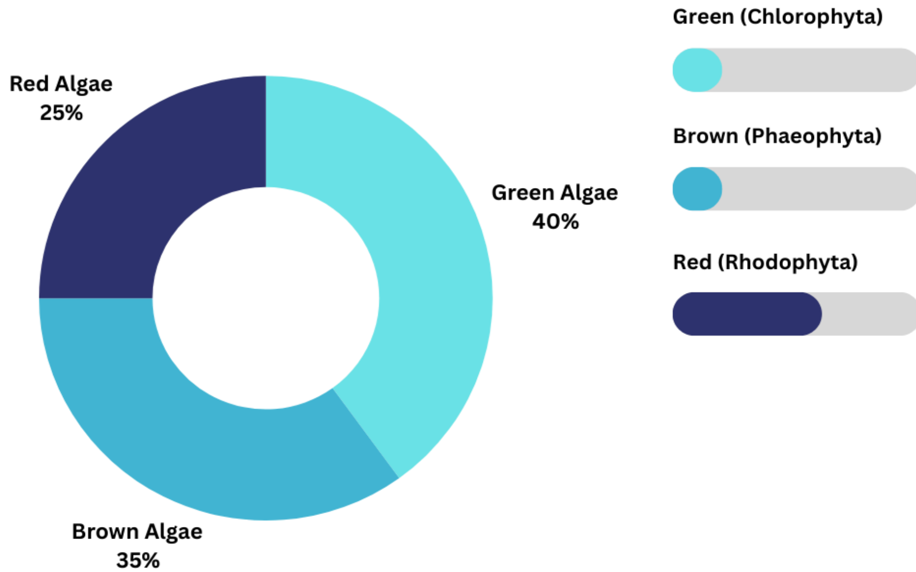
Chart 1
Seaweed species distribution in Sri Lanka. Source - Author



Seaweed's strong biophysical properties, such as high tensile strength, moisture resistance, and a low ecological footprint, allow its use in both bio-composite production and environmental engineering. Integrating seaweed cultivation with coastal protection can therefore foster a circular economy and restore marine habitats.

In China, coastal erosion management combines hard engineering methods (seawalls, groynes, and breakwaters) with softer approaches like beach nourishment and planting *Spartina alterniflora*, though its invasiveness remains contested (Luo et al., 2015, pp. 135–140). In southern regions, mangrove afforestation and coral reef transplantation enhance ecosystem resilience, while integrated strategies and regulatory tools, such as natural reserves and setback lines, balance defense efforts with ecosystem conservation (Luo et al., 2015, p. 141).

Mangroves Dense root systems absorb wave energy and trap sediments. Global Tropics Coral Reefs Dissipate wave energy (up to 97%) and support sand production. Caribbean, Pacific. Oyster Reefs Stabilize sediments and reduce wave energy. Gulf of Mexico, USA Saltmarshes Root systems stabilize sediment and attenuate wave energy. Netherlands, USA. Seagrasses Reduce wave energy through vegetation friction. Mediterranean, Australia. While effective, many existing NbS are limited to specific ecosystems and can have slower growth rates or face susceptibility to climate change. This creates a space for innovative, adaptable, and multi-functional NbS.

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Table 1

Precedent Studies on the Existing Nature-based Designs for Coastal Erosion. Source - Author

Existing Nature-Based Designs/ structures for Coastal Erosion	Mechanisms Explained	Location
Coral Reefs	Dissipate wave energy (up to 97%), reduce wave height (up to 84%), and support sand production for beaches.	Global (e.g., Caribbean, Pacific)
Mangroves	Dense root systems absorb wave energy, trap sediments, and reduce storm surge impacts.	Tropical and subtropical coasts
Oyster Reefs	Stabilize sediments, reduce wave energy (up to 90%), and support sediment deposition behind reefs.	Gulf of Mexico, USA, Europe
Saltmarshes	Root systems stabilize sediment, attenuate wave energy (up to 60%), and buffer against storm surges.	Netherlands, USA
Seagrasses	Reduce wave energy through vegetation friction and stabilize sediments via root systems.	Mediterranean, Australia
Polychaete Reefs	Honeycomb structures attenuate waves, stabilize sediments, and increase coastal resilience.	Europe (e.g., Baie du Mont Saint Michel, France)
Artificial Reefs (e.g., ReefBalls)	Mimic natural reef structures, dissipate wave energy, and enhance habitat for marine organisms.	USA, Australia

Note: *Mangrove dense root systems absorb wave energy and trap sediments. Global topics.*

Coral Reefs Dissipate wave energy (up to 97%) and support sand production. Caribbean, Pacific. Oyster Reefs stabilize sediments and reduce wave energy. Gulf of Mexico, USA Saltmarshes Root systems stabilize sediment and attenuate wave energy. Netherlands, USA. Seagrasses reduce wave energy through vegetation friction. Mediterranean, Australia. While effective, many existing NbS are limited to specific ecosystems and can have slower growth rates or face susceptibility to climate change. This creates a space for innovative, adaptable, and multi-functional NbS.

III. Methodology

The research adopted an interpretivist-constructivist approach, focusing on qualitative environmental analysis. The study uses an integrated approach of literature review, stakeholder interviews, and visual analysis. Literature builds theoretical bases, interviews add localized insights, and visual analysis tracks erosion trends and tests seaweed's feasibility. Together, these methods ground the research into context-specific, sustainable solutions.

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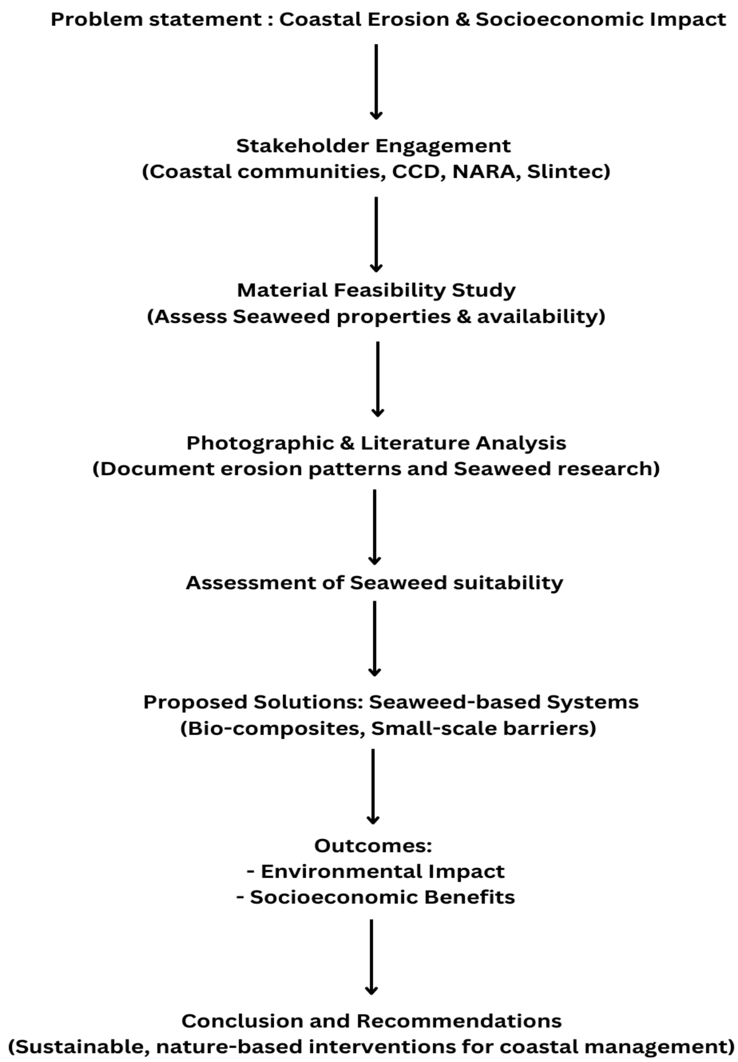
Figure 2

Conceptual Framework for the Project. Source - Author



NARA and CCD collaborated on a case study to assess the ecological feasibility of seaweed-based erosion mitigation in Hikkaduwa, utilizing Google Earth imagery and community engagement.

In 2024, the CCD built a barrier at Thiranagama, which has slowed erosion but not fully prevented it. Photographic analysis indicates uneven coastal change, with stronger wave impact and greater erosion at point X than point Y, underscoring the need for localized, site-specific mitigation strategies.

The Nature-Based Solution Evaluation Framework guided assessment across three criteria: effectiveness, scalability, and ecological compatibility.

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Figure 3

Coastal area of Thiranagama, Hikkaduwa with marked widths of the coast. Source - Google Earth

Interviews with local experts and community members revealed both technical and social dimensions of erosion control. The study replaced the previous 'Material Feasibility' assessment with an 'Ecological Feasibility Assessment, emphasizing environmental outcomes. Findings were structured into a comparative matrix linking environmental problems with seaweed responses and ecological outcomes.

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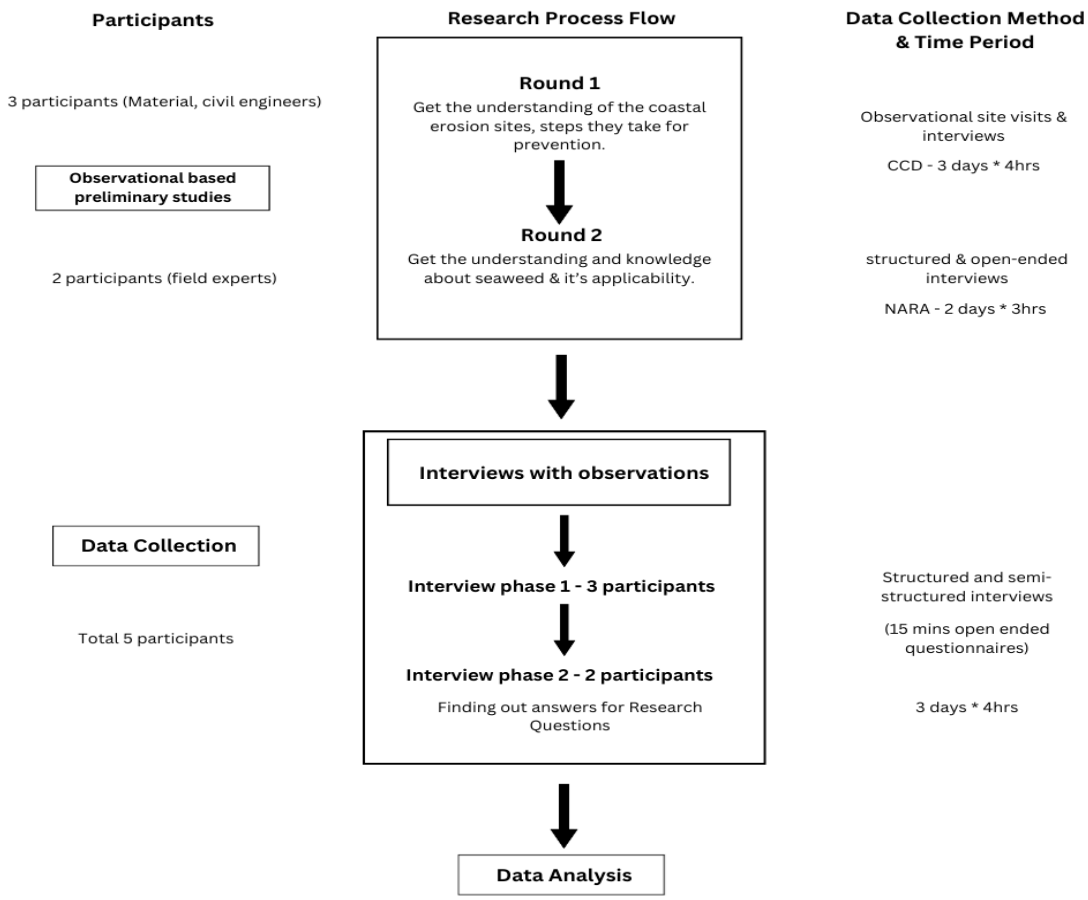
Figure 4
Flow Chart. Source - Author



Findings and Discussion

Google Earth analysis revealed a beach width reduction of approximately 18 meters between 2011 and 2023 in Thiranagama, Hikkaduwa. Seaweed-dense coastal zones exhibited reduced erosion rates, suggesting that seaweed can act as a sediment stabilizer. Seaweed species, including Sargassum illicifolium, are adaptable to wave energy, demonstrating their potential in forming systems that can withstand dynamic coastal changes.

Field interviews highlighted the socioeconomic potential of integrating seaweed farming into community livelihoods. Coastal residents expressed enthusiasm for sustainable aquaculture initiatives that could replace unstable income sources like fishing and tourism. Women participants identified seaweed cultivation as a low-cost, accessible livelihood supporting empowerment and ecological stewardship. The research found that collaborative frameworks involving NARA, Seacology, and local NGOs are crucial for scaling seaweed-based NbS. Such systems contribute to both ecological regeneration and economic resilience.

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An environmental problem-mechanism matrix (summarized below) outlines the relationship between erosion causes, ecological responses, and seaweed's mitigating mechanisms:

- Environmental Problem: Shoreline retreat and sediment loss
- Ecological Mechanism: Wave attenuation, sediment trapping
- Seaweed Response: Flexible fronds and holdfast structures
- Outcome: Reduced erosion, enhanced coastal resilience

Thus, seaweed-based NbS bridge ecological functionality with socioeconomic benefit, offering a scalable model for coastal adaptation in Sri Lanka.

Conclusion and Recommendations

This study reframes seaweed from a harvested commodity to an ecological partner in coastal resilience. Through evidence of measurable wave attenuation, participatory co-management, and policy potential, it proposes seaweed-based NbS as a viable and locally adaptable strategy for erosion mitigation in the Global South.

The next research phase will focus on longitudinal monitoring of biofouling, biodiversity shifts, and multi-village scalability.

Tides, it seems, can indeed be designed with communities, one strand at a time.

Acknowledgment

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