Revista de
Direito Econômico e
Socioambiental

ISSN 2179-8214

REVISTA DE DIREITO ECONÔMICO E SOCIOAMBIENTAL

vol. 15 | n. 2 | maio/agosto 2024

Periodicidade quadrimestral | ISSN 2179-8214

Curitiba | Programa de Pós-Graduação em Direito da PUCPR

https://periodicos.pucpr.br/direitoeconomico

Revista de
Direito Econômico e Socioambiental

doi: 10.7213/revdireconsoc.v15i2.31364

ISSN 2179-8214

Disaster management in the Sundarbans delta ecosystem through environmental governance and sustainable planning

Gestão de catástrofes no ecossistema do delta do Sundarbans através da governação ambiental e do planeamento sustentável

José Noronha Rodrigues[*, I]
[I] Universidade Nova de Lisboa (Lisboa, Portugal)
jose.n.rodrigues@uac.pt
https://orcid.org/0000-0002-7729-4954

Sumanta Bhattacharya[**, II]
[II] Maulana Abul Kalam Azad University (Kolkata, India)
sumanta.21394@gmail.com
https://orcid.org/0000-0003-2563-2787

Como citar este artigo/*How to cite this article*: RODRIGUES, José Noronha; BHATTACHARYA, Sumanta; SACHDEV, Bhavneet Kaur; CABETE, Dora. Disaster management in the Sundarbans delta ecosystem through environmental governance and sustainable planning. **Revista de Direito Econômico e Socioambiental**, Curitiba, v. 15, n. 2, e268, maio/ago. 2024. doi: 10.7213/revdireconsoc.v15i2.31364.

[*] Researcher at CEDIS, Nova School of Law, FD, Universidade Nova de Lisboa – School of Law, Campus de Campolide, 1099-032 (Lisboa, Portugal). Vice-President of the School of Business and Economics of the University of Azores, Portugal, Scientific Coordinator of the Master's Degree in Company and Employment Law, as well as of the Degree in Law at the University of Santiago - Cape Verde, Visiting Professor in the Master's Degree in Civil Law and in the Master's Degree in Tax Law at the Catholic University of Mozambique. Doctor in Law (PhD) *cum laude*, by the University of Santiago de Compostela (Spain), recognized the equivalence of the degree of Doctor in Law by the Lisbon University Faculty of Law, DEA in European Union Law (2008). Master's in International Relations (2004). Post-Graduate in Regional Law (1998). Post-Graduate in Labor Law (2003) and Graduated in Law (1996). He is also the Delegate for the Azores of the Instituto de Derecho Iberoamericano and holds the Chair of the Policy Center for the United Nations Convention on the Rights of the Child.
[**] Research Scholar at Maulana Abul Kalam Azad University (Kolkata, India).

Bhavneet Kaur Sachdev[***, III]
[III] University of Calcutta (Kolkata, India)
bhavneet829@gmail.com
https://orcid.org/0000-0001-9156-0086

Dora Cabete[****, I]
[I] Universidade Nova de Lisboa (Lisboa, Portugal)
dora.cr.rodrigues@uac.pt
https://orcid.org/0000-0002-0117-8818

Recebido: 12/03/2024 Aprovado: 21/05/2024
Received: 03/12/2024 *Approved: 05/21/2024*

Abstract

The Sundarbans region is facing significant impacts on its ecosystem, business, agriculture, and environment due to inadequate disaster management. Storm surges, cyclones, and rising sea levels threaten the mangrove environment, causing permanent damage to farming and fishing communities, poverty, and revenue loss. The loss of mangroves affects ecological services like carbon sequestration, coastal protection, and biodiversity. To mitigate these risks, laws, growth promotion, catastrophe management plans, improved infrastructure, and public engagement in disaster response planning are necessary. Balancing environmental protection and economic expansion through climate-resilient farming techniques and sustainable agriculture is crucial. Tighter regulations, sustainable development strategies, stakeholder engagement, and advanced technology like AI can contribute to creating a resilient Sundarbans that protects the environment, improves community welfare, and ensures a sustainable future.

Keywords: Sundarbans; disaster management; mangrove degradation; sustainable development; environmental governance.

[***] Political Science hons at University of Calcutta (Kolkata, India). Master's in Development Studies, Indira Gandhi Open University, Delhi, India.
[****] Researcher at CEDIS, Nova School of Law, FD, Universidade Nova de Lisboa – School of Law, Campus de Campolide, 1099-032 (Lisboa, Portugal). Doctor (PhD) in Business Economic Sciences – specialization in Economics - at the School of Business and Economics of the University of the Azores. PhD candidate in Law at the Universidade Nova de Lisboa - School of Law. Master's and postgraduate degree in Social Sciences at the University of the Azores. Degree in Sociology (UAc) and in Law (UAL). She is a guest lecturer at the Azores University, a guest lecturer at the University of Santiago - Cape Verde and a lawyer.

Resumo

A região de Sundarbans está a enfrentar impactos significativos no seu ecossistema, negócios, agricultura e ambiente devido a uma gestão inadequada das catástrofes. As vagas de tempestades, os ciclones e a subida do nível do mar ameaçam o ambiente dos mangais, causando danos permanentes às comunidades agrícolas e piscatórias, pobreza e perda de receitas. A perda de mangais afecta serviços ecológicos como o sequestro de carbono, a proteção costeira e a biodiversidade. Para mitigar estes riscos, são necessárias leis, promoção do crescimento, planos de gestão de catástrofes, melhores infra-estruturas e envolvimento do público no planeamento da resposta a catástrofes. É fundamental equilibrar a proteção ambiental e a expansão económica através de técnicas agrícolas resistentes ao clima e de uma agricultura sustentável. Regulamentos mais rigorosos, estratégias de desenvolvimento sustentável, envolvimento das partes interessadas e tecnologia avançada como a IA podem contribuir para criar um Sundarbans resiliente que proteja o ambiente, melhore o bem-estar da comunidade e garanta um futuro sustentável.

Keywords: *Sundarbans; gestão de catástrofes; degradação dos mangais; desenvolvimento sustentável; governação ambiental.*

Contents

1. Introduction

The Sundarbans are widely recognized for their ecological significance and the abundant biodiversity that they possess. They are located in the delta region and straddle the boundary between Bangladesh and India. This mangrove forest ecosystem encompasses a territory of more than 10,000 square kilometres and is home to a diverse array of plant and animal species, including the Bengal tiger, which is in imminent danger of extinction. However, the fragile ecology that exists here is in grave danger as a result of climate change.

Climate change is having a significant impact on the Sundarbans, primarily through rising sea levels and increased extreme weather events. The melting of polar ice and thermal expansion of seawater due to global warming are causing frequent flooding in the Sundarbans, posing a threat to its unique biodiversity, especially the mangrove forests. Without action, this ecosystem may be lost. Additionally, climate change is linked to more frequent and intense cyclones (JABIR et al., 2021), which can be highly destructive to the Sundarbans' delicate ecology and vulnerable wildlife.

Climate change has led to unpredictable rainfall patterns and longer dry spells, disrupting the delicate salt balance in mangroves and jeopardizing their freshwater supply. As a result, erosion and high tides become more damaging to the mangroves, creating difficulties for their recovery. These environmental changes in the Sundarbans have extensive effects, endangering unique aquatic species and the Bengal tiger, which is at risk of extinction due to habitat loss. Additionally, the Sundarbans, acting as a natural barrier against climate change, sequester carbon, but with its declining capacity, a cycle of worsening climatic consequences is initiated. Mitigation strategies currently focus on addressing the effects of global warming on the Sundarbans.

Governments, international organizations, and communities are collaborating to improve disaster preparedness, combat climate change, and adopt climate-resilient practices. These efforts are crucial to safeguard the Sundarbans, a vital environment for millions of people and the economy. However, the region is facing significant challenges caused by global warming, including rising sea levels and increased salt content, which are endangering mangrove forests and agricultural productivity. Changes in fishing patterns and disruptions to hydrological parameters are also impacting the industry. Moreover, the increasing frequency and unpredictability of monsoon rains and storms are negatively affecting both ecosystems and society in the Sundarbans. (GHIMIRE & VIKAS, 2012)

2. Ecological impact on Sundarbans Delta region and climate change

The Sundarbans, spanning an area of 10,200 square kilometres, houses the largest mangrove forest globally. Bangladesh holds 6,000 square kilometres of protected forest, while India has 4,200 square kilometres. Additionally, there is a non-forest area called the Sundarbans, covering 5,400 square kilometres in India. Unfortunately, the Sundarbans, home to tigers

and mangroves, is experiencing significant damage due to climate change, affecting both its inhabitants and wildlife. (AHUJA, 2022)

The Sundarbans is a UNESCO World Heritage Site known for its rich biodiversity. It encompasses 48 out of 102 islands in the Sundarbans Reserve Forest and is home to the endangered Royal Bengal Tiger. Additionally, it supports a population of over 4.5 million people on the remaining 54 islands (GHOSH; ROY, 2021a). This mangrove ecosystem is highly productive, thanks to its abundant forest biomass and nutrient supply. It plays a vital role in supporting diverse species through detritus-based food webs and serves as a crucial breeding habitat for many species. Moreover, it contributes to the fish population and aquatic variety in the northern Indian Ocean.

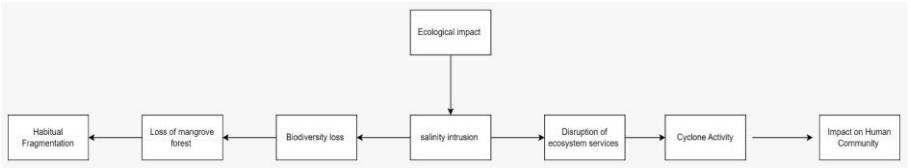
The Sundarbans ecosystem is suffering from rising temperatures and natural disasters. It is a low-lying delta region that is highly vulnerable to climate change and other disasters. The devastation of mangrove forests is made worse by the effects of climate change, which include rising sea levels and the degradation of coastal areas (HAZRA et al., 2015). The mangrove forests, crucial for life in the Sundarbans, are at risk due to rising sea levels and degradation of coastal areas. Their disappearance makes the region more susceptible to harm.

Recent studies from 2013 indicate that mangrove species, including those found in Kolkata, migrated 180 km away from the Sundarbans delta region due to changes in the Hooghly River's chemical oxygen requirement. Specific types of mangrove plants, like Thespesia populnea, Barringtonia acutangula, Cryptocoryne ciliata, Derris trifoliata, Sonneratia caseolaris, and Hibiscus tiliaceus, are now growing outside the Sundarban. This migration indicates extreme stress in the aquatic ecosystem, with low salinity and high COD levels favouring mangrove development. The rising salinity of the Ganges River is another contributing factor to this unusual phenomenon. (MANDAL, 2021)

As shown in figure 1, the Sundarbans, a crucial ecosystem, is experiencing negative impacts on biodiversity due to disruptions in the food chain and breeding locations. Rising sea levels are causing saltwater intrusion, contaminating freshwater supplies, hindering plant growth, and reducing accessible drinking water for both humans and animals. As a result, many species are relocating and searching for new habitats, leading to habitat fragmentation, reduced genetic diversity, and decreased ability to adapt to new environments. The Sundarbans are essential for absorbing

carbon, filtering water, and protecting coastlines, but they are at risk due to natural disasters and climate change. Cyclones are expected to become more frequent and intense, threatening the Sundarbans. When storms hit, mangrove trees, wildlife, and human settlements suffer, and it takes longer for the environment to recover, increasing vulnerability to future disasters.

Figure 1: Ecology impact of Climate Change on Sundarbans Region.



Source: Authors.

The Sundarbans is facing threats from climate change and natural disasters. These challenges are damaging land, fisheries, and water sources, impacting the region's economic and social stability. To protect the Sundarbans, both preventative and responsive actions are required. International cooperation is needed to reduce greenhouse gas emissions and slow down climate change. Sustainable management practices, restoration of destroyed mangrove areas, and the establishment of protected zones are necessary to enhance the ecosystem's resilience. Additionally, community-based adaptation strategies and awareness are vital for safeguarding this valuable natural treasure.

The increasing level of human activity in the Ganges and Brahmaputra River basins is pushing the rivers to reroute. Furthermore, since the 18th century A.D., the coastal streams of the Sundarbans Delta region have been embanked for extensive aquaculture activities. It increases the vulnerability of the riverine, coastal, marine, and wetland ecosystems in the delta region. The delta region loses land because of the attempt to flush the sediment from the river to the sea that follows, which in turn causes sea levels to rise and the land ecology to be destroyed. It also amplifies the cyclone's impact on the manner of life on the islands (RUDRA, 2014).

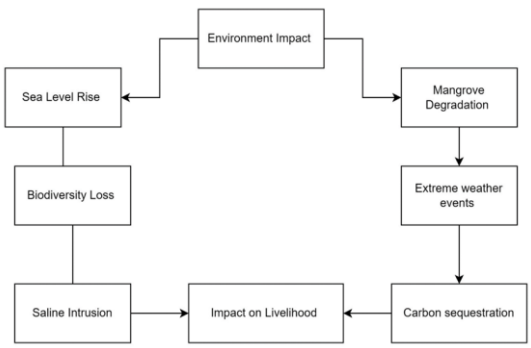
3. Impact of climate change and disaster on the environment in the delta ecosystem

Climate change in the Sundarbans region poses numerous challenges for the human population. It affects various factors such as river discharge, tides, temperature, rainfall, and evaporation, which in turn impact the mangroves' physiological processes, productivity, and biodiversity. Rising sea levels and the increase in cyclones will cause changes in wetland habitats, leading to reduced food security and a higher risk of waterborne illnesses. (GHOSH; ROY, 2021b)

The Sundarbans region is already prone to devastating cyclones, with the Bay of Bengal experiencing 9 out of the 14 deadliest tropical cyclones in history. Global warming is anticipated to heighten cyclone activity, leading to heavier rainfall and more severe flooding in the area. The semi-enclosed nature of the Bay also increases the risk of cyclones hitting the Sundarbans, causing even greater devastation. Consequently, the region is projected to face more challenges and damages due to climate change's impact on storm intensity and the probability of cyclone landfalls. (DANDA, 2019).

As depicted in figure 2, the Sundarbans delta ecosystem is highly susceptible to the impacts of global warming and natural disasters. Climate change and increased occurrences of catastrophes are jeopardizing the unique mangrove forest and estuarine ecosystem. Rising sea levels and melting glaciers are destroying crucial mangrove habitats, leading to floods, coastal erosion, and saltwater intrusion. Such changes threaten the ecological stability and essential services of the Sundarbans. Moreover, climate change factors like elevated sea levels, droughts, and high temperatures are negatively impacting the viability and health of the mangrove forests. The disappearance of these habitats would have a devastating effect on biodiversity, as many species rely on them for activities like feeding, nesting, and reproduction. (SÁNCHEZ-TRIANA et al., 2016a).

Figure 2: Environment impact on the Sundarbans region.



Source: Authors

The Sundarbans, an ecologically rich area, is under the grave threat of extinction for various plant and animal species due to habitat loss caused by climate change. Bengal tigers, estuarine crocodiles, and numerous bird species are especially vulnerable due to the destruction of their habitats. Climate change is increasing land and water salinity, reducing freshwater availability for both animals and humans and stunting plant growth. The Sundarbans' vital role in carbon sequestration is being diminished by mangrove degradation, exacerbating climate change. Additionally, millions of people reliant on the Sundarbans face declining income and food security due to rising sea levels and extreme weather events. Immediate action is necessary to address these challenges, including sustainable livelihood practices, disaster preparedness, and climate adaptation methods. International cooperation and reduced greenhouse gas emissions are essential to mitigate the long-term impact of climate change on this critical ecosystem.

4. Disaster and Sundarbans delta ecosystem

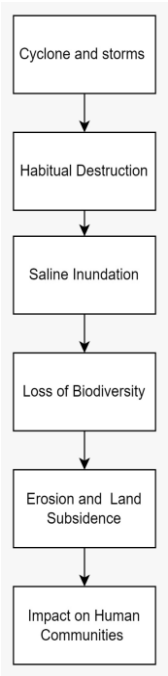
The Sundarbans, a region in the Ganges-Brahmaputra-Meghna delta, is being severely affected by climate change-related disasters and rising sea levels. Cyclones pose threats to the livelihoods of the economically disadvantaged in the area. Efforts have been made to lessen the impact of these cyclones.

Large-scale implementation of the reduction plan can minimise harm to resources. In this regard, it has been shown that mangroves provide remarkably high levels of ecosystem services, such as the coast's natural bio-shield, which protects against storm surges, tsunamis, and cyclones. (CHOWDHURY et al., 2021) A reduction plan can minimize harm to resources. Mangroves provide high levels of ecosystem services, including acting as a natural bio-shield against storms.

As shown in figure 3, cyclones and storm surges in the Bay of Bengal pose a significant threat to the Sundarbans. They cause floods, damage barriers, and endanger wildlife habitats. This leads to disruptions in seed dispersal, uprooting of trees, loss of vegetation, and alterations in the landscape. Additionally, the salinity in soil and water is reducing freshwater sources, impacting water availability for both animals and humans. (KRAUSS;

OSLAND, 2019). As a result, millions of people living in the Sundarbans delta region are at risk, as these natural disasters can destroy homes, agricultural land, fishing opportunities, and livelihoods. This contributes to increased poverty and vulnerability among the residents, as shown below in figure 3.

Figure 3: Shows the effect of disaster on the Sundarbans Delta Ecosystem.

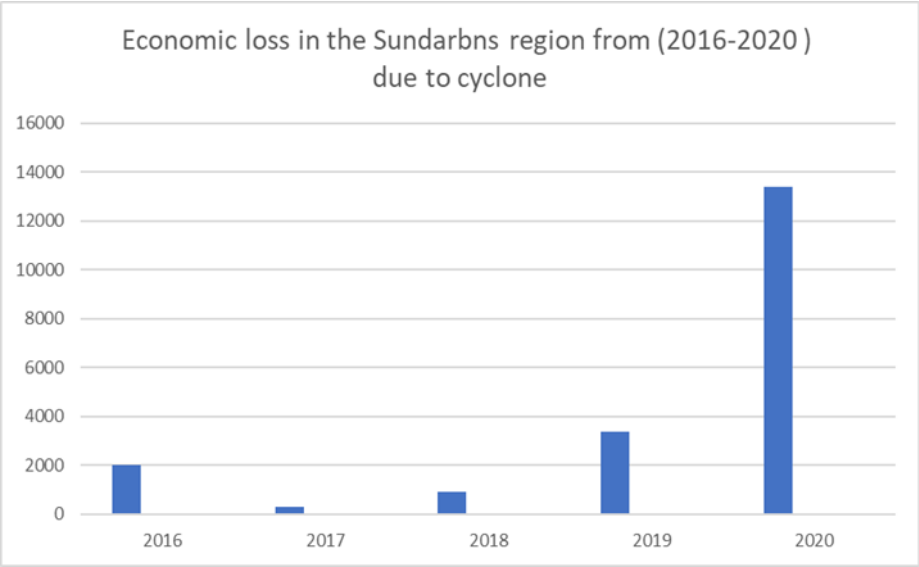


Source: Authors

Cyclones and storm surges worsen coastal erosion and ground subsidence in the Sundarbans delta, increasing vulnerability to natural disasters and rising sea levels. To reduce this vulnerability, techniques like ecological restoration and disaster preparedness are necessary. Building stormproof structures, implementing early warning systems, and improving disaster response processes can help minimize cyclone and storm surge damage. Preserving mangrove habitats is essential for enhancing ecosystem resilience. Engaging local communities in disaster risk reduction and ecosystem management strategies promotes sustainable practices and overall resilience in the Sundarbans delta.

Damage in the Sundarbans was first estimated at over 1,600 square km. The UNESCO World Heritage site is already under attack from multiple aspects of climate change, and this announcement comes as the Forest Survey of India predicts a 2% loss of mangrove cover in the delta between 2017 and 2019. When storms like Amphan threaten, the mangroves in the area protect Kolkata from the worst of the weather.

Figure 4: Economic Loss in the Sundarbans region due to cyclone.



Source: GHOSH; MISTRI, 2023.

Cyclone Amphan has caused extensive destruction in the Sundarbans, a large mangrove forest covering 4,263 square kilometers in the Indian Sundarbans. The impact has been worse on the Indian side, particularly in the Patharpratima and Kultali sections. Some of the worst-affected regions in South 24-Parganas include Ghoramara Dweep, Kalinagar, Naamkhana, Bakkhali, Frasergunj, Sagar, and Pathor Pratima Island.

Salinity is causing the yellowing and reddening of trees in the Sundarbans after the cyclone (The Hindu, 09.06.2020). Planting more trees may not be sufficient to restore the mangroves for a long time. Experts highlight that mangroves have multiple benefits, as they not only reduce wind speed during cyclones but also serve in wave mitigation. (SEN, 2020)

Climate change is causing two types of calamities in the Indian Sundarbans: cyclones and storm surges causing extensive damage, as well as slow poisoning from Bhat, with increased soil and water salt levels, affecting residents' health and livelihoods. Rising sea-surface temperatures in the Bay of Bengal are intensifying cyclones despite fewer occurring, and higher sea levels are increasing salinity in soil and water, impacting the mangrove forests and people's lives in this deltaic region. (BHATTACHARYA, 2023)

The Sundarbans is frequently confronted with numerous environmental risks including cyclonic storms. Approximately nine cyclones hit the area every decade, with a third of them being highly severe. Recent examples of devastating cyclones include Sidr (2007), Aila (2009), Phailin (2013), Hudhud (2014), and Bulbul (2019).

Environmental dangers have been increasing for centuries, posing a threat to human safety. The failure of embankments has affected the region's ability to provide sufficient food, and clean water, and maintain adequate WASH (water, sanitation, and hygiene) infrastructure. Salinity in soil and water sources has hindered crop production and led to health issues, particularly diarrhoea in children. In addition, residents in the Indian Sundarbans are currently facing three crises: the impact of the strongest tropical storm in the Bay of Bengal, Amphan, occurring during the COVID-19 pandemic and alongside the ongoing aftermath of natural disasters. (SENGUPTA, 2020)

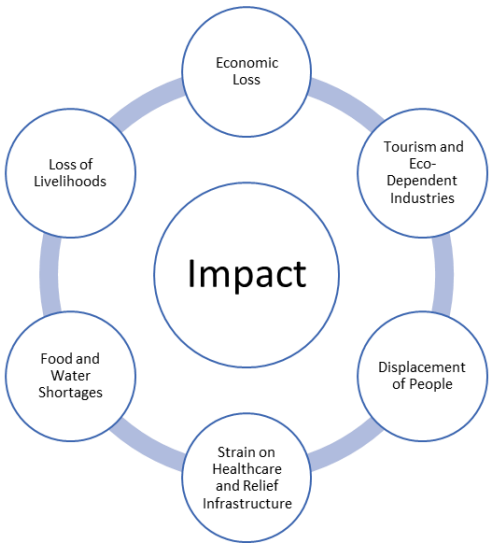
5. Impact of Sundarbans disaster on population and Indian economy

The biosphere reserve is a part of the largest mangrove forest in the world, which is found in the Sundarbans, which span Bangladesh and India. This region is home to 42 mammal species, including the critically endangered Royal Bengal Tiger, and over 300 bird species. There are 4.5 million people living in the Bay of Bengal's Indian Sundarbans, who are mostly dependent on fishing and agriculture for their livelihood. As many as 54 of the 104 islands are inhabited by people, and at least one member of every fifth household has left to pursue better economic opportunities elsewhere. Currently, the Sundarbans region of India (SBR), which is made up of 19 community development blocks, is managed by the West Bengal districts of North 24 Parganas and South 24 Parganas. There are about 4,200

square kilometres designated as protected forests, and there are 5,400 square kilometres that have no trees at all. (GHOSH, 2019)

As shown in figure 5, natural disasters in the Sundarbans have profound effects on communities relying on the land and sea for their livelihood. Disruptions from these catastrophes often force people to relocate, leading to mass migration to urban areas and exacerbating social and economic issues. Agriculture and fishing suffer as crops are destroyed, freshwater is contaminated, and fishing trips are cancelled. This has direct consequences on food security and rural incomes. Furthermore, the Sundarbans' infrastructure, such as highways, bridges, schools, and hospitals, is at risk and costly to rebuild. The perceived risk of disasters also reduces tourism, impacting tourism earnings and the livelihoods of those working in the industry. (KIPER, 2013).

Figure 5: Impact of Disaster on the economic sector.



Source: Authors.

The Sundarbans face the threat of losing its distinctive biodiversity and ecosystem services. Disasters can destroy the mangrove forests and their inhabitants, disrupting the balance and reducing the region's ability to provide essential services like carbon sequestration and coastal protection. The economic costs of natural disasters in the Sundarbans are significant. (ADLA et al., 2022). Disasters in India have a significant financial impact on the country. The costs of providing help, relief supplies, and assistance will

primarily be shouldered by the Indian economy. The insurance industry and public welfare programs also face increased costs. Both the government and commercial insurance must provide compensation and financial aid to the victims.

The Indian Sundarbans, known for its ecological vulnerability and rich biodiversity, has been a top priority for the Worldwide Fund for Nature (WWF) since 1973. However, global warming and climate change have posed threats to both indigenous people and wildlife in the region. The rising sea levels and increased flooding make the low-lying areas and coastal islands more susceptible to damage. Moreover, human-animal conflicts are prevalent, endangering the survival of various species. To ensure the future of the Sundarbans, it is crucial to integrate conservation efforts with climate change mitigation strategies and enhance the resilience of communities and ecosystems.

Long-term projects including the availability of clean energy, sustainable means of sustenance, and efficient handling of human-animal conflicts are the main focus (JAMAL et al., 2022). Numerous local neighbourhoods depend on it for financial stability. Fish harvesting from nearby waterways, beekeeping, and the natural flora are highly valued in the area's markets. The local community has developed strong ties to the land, air, water, wildlife, and plants of the area, and these elements have all become intricately embedded in local culture and customs throughout time.

6. Impact of disaster and climate change on the agriculture, wetland and water resources

The Sundarbans region, known for its agriculture, wetlands, and water resources, is facing severe impacts from natural disasters and climate change. Covering 9630 square kilometers, with 4264 square kilometers of marsh and mangrove, the area was once entirely covered by mangroves but is now partially used for farming and fisheries. Around fifty-four out of a hundred islands are inhabited significantly, and the population has grown from 1.2 million in 1951 to over 4.4 million in 2011. (SÁNCHEZ-TRIANA et al., 2016b).

The primary industry in this region has been rain-fed paddy production, but agricultural prospects are poor due to low irrigation (2.36-19.05%) and cropping intensity (101.31-171.05%). This leads to a high

percentage of the working-age population leaving the community in search of employment. As a result, fishing becomes the main source of income for almost everyone in the area. Limited access to modern energy services further restricts economic activities in the Indian Sundarbans. (GUPTA et al., 2021).

The agricultural fields in the Sundarbans are prone to natural disasters like cyclones and storm surges, which can contaminate fertile soils and ruin crops, leading to poverty and food security concerns. Climate change and rising sea levels also pose threats to the delicate wetland ecology, causing reduced wetland area, mangrove dieback, and increased salinity, which can harm plants, animals, and biodiversity in the region. Additionally, the availability of freshwater supplies in the Sundarbans is at risk due to climate change-induced droughts and shifts in precipitation patterns (WELLE, 2023). This threatens the biological balance of mangrove forests and the availability of clean drinking water for nearby residents. Natural disasters such as cyclones and floods can further contaminate water supplies (CHANDA; AKHAND, 2023).

When pollutants, fertilisers, and pesticides from flooded agricultural land wash into basins of water, contamination can happen. This has an impact on the local aquatic life as well as the people who utilise the water for drinking and other uses. Rising sea levels and storm surges are making fresh water sources brackish or saltwater, reducing availability for both humans and animals, disrupting the fragile ecosystem of the Sundarbans.

The people of the Sundarbans region depend on agriculture, fishing, and aquaculture for their livelihoods. However, climate change and natural disasters have put their incomes and safety at risk. Declining fish supplies and lower agricultural output are exacerbating poverty and food insecurity. Land degradation caused by cyclones, rising sea levels, and coastal erosion has further reduced arable land and space for cities and industry. The recent destructive Amphan cyclone has added to their difficulties, with homes destroyed, farms flooded, and betel bushes lost. Insufficient infrastructure and resources make matters worse, as their savings and salaries were meant to help during the pandemic. Considering these dire circumstances, families who had saved for future businesses or fishing will now have to start over (WATERAID et al., 2020)

Climate change is causing significant harm to farmers and communities in the Sundarbans region. Farmers face heat stress and limited

water, resulting in loss of livestock and reduced income. Changes in temperature and salinity negatively affect fishermen, impacting fish populations and the marine ecosystem. Cyclones and floods are especially devastating due to poor infrastructure and resources, affecting the impoverished. The economy, reliant on agriculture, fishing, and gathering forest products, is suffering from declining wages and increasing poverty. Unfortunately, limited resources and access to capital, technology, and information hinder the ability to adapt to resilient agricultural practices and diversify income (MARCINKO et al., 2021).

Sea water agriculture could be a viable solution for maintaining agriculture in the Sundarbans delta region due to increased salt levels in the soil. Salty water can be filtered using biofiltration for use in wetland areas. Research in aquaponics, climate technology, and food technology could contribute to the development of a framework for indoor wetland farming. According to Clarke et al. (2015), wetlands can support biodiversity and serve as a draining pond. Additionally, reducing soil salinity can be achieved through rainwater intervention by collecting subterranean rainfall. Implementing these techniques will boost agricultural output in the Sundarbans delta region. (HAZRA et al., 2002).

7. Role of technology in disaster mitigation in the Sundarbans delta region

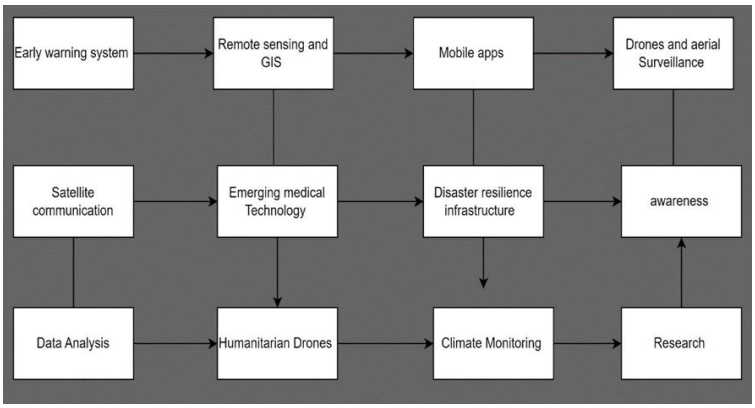
Technology is vital for disaster mitigation in the Sundarbans Delta region. It helps provide early warnings, improve readiness, enhance response capabilities, and facilitate recovery operations. By incorporating technology, the region can reduce the human and environmental impact of cyclones and other natural disasters. It has proven to save lives in the Sundarbans delta.

Advanced meteorological and hydrological technology, alongside early warning systems, enables timely detection and prediction of cyclones, storm surges, and harsh weather conditions. Communities are provided with ample notice to relocate, protect belongings, and safeguard lives and property. Utilizing satellites, scientists monitor the Sundarbans in real-time to track weather patterns, coastline erosion, and vegetation changes. This data aids in assessing disaster risks and developing effective disaster management strategies. Communicating precise and prompt information to

marginalized populations is a pivotal role of information and communication technologies (ICTs).

As depicted in figure 6 below, During emergencies, people can access important information through mobile phones, the internet, and local radio stations. Geographic Information Systems (GIS) technology allows for visualization of critical infrastructure, evacuation routes, and vulnerable areas, helping planners and first responders identify disaster hotspots and prepare accordingly (WAHID et al., 2007). GIS also helps map out danger zones quickly and facilitate preventative measures. By using real-time geographic data, resource allocation for emergency response can be optimized and disaster risks can be modeled more effectively. Overall, GIS technology is crucial in making informed choices related to disasters and improving preparedness and mitigation measures. (ESDS, 2022).

Figure 6: Role of Technology in disaster prevention.



Source: Authors.

Drones and remote communication are useful during natural disasters because phone lines are often down. Satellite phones and drones can be used to quickly set up emergency communication links and survey the area from above, gathering vital data for rescue and relief efforts. Also, agriculture technology, such as climate-resilient crops, weather-resistant seeds, and precision farming, can help farmers in the Sundarbans adapt to their changing climate. (PAULETH, 2022). These methods increase crop yields and make farming communities more resilient to climate change.

Installing simple early warning systems, like sirens and warning lights, in communities can effectively alert residents of impending danger.

Analyzing historical catastrophe data alongside real-time information can assist researchers and policymakers in identifying patterns, assessing risks, and designing evidence-based policies to reduce the impact of future disasters. Advanced climate modelling tools aid in simulating climate change scenarios and enable authorities to plan and adjust policies accordingly. The Sundarbans Delta region can enhance resilience and minimize harm through the integration of these technologies into disaster management practices. However, it is crucial to ensure accessibility and adaptation of these technologies to meet the needs of local populations, particularly those with limited resources and technological literacy. Successful implementation of technological disaster mitigation strategies in the region requires community participation and capacity-building efforts (MAJD et al., 2019)

Satellite mapping of the Sundarbans deltas will simplify the monitoring of biological activity, biodiversity, and agricultural operations. It will enable a comprehensive examination of ecological and economic activities using techniques like stress mapping and vegetation index. Furthermore, it will support research on endangered species and local populations. (MANNA; RAYCHAUDHURI, 2019). Also, the soil mapping in the Sundarbans delta will create a database of soil content and facilitate monitoring of salinity, pH, organic matter, and other characteristics. This will improve agricultural operations in the region. (BISWAS et al., 2017).

8. Role of policy and governance in disaster management

The Government of West Bengal has implemented various measures to manage and control disasters in the Sundarbans region. They are constructing and enhancing roads, ferry ghat jetties, and bridges to connect the islands to the mainland. Efforts are also being made to connect remote areas of Sundarbans to district roads and state highways. Improving drainage systems, including sluices, culverts, and canals, is being prioritized for effective drainage, irrigation, and re-excavation. Additionally, the government is focusing on providing high-quality seeds and manures to promote crop growth in the summer season. To meet the drinking water needs, tube-wells are being installed, taking into consideration the groundwater depth. These initiatives aim to develop the social infrastructure of the region and ensure disaster resilience.

Efforts are being made to improve school infrastructure in female schools to reduce student attrition. The residents of Sundarbans need to be educated about protecting its natural resources, with the support of local government, organizations, and educational institutions. Providing bicycles to girls will enable them to move around conveniently and be prepared for natural disasters. Courses are being planned to teach farmers and fishers new techniques. Training programs are being offered to marginalized youth, especially those who have dropped out of school, to enhance their livelihoods and social well-being in Sundarbans.

The Board currently oversees one fish farm in Jharkhali, which consists of 50 hectares of land. Out of this, 12 hectares are used for fishing. Additionally, a second fish farm was established in Jharkhali, covering 150 acres, and it has been handed over to a co-op for operation. There is a focus on providing fish fingerlings to fishermen. To protect biodiversity, a social forestry initiative has been introduced, involving the planting of mangroves, fruit-bearing trees, and other plants in different natural regions. (GOVERNMENT, 2020)

Effective disaster management in the Sundarbans requires strong policies and leadership to minimize the impact of disasters and enhance resilience. This can be achieved through well-defined policies and governance structures at regional, national, and local levels. Priority should be given to measures that build resilience, promote climate change adaptation, and establish early warning systems. Regulating land-use and implementing effective planning strategies are crucial to reduce vulnerability to natural catastrophes in the Sundarbans.

Policymakers can adopt important measures to reduce vulnerability to disasters, such as limiting development in vulnerable areas, safeguarding natural buffers like mangroves, and enforcing resilient building codes. It is essential to involve communities in the decision-making process of disaster management, which can be facilitated through policies promoting community participation, information sharing, and capacity building (BANERJEE et al., 2023).

Good governance is crucial for reliable infrastructure and essential services. It is important to invest in disaster-resistant infrastructure to ensure the safety of people and their belongings. Policymaking frameworks should support the development and maintenance of early warning systems and communication networks. This requires investment in technology,

communication skills training, and coordination structures. Governance institutions should have clear strategies and plans for responding to and recovering from disasters.

Disaster management plans need to include strategies for dealing with climate change. This involves finding ways to enhance the Sundarbans' ability to withstand the effects of climate change. Implementing policies that establish financial tools and insurance for catastrophic risks can help communities and governments bear the financial burdens associated with disasters.

All organizations must collaborate to ensure effective governance. This requires cooperation among government branches, non-governmental organizations, corporations, and communities. Policy frameworks should promote partnership and cooperation to manage disasters efficiently. By implementing strong policies and governance frameworks, the Sundarbans region can enhance disaster management, increase resilience, and reduce the impact on people and the environment. Strong policy and leadership are needed to ensure the Sundarbans remains sustainable for future generations.

9. Role of law in disaster management in Sundarbans region

When the embankments of the Sundarbans break, saltwater floods fields and destroys crops. This leads to people resorting to exploitative practices or making dangerous migrations. The Bengal Embankment Act, a law dating back almost 140 years to the colonial era, governs the construction and maintenance of embankments in West Bengal. The Irrigation and Waterways Department has complete authority over these embankments, which are considered public spaces. However, the social and ecological context has changed significantly since the law was enacted. The choices made by the department regarding the embankments have a profound impact on the lives and livelihoods of those who reside in the Sundarbans region. (OHDEBAR, 2020).

To reduce the vulnerability of people living in transition zones, it is essential to enhance disaster risk reduction efforts and adjust embankment networks if necessary. Encouraging individuals to leave the buffer zone is crucial, and various measures can be implemented to facilitate this, including financial incentives. Preserving natural environments is also important, as it creates new income-generating opportunities and contributes to the conservation of biodiversity. These initiatives not only lower vulnerability but

also reduce exposure to risks by providing ecosystem services. Ultimately, improving these aspects greatly improves the success of relocation in transition zones.

Additionally, reinforcing existing structures is of utmost importance. By bolstering the government's capacity to execute the planned strategy, we can ensure a more effective implementation of the proposed measures (SÁNCHEZ-TRIANA et al., 2016c).

Law is crucial in managing disasters in the Sundarbans. It helps with reaction, recovery, and prevention, reducing risks and protecting vulnerable groups. Legal frameworks are used to implement a comprehensive approach, aiming to decrease vulnerability and increase resilience. Laws governing architectural norms and construction standards are essential for protecting buildings against cyclones and storm surges, reducing casualties and property losses. Zoning and land use regulations also play a role in enhancing resilience, possibly through protecting vital natural buffers like mangrove forests in high-risk areas.

Establishing rules and legal frameworks is crucial for efficient disaster management in the Sundarbans. These frameworks provide guidelines for coordinating response activities, mobilizing resources, and ensuring successful relief operations. They also enable the setup and maintenance of early warning systems to alert at-risk individuals promptly. Additionally, legal frameworks for disaster risk insurance and risk financing mechanisms address the financial aspects of response and recovery efforts. Community participation and engagement in decision-making are vital for empowering local communities to contribute to their safety. Legal frameworks on adaptation and accountability guide policies to reduce vulnerability to climate change and extreme weather events. Enforcing strong legal frameworks improves disaster management, resilience, and protection for both human populations and the Sundarbans ecosystem.

10. Role of industries in the disaster management in Sundarbans region

The industrial sector in the Sundarbans region plays a crucial role in disaster management. Industries must adopt environmentally and socially responsible practices to reduce disaster risks and build resilience. Before starting operations, thorough Environmental Impact Assessments (EIAs) must be completed to protect vulnerable ecosystems and prevent further

harm. Businesses should also invest in infrastructure that can withstand natural disasters (ISSAR; MATHUR) and prioritize strong waste management systems.

Businesses need to have well-planned emergency procedures in place, including evacuation plans, communication during disasters, and collaboration with local government and communities. They should offer comprehensive instructions for each category. Industries can support the development and maintenance of early warning systems, strengthening their workforce and communities through capacity-building programs. Industries relying on Sundarbans resources should practice sustainable management to maintain natural resources, preventing disasters. Effective waste management and pollution control measures are crucial to avoid harming the environment and contaminating the water supply. Industries can also mitigate disasters by reducing greenhouse gas emissions and promoting renewable energy sources. By adopting these precautions, industries play a crucial role in preventing future disasters (ABUBAKAR et al., 2022).

As shown in figure 7, companies operating in the Sundarbans region play a crucial role in the region's Corporate Social Responsibility (CSR) programs. These programs focus on protecting the unique environment, involving the community, and preparing for disasters. By supporting projects that enhance community resilience, businesses contribute to the overall well-being of the region. To achieve this, businesses must collaborate with and understand the challenges faced by local residents. By involving locals in the planning process, businesses can develop more effective strategies for managing and mitigating the impact of disasters.

Figure 7: Industrial contribution to disaster management.

Source: Authors.

11. Future perspective and disaster model for west Bengal Sundarbans delta ecosystem

The Sundarbans, a critical biodiversity hotspot, is facing increasing vulnerability to disasters due to climate change. Cyclones, storm surges, and rising sea levels pose a significant threat to the region. With rising temperatures and shifting climate patterns, these disasters are projected to become more frequent and intense. This puts the unique ecosystem and valuable services of the Sundarbans at risk, including the loss of habitat, species, and important services like carbon sequestration and coastal protection. Overall, disaster management is crucial to mitigate the growing environmental threats faced by the Sundarbans.

The local economy heavily depends on agriculture and fishing, which have been severely affected by natural disasters causing crop failures, destruction of fishing communities, and a loss of income. This has worsened poverty and food insecurity. More frequent and intense disasters are forcing some people to relocate for safety. These catastrophes also have negative effects on health and social well-being, leading to higher rates of illnesses, accidents, and mental health issues. It is crucial to ensure quick access to healthcare and supplies before, during, and after disasters, especially for vulnerable sections of society.

The Sundarbans region requires investments in disaster-resilient infrastructure to protect against cyclones, floods, and extreme events. This involves building embankments, flood control systems, and safe cyclone shelters. A proactive disaster management strategy focused on risk reduction and adaptability is needed. To achieve this, actions should include

improving early warning systems, preserving ecosystems, and adjusting agricultural techniques to changing weather patterns. Active participation and empowerment of local communities are crucial, ensuring efficient outcomes. Involving them in decision-making processes and providing relevant information and tools enables them to contribute to their own safety and resilience.

Bangladesh and India need to work together on a global level to maximize the advantages of the Sundarbans ecosystem. It is crucial to gain support and cooperation from the global community to address shared issues and implement coordinated disaster management plans. Ongoing research and innovation are necessary to grasp the specific risks and consequences of disasters in the Sundarbans. By utilizing advanced technologies and approaches, we can enhance preparedness measures and provide more effective disaster relief efforts.

The Sundarbans, a densely populated archipelago consisting of 54 islands, is at risk of permanent submersion due to rising sea levels. This poses serious health concerns as prolonged exposure to salt can lead to various fertility-related issues such as urinary and urethral infections. Additionally, consuming excessive sodium in one's diet can raise blood pressure.

The alteration of the delta's natural flow, caused by diversions and abstractions upstream, worsen the challenges of floods and saltwater intrusion. Dams, improper agriculture, waste management, mining, and river redirections further contribute to the problem. West Bengal recognizes the impact on rural and tribal communities and has implemented initiatives to preserve biodiversity and regulate development. The Ganga-Brahmaputra delta, shared by Bangladesh and India, is a collaboration, and scientific research and technology offer solutions like reducing carbon emissions and utilizing renewable energy.

To effectively anticipate natural disasters and protect communities, key measures are essential. This includes the use of a geomorphology analyzer for accurate predictions, as well as the integration of artificial intelligence and machine learning for disaster prevention. Digital satellite security plays a critical role in ensuring public safety, while mobile health centers are necessary for healthcare access in remote areas. Furthermore, the establishment of emergency command centers in vulnerable regions assists in rapid response and crisis management. In our pursuit of sustainability, practices like natural farming, nanotechnology, vertical

farming, and crisis management training for farmers and locals are vital. The rehabilitation of watersheds should also not be overlooked. To ensure success, support from green and blue bonds is necessary for investors and effective disaster management. Encouraging the international community to adopt resilient economic strategies and catastrophe management is crucial for the delta region.

12. Conclusion

Cooperation among development partners, NGOs, government agencies, and legislators is crucial for successful disaster management in the Sundarbans. The region's increasingly severe climate-related risks require a comprehensive plan to protect vulnerable communities and unique ecosystems. The government plays a key role in disaster management and should establish policies and legal frameworks for mitigating hazards, spatial planning, and environmental protections. Prioritizing investments in typhoon shelters, early warning systems, and resilient infrastructure is essential. Moreover, allocating adequate funds for the prevention, mitigation, and restoration of catastrophes is imperative.

Non-governmental organizations (NGOs) play a crucial role in supporting government initiatives by engaging with local communities, providing emergency preparedness knowledge, and aiding in the development of localized strategies. They also have the ability to advocate for legislative changes related to social welfare, environmental protection, and sustainable development. Development partners, such as international organizations and donor agencies, can provide significant assistance to the Sundarbans in managing disasters. Through outside funding, technical assistance, and capacity-building programs, they can help strengthen local capacities for risk reduction and improve disaster response.

Effective coordination and cooperation among all parties involved is essential for managing disasters. This includes establishing shared planning spaces and regular communication channels to ensure successful collaboration. Multi-stakeholder discussions are also important for consensus and incorporating diverse perspectives in disaster management approaches. Sustainable development is crucial in emergency preparedness, requiring a delicate balance between environmental protection and economic growth. Strengthening and increasing resilience in the Sundarbans

can be achieved by supporting eco-friendly industries, promoting climate-resilient agriculture, and encouraging sustainable lifestyles.

In conclusion, the effective management of disasters in the Sundarbans necessitates the collective efforts of non-governmental organizations (NGOs), government agencies, development partners, and local communities. Implementing strong legislation, building capacity, embracing sustainable development practices, and involving stakeholders are essential to protecting this priceless environment from the growing threats posed by climate change and natural disasters. By fostering cooperation and collaboration, these parties can bolster the Sundarbans' ability to withstand the mounting pressures it faces.

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Declaration of authorship and specification of contribution to the article	
José Noronha Rodrigues	**Contribution:** coordination of article structure and activities; guidance on the stages of data collection, writing and structuring; development of the text, research in public sources; bibliography study; Bibliography analysis and final review of the article.
Sumanta Bhattacharya	**Contribution:** writing and structuring; development of the text, research in public sources; bibliography study; Bibliography analysis and final review of the article
Bhavneet Kaur Sachdev	**Contribution:** writing and structuring; development of the text, research in public sources; bibliography study; Bibliography analysis and final review of the article

Dora Cabete	**Contribution:** coordination of article structure and activities; guidance on the stages of data collection, writing and structuring; development of the text, research in public sources; bibliography study; Bibliography analysis and final review of the article