Review Article

Mangroves as Natural Shields: A Comprehensive Review of Their Role in Mitigating Natural Disasters and Conservation Strategies

Abstract:

Mangrove ecosystems play a crucial role in mitigating the impact of natural disasters on coastal regions worldwide. This comprehensive review paper synthesizes multidisciplinary studies to explore the contribution of mangroves in reducing the risk of catastrophes such as storm surges, tsunamis, hurricanes, and coastal erosion. By analysing the complex relationships between mangroves and natural disasters, we delve into factors such as species composition, forest structure, hydrological regimes, and coastal geomorphology. Additionally, we investigate the socioeconomic implications of mangrove conservation and restoration efforts, highlighting their potential to enhance resilience and sustainable development in coastal communities.

The paper presents a detailed examination of wave characteristics, types, and attenuation mechanisms, focusing on how mangrove features such as prop roots, knee roots, and pneumatophores influence wave dissipation. We discuss various numerical and statistical models used to predict wave attenuation through mangroves, providing insights into their strengths and limitations. Furthermore, we explore global and India-specific mangrove cover status, important species, and conservation measures, including legal frameworks and initiatives by governmental and non-governmental organizations.

Finally, the review underscores the urgency of conserving and restoring mangrove ecosystems to safeguard both human well-being and ecological integrity in the face of escalating climate-related threats. It advocates for evidence-based decision-making and policy development in disaster risk management and climate adaptation, emphasizing the pivotal role of mangroves as natural shields against natural calamities. Overall, this paper contributes to the understanding of mangrove-mediated hazard reduction and provides guidance for maximizing the resilience of coastal communities in an increasingly volatile world.

Key words: Mangroves, Natural shield, Mitigation, Ecosystem services, Resilience.

Introduction:

Globally, ecosystems, infrastructure, and human lives are all seriously threatened by natural disasters. There is an urgent need for efficient mitigation techniques to lessen the negative effects of these catastrophes, as their frequency and intensity are rising. The conservation and restoration of mangrove ecosystems has been identified as a potentially effective strategy because of their exceptional capacity to serve as natural barriers against a range of natural catastrophes.

Mangroves are found in coastal areas throughout the tropics and subtropics and are distinguished by their robust intertidal forests. Because they act as a barrier against storm surges, tsunamis, hurricanes, and other extreme weather occurrences, these ecosystems are vital to the preservation of the shore. Their complex root systems reduce coastal erosion and flooding by absorbing sediment and absorbing wave energy. Furthermore, mangroves sustain fisheries, offer habitat to a wide variety of flora and fauna, and aid in the storage of carbon, making them vital resources for both the environment and human societies.

Over the past few years, there has been a growing concentration in scientific research to determine how mangroves reduce the impact of natural catastrophes and to measure how successful they are as barriers to protect. This study, which draws from a variety of multidisciplinary studies in the fields of ecology, hydrology, geomorphology, and socioeconomics, summarizes the state of knowledge regarding the contribution of mangroves to catastrophe risk reduction. Our goal is to give insights that can guide conservation and management strategies for maximizing the resilience of coastal communities in the face of increasing climate-related threats by investigating the underlying processes and spatial dynamics of mangrove-mediated hazard reduction.

We investigate the complex relationships between mangroves and natural catastrophes by thoroughly examining the scientific literature, taking into account elements like the species composition of the mangroves, the structure of the forest, the hydrological regime, and the geomorphology of the coast. Additionally, we look into the socioeconomic effects of mangrove restoration and conservation initiatives, including how they might improve livelihoods, lessen vulnerability, and encourage sustainable development in coastal regions.

By enhancing our understanding of the intricate relationship between mangroves and natural disasters, this review aims to contribute to evidence-based decision-making and policy development in disaster risk management and climate adaptation. Recognizing the pivotal role of mangroves as natural shields underscores the urgency of concerted action to conserve and restore these invaluable coastal ecosystems, thereby safeguarding both human well-being and ecological integrity in an increasingly volatile world.

1. **Status of mangrove cover:**

1.1. Status of mangrove cover worldwide:

As per Global Forest Resource Assessment, 2020 (FRA 2020), world over, 13 countries have Mangrove forests covering an estimated 14.79 million hectares. The largest Mangrove area is reported in Asia (5.55 million hectares), followed by Africa (3.24 million hectares), North and Central America (2.57 million hectares) and South America (2.13 million hectares). Oceania has reported the smallest area of Mangroves (1.30 million hectares). More than 40 percent of the total area of Mangroves was reported to be in just four countries: Indonesia (19 percent of the total), Brazil (9 percent), Nigeria (7 percent) and Mexico (6 percent). (FSI,2021).

1.2. Status of mangrove cover in India:

The 2021 assessment shows that Mangrove cover in the country is 4,992 sq km, which is 0.15% of the country's total geographical area. Very Dense Mangrove comprises 1,475 sq km (29.55%) of the Mangrove cover; Moderately Dense Mangrove is 1,481 sq km (29.67%) while Open Mangroves constitute an area of 2,036 sq km (40.78%). There has been a net increase of 17 sq km in the Mangrove cover of the country as compared to 2019 assessment. (FSI,2021).

2. **Important species of mangrove forest in India :**

Important species of Mangrove ecosystems in India include *Avicennia officinalis, Rhizophora mucronata, Sonneratia alba, Avicennia alba, Bruguiera cylindrica, Heritiera littoralis, Phoenix paludosa, Morinda citrifolia* & *Ceriops tagal.* (FSI,2021).

3. **Wave and wave attenuation:**

3.1. Wave characteristic:

Wave height (H) is twice the amplitude (a), length (L) is the distance between peaks or troughs, and steepness is defined as H / L. The period (T) is the time between two subsequent peaks crossing a given location, and the frequency (f) is the number of peaks (or troughs) passing a given point during a given time. (Masselink *et al.*, 2011)

3.2. Wave types:

Table 1 : Physical mechanism of different wave types

Sl.No	**Wave type**	**Physical mechanism**	**Wave period**

1.	Wind waves	Wind shear , gravity	< 15 s
2.	Swell waves	Wind waves	< 30 s
3.	Tsunami	Earthquakes, landslides, submarine slumping	10 min – 2 hours
4.	Tides	Gravitational action of the moon and sun, earth's rotation	12 – 24 hours
5.	Storm surges	occur during storms, hurricanes, cyclones, typhoons	1-3 days

(Massel,1996)

3.3.Wave attenuation and equation:

3.3.1. Wave attenuation:

Wave attenuation occurs when waves lose or dissipate energy, resulting in a reduction in wave height.

3.3.2. Wave attenuation equation:

$$r = -(\Delta H / H) * (1 / \Delta x)$$

- r is the rate of wave height reduction per unit distance
- ΔH is the change in wave height
- H is the initial wave height
- x is the distance travelled by the wave

$$H_x = H_0 \cdot e^{(-r.x)}$$

- H_x is the wave height (cm) after the wave has travelled x metres
- H_0 is the incident wave height (Mazda *et al.,* 2006).

Factors affecting wave attenuation in mangroves:

Water depth relative to structure of mangrove trees

a) Prop roots
b) Knee roots
c) Pneumatophores
d) Trunks, branches and leaves
e) The age of trees

Distance travelled through mangrove

Shore slope and topography

Wave height and period

Prop roots:

Rhizophora spp. have prop roots that create a network above their substrate. These prop roots provide significant resistance to the flow of water. Above the prop roots, the trunks pose less of a barrier to waves, enabling them to pass more freely. This leads in substantial wave attenuation at shallow depths, followed by a decrease in wave attenuation as the water depth increases and the waves are less impacted by the prop roots.

Knee roots:

While the knee roots of Bruguiera spp. are structurally distinct to the prop roots of Rhizophora spp., they attenuate waves in the same way. Brinkman et al. (1997) discovered that wave height reduction was highest at shallow depths; in deeper water, wave heights decreased less with distance, and more wave energy was carried further into the forest.

Pneumatophores:

Sonneratia spp. and Avicennia spp. feature distinctive pneumatophores, aerial roots that emerge from the substrate and provide an air supply to the roots. Avicennia's aerial roots are slender and reach a height of 20 to 30cm. Sonneratia aerial roots develop secondary thickening, making them more cone-shaped and reaching heights of over a metre in certain species. Sonneratia pneumatophores, like Rhizophora prop roots and Bruguiera knee roots, operate as barriers to water movement at shallow depths, resulting in enhanced wave attenuation.

Trunks, branches and leaves:

Many mangrove species lack aerial roots, including *Kandelia candel* and *Nypa fruticans*. As waves pass through these species, wave attenuation is projected to be reduced in shallow water depths since the waves will only touch the tree trunks or bases. Wave attenuation is projected to grow as water depth increases and the waves reach the branches and leaves.

The age of trees:

The age of the trees influences their ability to attenuate waves, which is mediated by their size, form, and density of trunks, branches, and aerial roots. Wave attenuation through the youngest trees reduced as depth increased. Wave attenuation was stronger among older trees and reduced less as depth increased.

Shore slope and topography:

Shore slope and terrain significantly impact wave energy dissipation, water depth, and shoaling/breaking. Mangroves generally develop on very gently sloping coasts, and no studies have been discovered that have particularly looked at the influence of slope on wave energy dissipation in mangroves. By fostering sedimentation over the longer term, mangroves can raise surface elevation, so generating shallower water, enhancing wave shoaling and energy dissipation.

Wave height:

According to Mazda et al. (2006), the rate of wave height decrease is determined by the initial wave height when water reaches mangrove branches and leaves. Larger waves were attenuated more.

Modelling the dissipation of wave energy through mangroves

Numerical and statistical models of wave attenuation in mangroves have been created to aid in the study and prediction of wave behaviour. Three models have been developed to forecast the decrease of waves moving through mangroves:

1. Vo-Luong and Massel's WAPROMAN model (2008)
2. Suzuki et al's modification of the SWAN model (2011)
3. Bao's regression model (2011) based on wave attenuation measurements in Vietnamese mangroves.

The WAPROMAN model

Massel et al. (1999) created a prediction model for wave propagation across mangrove ecosystems. Mangrove trunks and roots were regarded as cylindrical components in the water column (leaves were excluded). The drag force was modified to account for interactions between plant elements based on trunk and root density. This first model assumed that the forest was uniform (i.e., the same tree morphology across the mangrove forest) and had constant water depth (i.e., no variation in surface height). The rate of wave attenuation was greatly influenced by the density of the mangrove forest, the diameter of the mangrove roots and trunks, and the properties of the incident waves. Hadi et al. (2003) utilised this model to examine wave attenuation in Rhizophora and Ceriops forests, concluding that the Rhizophora forest attenuated waves more effectively.

Vo-Luong and Massel (2008) improved the model, naming it the WAPROMAN model (WAve PROpagation in MANgrove Forest). The new model allows for a sloping or uneven terrain, as well as mangrove species that fluctuate in density and position. The main elements that reduce waves are wave-trunk interactions and wave breaking.

The WAPROMAN model has the following input parameters:
-Measure topography along a transect parallel to on-coming waves at 1 m - 2 m intervals.
-Measure wave height period and spectrum

-Measure mangrove tree characteristics in different horizontal layers (e.g. aerial root layer, trunk layer, canopy layer) and areas of the forest, including the number and diameters of trunks or aerial roots in each layer in every area.

Modelling wave dissipation in vegetation using SWAN

Simulating **Wa**ves **N**earshore

A third- generation wave model that computes random, short-crested wind-generated waves in coastal regions. This model is freely available on the internet (https://swanmodel.sourceforge.io/features/features.htm) and is used by coastal engineers to model wave dynamics. This model includes vertical layers such as those seen in mangroves (e.g. bottom layer containing aerial roots, higher layers containing leaves and branches), and horizontal variation in vegetation characteristics (e.g. due to different species being present in different areas).

Limitation : SWAN does not account for wave tunnelling.

Regression model

$Hx = (0.9899\ H0 + 0.3526)\ .\ e^{(0.048 - (0.0016\ TH) - (0.00178\ \ln(TD)) - (0.0077\ \ln(CC))\ .\ x}$

where

Hx is wave height a distance *x* into the forest (measured in cm),

H0 is incident wave height (measured in cm),

TH is average tree height (m),

TD is tree density (no. of trees / hectare), and

CC is canopy closure (%).

Advantages

Average tree height, Tree density and Canopy closure, these parameters are easy to estimate.

Disadvantages

The model was constructed using data from small waves (wave heights less than 70 cm), hence caution should be exercised before applying the model to forecast mangrove attenuation of bigger storm waves.

Determining the required width of a mangrove belt

Forest Structure Index (FSI) = - 0.048 + 0.0016 TH + 0.00178 ln(TD) + 0.0077 ln (CC)

Where,

TH is average tree height (m),

TD is tree density (no. of trees / hectare),

CC is canopy closure (%).

Required band width,

B_w= 2.405 / FSI

Conservation measures of mangrove forest globally:

Mangrove forests, vital coastal ecosystems found in tropical and subtropical climates, require worldwide conservation efforts to ensure their survival. Efforts include habitat protection via the development of marine protected areas and reserves, long-term management approaches such as community-based conservation programmes, and restoration projects to rehabilitate degraded mangrove regions. Furthermore, increasing knowledge of the ecological value of mangroves among local populations, legislators, and stakeholders is critical for gaining support for conservation initiatives. Integrated methods that include the socioeconomic demands of local populations while prioritising ecological protection are necessary for the long-term health of mangrove ecosystems globally. Collaboration among governments, non-governmental organisations, and international agencies is critical for addressing the multiple dangers to mangrove forests, such as deforestation, pollution, and climate change, as well as promoting effective worldwide conservation strategies.

Conservation measures of mangrove forest in India:

Mangrove forests in India require conservation efforts due to their ecological importance and the risks they confront. Efforts include creating protected areas such as sanctuaries and reserves to conserve mangrove ecosystems. Government measures, such as the Coastal Regulation Zone (CRZ) rules, limit some activities near mangroves in order to reduce habitat degradation. Furthermore, community-based conservation programmes include local communities in mangrove restoration, afforestation, and sustainable resource management, instilling a feeling of ownership and responsibility. Educational programmes create awareness about the importance of mangroves and encourage the public to participate in conservation efforts. Furthermore, research and monitoring programmes give useful information for making sound management decisions. Integrating traditional ecological knowledge with contemporary conservation tactics improves the efficacy and sustainability of mangrove conservation in India.

Species used in India for mangrove rehabilitation:

- *Aegiceras corniculatum,*
- *Avicennia marina,*

- *Avicennia officinalis,*
- *Bruguiera sexangula,*
- *Bruguiera parviflora,*
- *Ceriops decandra,*
- *Excoecaria agallocha,*
- *Heritiera fomes,*
- *Kandelia candel,*
- *Rhizophora apiculata,*
- *Rhizophora mucronata,*
- *Sonneratia apetala,*
- *Sonneratia caseolaris.*

Conservation measures in Tamilnadu:

Mangrove forests must be conserved in Tamil Nadu due to its ecological importance and function in safeguarding coastal regions from erosion and storm surges. To protect these essential ecosystems, a variety of safeguards have been put in place. First, strong rules and policies have been put in place to restrict activities that endanger mangrove environments, such as deforestation, aquaculture expansion, and industrial development. Furthermore, community engagement and awareness programmes have been launched to encourage sustainable practices among local inhabitants, encouraging them to join in mangrove restoration and conservation efforts. Furthermore, government agencies and non-profit organisations have launched mangrove restoration initiatives, such as planting native mangrove species and repairing damaged regions. These conservation methods attempt to maintain biodiversity, minimise the effects of climate change, and safeguard the long-term viability of Tamil Nadu's mangrove forests.

T.N. intends to enhance the present mangrove cover in five years.

Under the Green Tamil Nadu Mission, fifteen hectares of mangroves were planted at Killai, Cuddalore district, and 67.8 square kilometres of mangroves would be cultivated over the following five years.

T.N. Forest Department will increase mangrove cover in Pichavaram by 100 hectares in 2023-24.

The Pichavaram mangroves are among the most prolific ecosystems in the state, additional mangrove plantations will shortly be set up along the Uppanar River in Kudikadu village over an extent of 25 hectares.

Conservation measures in legal framework :

Various regulatory frameworks in India promote the conservation of mangrove forests, which are vital ecosystems. The Coastal Regulation Zone (CRZ) Notification, issued under the Environment Protection Act of 1986, defines restrictions controlling operations in coastal regions, including mangrove protection. Mangroves are also recognised as environmentally sensitive places under the Wildlife Protection Act of 1972, which protects the creatures that live there. The Forest Conservation Act of 1980 requires government clearance before any diversion of forest land for non-forest activities, including mangrove regions. Furthermore, programmes such as the National Mangrove Committee and the National Forest Policy prioritise sustainable management and conservation activities. These legislative measures define criteria for mangrove conservation, including limits on land-use changes, deforestation, and industrial operations, while also encouraging community engagement and awareness to ensure the long-term survival of these critical ecosystems.

Organisations engaged in mangrove protection worldwide:

International Union for the Conservation of Nature (IUCN): The IUCN plays an important role in organising worldwide conservation efforts, particularly mangrove habitats. They offer assessments, guidelines, and policy suggestions for mangrove protection.

United Nations Environment Programme (UNEP): The United Nations Environment Programme (UNEP) promotes mangrove conservation through a variety of initiatives, including the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), which addresses issues affecting coastal and marine ecosystems, such as mangroves.

Ramsar Convention on Wetlands: The Ramsar Convention, an international convention for the conservation and sustainable use of wetlands, recognises the value of mangrove ecosystems. Many mangrove regions across the world have been recognised as Ramsar sites, resulting in worldwide recognition and funding for conservation initiatives.

Mangrove Action Project (MAP): MAP is a non-profit organisation focused on mangrove protection and restoration. They collaborate with local people, governments, and other stakeholders to promote sustainable management methods and raise awareness of the value of mangrove ecosystems.

World Wide Fund for Nature (WWF): The World Wildlife Fund is actively involved in mangrove conservation programmes across the world. They collaborate closely with local people and governments to conserve habitat, restore it, and implement sustainable management practices.

Organizations involved in mangrove conservation in India:

Ministry of Environment, Forest and Climate Change (MoEFCC): The national government authority in charge of developing and executing environmental, forest, and wildlife conservation policies and programmes, including mangrove protection.

Indian Council of Forestry Research and Education (ICFRE): ICFRE is in charge of scientific research, training, and extension in forestry. It contributes significantly to mangrove ecosystem research and it's protection.

State Forest Departments: Each Indian state has its own forest agency that is in charge of protecting, conserving, and managing forests, including mangroves.

National Institute of Oceanography (NIO): NIO performs research and surveys of coastal ecosystems, particularly mangroves, and provides essential data for conservation activities.

Mangrove Foundation: The Mangrove Foundation of Maharashtra is committed to the protection and sustainable management of the state's mangroves.

Indian National Trust for Art and Cultural Heritage (INTACH): INTACH has worked on a variety of conservation initiatives, including mangroves, with an emphasis on their ecological and cultural relevance.

WWF-India (World Wide Fund for Nature): WWF-India focuses on a variety of conservation programmes, including mangrove protection, via research, lobbying, and community outreach.

Conclusion:

Finally, mangroves act as a critical natural screen against natural calamities, significantly lessening their impact. Mangroves provide substantial protection against storm surges, coastal erosion, and tsunamis by serving as natural barriers that disperse wave energy and stabilise shorelines. Furthermore, their capacity to absorb extra water helps to reduce floods after major rainstorm occurrences. Furthermore, mangrove ecosystems provide critical habitat for a variety of marine and terrestrial species, helping to boost overall biodiversity and ecosystem resilience. As a result, conserving and rebuilding mangrove ecosystems is critical not just for protecting coastal populations, but also for maintaining coastal ecosystem balance and resilience in the face of natural disasters.

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