



Towards a Cleaner Bay: Combating Marine Pollution to Revive Coastal Biodiversity in the Bay of Bengal

Sk. Mahmud Hasan^{a*}

Abstract

The Bay of Bengal is considered as one of the ecologically rich but environmentally sensitive maritime zones globally. The biodiversity along the coast comprising of mangroves, sea-grass bed, coral reefs, and many marine fishes & animals is instrumental in maintenance of fisheries and shore line protection as well as the livelihood of millions of people in Bangladesh. But increasing water pollution, caused by industrial wastes, plastic junks, farm waste and oil spillage among others have highly affected the quality of water and have impaired delicate environments. This paper will discuss the degree, origins and environmental implications of marine pollution in the Bay of Bengal, especially in terms of its effects on coastal biodiversity. The application of the mixed-method (which involves the analysis of empirical data samples, interviewing the stakeholders, and field observations) will reveal major pollution hotspots and evaluate the current mitigation framework. The results also indicate major enforcement gaps, waste management infrastructure gaps as well as gaps in cooperation between regions. The paper suggests a coordinated strategic approach that brings together the assimilation of tighter controls and regulation, community-based conservation, technological advancement, and furthering cooperation between regions to replenish and maintain the biodiversity of coastal areas.

Keywords: Marine Pollution, Coastal Biodiversity, Bay of Bengal, Ocean Governance

Introduction

Coastal biodiversity refers to the diverse ecosystems and species found at the interface of land and sea, characterized by high biological productivity due to inputs from both terrestrial and marine environments. These ecosystems, including mangroves, coral reefs, salt marshes, and seagrass beds, provide essential goods and services such as fisheries nursery grounds, water filtration, climate regulation,

*Corresponding Author: Sk. Mahmud Hasan  smhasan2142@gmail.com

^aCommander Sk. Mahmud Hasan, (G), BCGM, psc, BN is a Officer-in-Charge, Gunnery School, BNS ISSA KHAN, Chattogram

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and shoreline protection (Brooke Maslo, Julie Lockwood, 2014). On the other hand, Marine pollution refers to the degradation of the earth's oceans. The vast preponderance of marine pollution can be attributed to ways in which humankind relates to the natural environment. Sources include runoff from the use of herbicides, chemical fertilizers, and insecticides in farming, industrial wastes, trailing from mine operations, oil spills, improperly treated sewage, and silt from erosion (Burns, 2017). Likewise, coastal biodiversity and marine pollution are closely linked, as pollution significantly impacts the health and sustainability of coastal ecosystems. Therefore, marine pollution often disrupts the ecological balance of biodiversified habitats.

One of the world's largest marine ecosystems 'The Bay of Bengal' provides essential resources to the bordering countries, especially Bangladesh. Its abundant biodiversity includes marine life such as fish, coral reefs, and mangroves, which are vital for the economic sustenance of millions residing in Bangladesh's coastal areas. Similarly, its ports drive trade and commerce. The bay also plays a crucial role in regulating the country's climate, supporting biodiversity, and protecting against natural disasters. The Bay of Bengal is heavily polluted by untreated sewage, industrial effluents, agricultural runoff, and plastic waste. Bangladesh alone contributes around 200,000 tons of plastic annually to the bay (CPD, 2023). Diesel pollution and oil refinery effluents harm marine organisms like sea stars and bottom-feeding fish, sometimes causing extinction or cancer. Additionally, oxygen depletion in polluted waters creates dead zones where marine life cannot survive (Refulio, Katherine, & Tracy, 2021).

The challenges of marine pollution in the Bay of Bengal threatens coastal biodiversity through plastic waste, oil spills, industrial runoff, and habitat destruction, endangering marine life and the livelihoods of millions. Moreover, addressing marine pollution in the Bay of Bengal is significantly hindered by resource limitations. Despite existing environmental laws covering marine pollution control, enforcement mechanisms are often inadequate due to institutional, strategic, and financial constraints. Additionally, the lack of coastal development plans and ineffective marine protected areas exacerbate the challenges in conserving marine biodiversity.

Marine pollution is a detrimental issue which adversely affects the coastal biodiversity in the Bay of Bengal. In connection to that, there are scopes to reduce the marine pollution. Bangladesh's current concern strategies in addressing marine pollution have several inadequacies (Alam, 2014). It is imperative that, there are

ways to improve these existing strategies, detrimental human habits and appliance. Presently, it is evident that Bangladesh needs to appreciate the implement several approaches to reduce marine pollution to save coastal biodiversity in order to accomplish strategic, operational, and preemptive measures.

Primary Sources of Marine Pollution in the Bay of Bengal

The Bay of Bengal located between countries with a high population density and fast economic development has to face considerable ecological stress, especially in the form of marine pollution. The major source of this pollution has been land-based and is strongly associated with industrialization, urban populations, unsustainable farming activities and poor disposal mechanism in the loose of the region. All these stressors worsen the condition of the water and destabilize the ecological system of one of the most productive marine ecosystems in the world (Holmgren, 2019).

Industrial Discharge and Effluence. A large contributor of marine pollution in the Bay of Bengal is the industrial effluents. Many industries - textile, leather, fertilizer, pharmaceutical and petrochemical plants - release the untreated or partially treated sewage water directly in the rivers that flow into the bay. Such discharges usually include toxic substances like heavy metals, chemical dyes, solvent, and hydrocarbon which remain in the marine water environment and cause acute toxicological risks to aquatic life (Burns, 2017). The fact that there is no enforcement of strict regulations, as well as the absence of significant wastewater treatment systems, particularly in the developing coastal areas, increases the extent of this type of pollution (Alam, 2023).

Nutrient Loading and Agricultural Runoff. Agriculture runoff is considered a major factor in nutrient enrichment and chemical pollution of the coastal waters. Pesticides and herbicides, in conjunction with nitrogenous and phosphatic fertilizers are used to promote farming in the upper lands, are significantly dissolved during rainfalls or irrigation. Once this type of nutrient is released into the ocean, it causes eutrophication - the growth of algal bloom, hypoxia and dead zones that are not habitable to marine life (Mancuso, 2023). It is not only a phenomenon resulting in the loss of biodiversity, but it also affects other vital ecological processes, e.g., primary production and nutrient recycling.

Urban Wastes and Municipal Sewage. Emptying of improperly treated or untreated urban sewage is one of the principal sources of marine pollution in the Bay of Bengal. City settlements in the coastal areas usually have no proper

treatment of the sewage system, hence a leakage of fecal contents, organic wastes, pharmaceuticals, and microplastics can enter the waters nearby (Refulio-Coronado, 2021). Among the impacts of such pollutants is the resulting surge in the Biological Oxygen Demand (BOD), proliferation of waterborne pathogens and the physicochemical nature of the marine environment. In turn, this leads to the extreme environmental pressure of such habitats as estuaries, lagoons, and coral reefs (Alam, 2023).

Plastic and Solid Waste Pollution. The Bay of Bengal has become a hotspot area in environmental issues of plastic pollution. Poor solid waste management systems and non-proper disposal lead to huge plastics wastes finding their way into the ocean through storm drains, rivers and dumping straight. These plastics, and particularly the single-use ones, break down into microplastics that are consumed by the maritime flora and thus cause bioaccumulation and the transfer of contaminants to the top of the trophic chain (Mancuso et al., 2023). Along with this, the wasted fishing equipment, more popularly referred to as ghost nets, keeps killing marine life even after the long after they have been disposed of, representing a further hazard to biodiversity (Lockwood & Maslo, 2014).

Oil Pollution and Maritime Sources. Marine pollution is also caused by the maritime activities that include inputs of maritime nature in addition to land-based inputs. Accidental and operational oil spills contaminate the marine food web with the hydrocarbons and disrupt fish spawning and destruction of sensitive ecosystems, mangroves, and coral reefs (Burns, 2017). The release of ballast water by vessels is a source of invasive alien species with the potential to interfere with the native ecosystem by competing with other organisms and destabilizing the current ecological process (Refulio-Coronado, 2021). In addition, the disposal of solid and toxic wastes into oceans and release of frequencies by the ships also contributes to the overall stress on the health of the oceans.

Coastal Biodiversity in the Bay of Bengal

One of the world most ecologically diverse and biologically productive coastal ecosystems can be found in the Bay of Bengal. The shoreline of this body is spread across several countries; Bangladesh, India, Myanmar, and Sri Lanka with a broad area of coastal habitats which comprises: mangrove forests, estuaries, coral reefs, sea-grass meadows, and mudflats. The flora and fauna within these ecosystems is remarkable supporting an impressive variety of flora and fauna and a good number of endemic and endangered species, notably the Irrawaddy

dolphin, olive ridley sea turtle, Bengal tiger, and so on. The Sundarbans mangrove forest, which spills over to the northern part of the bay, is the biggest continuous mangrove forest of the world and a major breeding and nursery area of innumerable marine and coastal life.

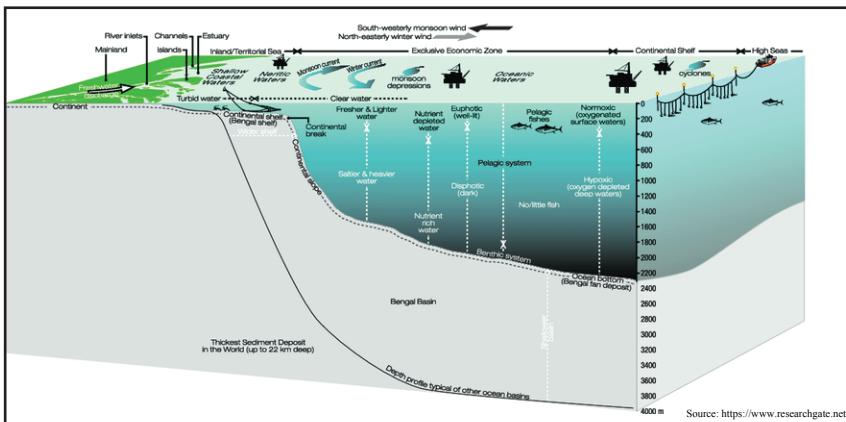


Figure 1: Salient Characteristics of the Marine System of Bangladesh Shown in the Schematic Diagram Using Actual Depth Profile of the Bay of Bengal

Biodiversity in the Bay of Bengal is a major requisite of the ecological stability and the livelihood status of the millions of people in the region living along the coastline. It offers essential ecosystem services, such as storm surge protection along the coastal lines, carbon sequestration, water treatment and fisheries productivity. Yet, the biodiversity is getting progressively jeopardized by man-made stress cases like marine pollution, destruction of habitat, overfishing, and climate-related transformations, like the rise of sea levels and ocean acidification. The erosion of these habitats does not only jeopardize marine life, but also exposes the social-economic ecosystem of the population along the coastlines. Hence, sustainable use of coastal biodiversity would require maintaining coastal biodiversity in this region because it is important to ecological sustainability, food security and disaster risk reduction in the region.

The Impact of Marine Pollution on Coastal Biodiversity in the Bay of Bengal

Destruction of Important Habitats. Habitat degradation in the Bay of Bengal is a main cause induced by marine pollution especially in the sensitive habitats, including mangrove forests, running waters, coral reef and seagrass beds. Discharges of land-based effluents which include industrial effluents, untreated

sewage and agricultural run-offs change the chemical content of coast waters ultimately destroying the ecosystems (Holmgren, 2022). To give one example, industrial contaminants such as heavy metals and synthetic material deposit in the sediment of mangroves where they affect the oxygenation of the roots of the plants, and retard their growth. Stressed already by increasing sea temperatures, the coral reefs are also affected by nutrient overloading, contributing to algal blooms that cover the colonies of corals and decrease biodiversity (Mancuso et al., 2023).

Eutrophication and Hypoxia. Eutrophication in Bay of Bengal is caused by a nutrient pollution such as excess nitrogen and phosphorus due to agricultural runoff and domestic wastes. This would respond with algal blooms which break down in large quantities of dissolved oxygen leading to hypoxic or anoxic conditions. Such hypoxic areas which are commonly called dead zones are a hostile habitat to the vast majority of marine organisms and caused the collapse of the benthic communities and disruption of trophic structures (Refulio-Coronado, 2021). Matters of fish kills and the vanishing of invertebrate community in the eutrophic zones do not only compromise biodiversity but also weaken coastal fishery.

Plastic and Micro-plastic Contamination. Plastic pollution is an increasing environmental disaster in the region of the Bay of Bengal. Gravity and micro-size plastics are consumed by organisms in oceans, which leads to intestinal congestions, malnutrition and exposure to toxics. Researchers have reported the occurrence of micro-plastic particles in fish, shellfish digestive tract and, even in plankton which are dangerous to human health via the food chain (Alam, 2023). Discarded fishing equipment and plastic waste in general have caused some marine turtles, dolphins, and seabirds to become entangled and die, all of which are major indicators of the well-being of marine ecosystems (Burns, 2017).

Hydrocarbon Congregation and Spillages of Oil. The impact, as well is severe because hydrocarbon pollution that is a result of oil spills, discharge of ballast water and ship scrapping yards in the Bay of Bengal poses a serious danger to the coastal biodiversity. Oil lays on the surface of the water preventing the pass of sunlight and transferring of oxygen that affects the primary productivity as well as photosynthesis of a plant in the ocean. Deposited along the coastlines, oil wastes compromise nesting and breeding areas of the marine animals, especially in mangrove and estuaries (Lockwood & Maslo, 2014). The long-term exposure of hydrocarbons to the fish eggs, larvae, and benthic invertebrates is toxic hence influencing the recruitment and population dynamics of the marine ecosystem.

Biodiversity Loss and Cumulative Impacts. Disparate impacts of such varied pollutants have long-term consequences of biodiversity at the marine life of the Bay of Bengal. The loss of keystone and flagship species changes the shape of communities and weakens the functioning of these ecosystems, including nutrient cycling, coastal defence, and fish yielding. A lot of species are becoming particularly vulnerable to extinction amid the loss of habitation, and the loss of food quality (Mancuso et al., 2023). Moreover, the reducing ecological resilience restricts the ability of these systems in the response to the disturbances, predisposing them to climate-related effects.

Bangladesh's Current Strategies and Capacity in Addressing Marine Pollution

Policy and Legal Frameworks. Bangladesh has come up with several policy tools in order to conserve its coastal and ocean environment. These important ones include National Environment Policy (2018), Bangladesh Environment Conservation Act (1995), Coastal Zone Policy (2005), and Bangladesh Delta Plan 2100. These are the documents that offer guiding principles on environmental protection, on management of the coastal zone as well as integration of the water resource planning. Nonetheless, these policies are usually non-specific when it comes to marine pollution sources that include oil discharges, marine wastes of plastic and ballast water. Additionally, lack of institutional mandate consistency and overlap also tends to cause laxity in implementation and inconsistency in policy.

Institutional Mechanisms. There are a number of ministries and agencies that are concerned with controlling marine pollution in Bangladesh and these agencies include the Ministry of Forest and Climate Change (MoEFCC), the Ministry of Shipping, and the Bangladesh Navy and Bangladesh Coast Guard. Their initiatives may be uncoordinated, although each contributes in his or her way leaving duplication of roles or vice versa by overlooking important roles.

Marine Waste Management and Pollution Control. Some programs have been launched in Bangladesh to minimize the land-based pollution which flows into the sea and one such program is the National 3R (Reduce, Reuse, Recycle) strategy of managing wastes and pilot projects of enhanced municipal wastes collection in coastal cities. Nonetheless, the untreated industrial waste, sewage, and plastics continue to enter rivers that empty into the Bay of Bengal in large numbers in spite of the efforts to stem this flow. Coastline towns such as

Chattogram, Khulna and Barisal do not have adequate infrastructures of waste management, and very few percentages of wastewater are treated prior to their discharge. Consequently, the oceanic life force still remains subjected to nutrient overloading, toxic waste, and abuse of plastic.

Monitoring and Scientific Research Capability. Bangladesh has a low scientific and technical ability to integrate the monitoring of marine pollution. The Bangladesh Oceanographic Research Institute (BORI), the Bangladesh Fisheries Research Institute (BFRI) are among institutions that have contributed significantly to activities in the coastal and marine research, but their activities are limited with shortage of budget, lack of skilled manpower, and marine observation instruments. This has led to limited and scattered data on data with respect to water quality, the load of pollution, and loss of marine diversity. There is lacking proactive marine ecosystem protection strategic planning since policy decisions will always be responsive and partial due to lack of definite data.

Regional Participation and International Cooperation. Bangladesh has participated in some international and regional programs in marine environmental protection like the South Asian Seas Programme (SASP) under the UNEP Regional Seas Programme, and the Bay of Bengal Large Marine Ecosystem (BOBLME) project assisted by FAO and GEF. The initiatives have helped in regional dialogue and capacity building, although their impact in cutting marine pollution in Bangladesh has been low with its implementation being on a volunteer basis and not on a follow up basis. Besides, the regional cooperation mechanisms continue to remain weak regarding binding, therefore, commitments, financial capabilities, and mutual surveillance or enforcement operations.

The Existing Limitations of Bangladesh's Current Strategies and Capacity in Addressing Marine Pollution

Poor Coordination and Fragmented Institutional Governance. The institutional framework that governs the marine environment in Bangladesh is fragmented in terms of responsibility and it has duplicative jurisdictions. The organizations like the Ministry of Environment, Forest and Climate Change (MoEFCC), Ministry of Shipping, Bangladesh Navy, and Bangladesh Coast Guard are also involved in controlling and observing activities along the sea. Coordination between these entities has however been wanting leading to inefficiencies in these bodies and duplication of efforts. A central directive or a centralized system of regulation that facilitates the ease of management of marine

pollution does not exist and this creates a problem of lack of uniformity in implementation of policies (Holmgren, 2022). Such institutional fragmentation degrades the capacity of Bangladesh to resolve cross sectoral problems such as the issue of disposing of waste on the coastline and pollution caused by shipping vessels.

Weak Legislative Foundation and Law Enforcement. As much as there exist a number of environmental laws like the Bangladesh Environment Conservation Act (1995), the Environment Court Act (2000) and the Ship Breaking and Recycling Rules (2011), they are not directly designed to deal with control of marine pollution. Further to that, there are poor enforcement systems and regulatory agencies are generally inadequately funded and manned. Misdemeanors imposed are either weak to work or non-practiced. Specifically, regulations regarding effluent handling of those industries bordering the coasts are not in good order and releasing effluence in rivers and estuaries into the Bay of Bengal has been done without any check (Alam, 2023). A good example is the shipping sites in Chattogram where shipbreaking still contributes to pollution of hydrocarbons and heavy metals because of the lapse in regulation and the inability to enforce the same.

Limited Monitoring and Scientific Capacity. Lack of strong marine monitoring and data collection limits the capability of Bangladesh to evaluate and control coastal and marine pollution greatly. Such institutions as the Bangladesh Oceanographic Research Institute (BORI) are not equipped with modern scientific equipment, nor laboratories or regular funding. Information pertaining to the marine environment is usually inconsistently acquired and, therefore, not appropriately consolidated into countrywide decision-making processes and thereof diffusion among institutions. In addition, marine biodiversity, pollution by toxic substances, and indicators of ecosystem health in a comprehensive baseline are archaic or do not exist at all (Refulio-Coronado, 2021). This is a major obstacle to the ability of Bangladesh to take adaptive management approaches, scientifically.

Inadequate Coastal and Urban Waste Infrastructure. The largest contributor of marine pollution in Bangladesh is land-based, which is the result of poor solid waste and wastewater management in coastal urban cities like Chattogram, Cox's Bazar and Khulna. These cities lack proper municipal infrastructure and raw sewage, plastics, and industrial wastes are directly leaked to the neighboring waterways. A small proportion of the produced wastes is managed and in small proportion is treated before disposal. Such waste ultimately reaches the Bay of Bengal leading to serious marine pollution and imperiling marine

biodiversity (Mancuso et al., 2023). Further, this is worsened by the low recycling industries and the lack of interest in sustainable waste management.

Poor Community Participation and Community Awareness. The general population and coastal communities are gradually being unaware of the long term effects of marine pollution in ecological and socio- economic terms. There are fewer programs of public engagement and the environmental education and local populations seldom play a role during decision making processes that deal with marine and coastal management. Community-based conservation has not proven effective in most areas however in some places success stories have been achieved (Lockwood & Maslo, 2014). As a result, chances of tapping local knowledge and guardianship in the conservation of biodiversity are usually missed.

Inadequate Emergency Response Mechanisms. The country is unprepared in case of an emergency in the marine environment in Bangladesh: oil spills, leaks of chemicals, ship or marine accidents. The nation does not have an elaborate marine pollution contingency scheme, skilled emergency forces and specialized equipment. The best responses to maritime incidents in most cases are ad hoc, uncoordinated and slow multiplying the level of damage to the environment and the associated economic cost. A serious weakness of the country, then, is that it does not have a formal disaster response system since Bangladesh has an ever-growing volume of maritime trade and a risk of shipping-related pollution is growing (Burns, 2017).

Scanty Participation in the Regional and International Mechanisms. In spite of being a signatory to various regional and international conventions like South Asian Seas Programme and MARPOL (International Convention for the Prevention of Pollution by Ships), Bangladesh has implemented them in a superficial manner. It does not have institutional procedures and diplomatic efforts that could work with other countries in joint monitoring of the sea or ensuring that pollution is controlled. Since the Bay of Bengal is a trans-boundary ecosystem, national strategies cannot be very effective, without integrating regional views (Refulio-Coronado, 2021). In addition, Bangladesh has failed to tap into international funding systems that are used in marine protection.

Financial and Technological Limitation. The solution to marine pollution and the need of biodiversity conservation at the coast will cost a lot of finance on infrastructure, technology and manpower development. As a developing nation, Bangladesh has a bandwidth of finances which hinders it to

deploy enough resources to these key areas (Shamsuzzaman and Islam, 2018). Moreover, it is not infrequent that the technical capability to monitor pollution, manage waste materials and restore eco-systems is very poorly developed or made inaccessible. This digital divide prevents the adoption of newer and efficient practices of conservation.

Threats from Land-Based Activities. The biologically and physically dissolved pollutants as well as the solid materials dumped in Bangladesh account to a greater percentage of the pollution received by the marine environment in this country and this is specifically related to the industrial discharge of untreated sewage, farm run off rich in fertilizers and pesticides, and the disposal of waste materials (<http://ijrpr.com>). The control of pollutant sources at land level has not been based on effective mechanisms in the prevailing strategies dealing with various pollution issues which ultimately end up in the marine environment. The integrated coastal zone approaches that deal with land-sea interface are yet to be arrived at fully.

Climate Change Impacts. Climate change is another dimension to the quest of marine pollution and taming the biodiversity in Bangladesh. Insecurities like rising of the sea levels, the increment of extreme weather conditions, alteration to the sea temperature and salinity, intensify the effects of pollution and pose a danger to coastal environments such as Sundarbans and coral reefs (IUCN, 2021). The existing approaches should improve the way marine conservation planning incorporates aspects of adaptation and mitigation of climate change.

Marine Protected Areas (MPAs) Effectiveness. Though Marine Protected Areas have been declared in Bangladesh, it has not been very successful in the way that they are managed and governed. The aspect of no comprehensive management plans, poor enforcement of laws in MPAs as well as ongoing fishing and pollution in adjacent areas restrict their capabilities to make a full contribution towards the conservation targets. The current MPA coverage has to be increased as well to fulfill international protection targets in biodiversity.

Ways Forward for Bangladesh to Overcome the Existing Limitations in Addressing Marine Pollution

Marine pollution in Bangladesh is a severe risk to the marine biodiversity, the economy of the nations as well as the health of the people. Although there are both domestic and international conventions on marine environmental protection, there still exist institutional, infrastructural and socio-economic barriers that have restrained effective marine environmental protection. In order to address these

obstacles, it is possible to propose the following pathways:

Institutional Strengthening Framework and Governance. Fragmented institutional framework is one of the major weaknesses in the marine pollution management of Bangladesh in the sense that it has created a network of agencies that operate in silo without any liaison. To combat this, the government ought to create a central-based maritime authority or a strong inter-agency task force focusing on marine environment protection. This organization ought to simplify the duties, enable an organized collaboration between the Ministry of Environment, Forest and Climate Change, Bangladesh Navy, Bangladesh Coast Guard, the Ministry of Shipping and other actors. In addition, national laws related to environment should be revised and aligned with international law, including MARPOL 73/78, UNCLOS, and the London Convention so that there is a complete legal framework and liability (Rahman & Hossain, 2022).

Investment in Monitoring and Surveillance Technologies. Bangladesh at the moment does not possess advanced equipment to detect and monitor the sources of marine pollution. Development of real-time monitoring and satellite surveillance is also necessary to know the status of spreading as well as prompt. AIS automation of identification of ships and remote sensing technology will enhance surveillance capacity to a large extent. In addition, such a national database on marine pollution that is fully integrated with GIS would allow policymakers to enhance environmentally informed choices. The presence of institutions such as the Bangladesh Oceanographic Research Institute (BORI) may be endowed with enhanced technologies and human resources to help in continuous monitoring of the marine (Islam & Tanaka, 2020).

Promoting Public Awareness and Stakeholder Engagement. Lack of deep awareness concerning the issue of marine pollution among the coastal communities and industry is also a relevant factor towards the escalation of marine pollution. Hence, Bangladesh needs to start massive campaigns promoting education on consequences of marine pollution with focus on economic and ecological issues. Communities and particularly communities which rely heavily on fishing ought to be educated about proper ways of doing things and on pollution. Also, the industries need to be facilitated to use environmentally friendly waste disposal mechanisms as an aspect of corporate social responsibility (CSR). NGOs, educational establishments, and the media will also have to contribute to ocean stewardship marketing (Jahan & Akter, 2021).

Upgrading of Waste Management Infrastructure in Coastal Regions.

Lack of effective waste management system in the urban coastal towns such as Chattogram, Cox's Bazar, and Khulna is a major reason of marine pollution. Dumping industrial effluents, domestic waste and un-treated sewage in the close rivers and finally into the sea is to be corrected on urgent basis. One of the counter measures that Bangladesh should take is to invest in the construction of modern solid waste treatment centres and sewage treatment plants (STPs) in coastal towns. It can be of use through incorporation of the Public-Private Partnerships (PPP) in order to guarantee sustainable and cost effective waste management systems. Also, stern punishment with regard to the violation of any industries in respect to environmental rules may serve as a deterrent (Kabir & Kabir, 2023).

Improvement of Regional Collaborations and Cross-border Pollution Management.

Since the Bay of Bengal is a common property, marine pollution cannot be addressed by the Bangladesh only. Monitoring and control of upstream river trans-boundary pollution is important and regional cooperation is important in controlling the pollution. Bangladesh ought to proactively participate in the regional organizations, that is, BIMSTEC, SAARC, and IORA and develop a collective marine pollution control system. It can also provide a "Bay of Bengal Marine Pollution Control Agreement" to encourage joint efforts such as marine protected areas (MPAs), oil spill contingency plans and cutback on waste among coast countries (Chowdhury & Karim, 2020).

Capacity Building and International Collaboration. Human resource limitation and technical knowledge restrict the capacity of Bangladesh to practice marine pollution control measures. Hence, specialized training in marine ecology, oceanography, maritime law and pollution response can facilitate the capacity building. It is possible to create training programs that should be provided to environmental officers, port authorities, coast guard officers, and other professionals in the maritime sector. Moreover, Bangladesh ought to solicit the services of international agencies such as the United Nations Environment Programme (UNEP), International Maritime Organization (IMO), and World Bank under the aspect of technical support, and funding. Scientific capacity to govern the marine environment may also be enhanced by linking with research institutions at local and international levels (UNEP, 2021).

Establishing Eco-Industrial Zones Near Coastal Areas. In order to reduce industrial pollution leakage into the sea, Bangladesh may encourage development of coastal urban Eco-Industrial Zones (EIZs). Some of the zones

would consist of the green infrastructure, Centralized Effluent Treatment Plants (CETPs), and circular economy practices, e.g. recycling waste between industries. EIZ promotes clean production, minimizes the impact of pollution by various factories, and facilitates environmental monitoring by clustering. Bright examples based in such countries as Vietnam and South Korea can be utilized as patterns (Hossain & Sultana, 2021).

Enacting a Comprehensive National Ocean Policy. The country of Bangladesh does not have one unified policy on the ocean in relation to control of marine pollutants and sustainable use of the oceans. An interdisciplinary National Ocean Policy may aid in the consolidation and integration of legal and institutional obligations that are disparate and do not fit with the sustainable development goals (SDGs), especially SDG 14 ("Life Below Water"). The policy ought to integrate marine spatial planning, regulation on pollution, conservation of biodiversity, and maritime industries in a systemic manner. This way, such a document would provide a long-term perspective on marine environmental governance, facilitate cross-sectorial integration, and inform the investment priorities (Bhuiyan, 2022).

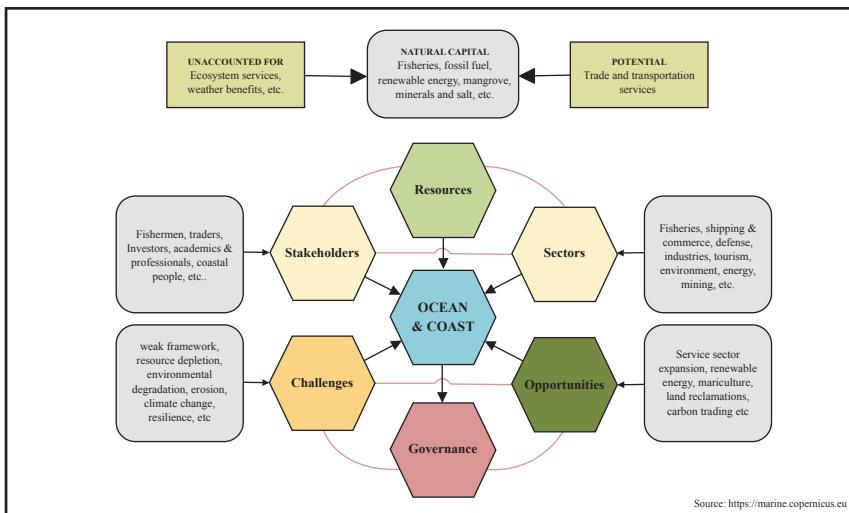


Figure 2: Ocean Governance Framework

Enforcement of Port Waste Reception and Management Facilities.

Large ports of Bangladesh such as Chattogram and Mongla have handled thousands of vessels every year which fill the port with oil sludge, bilge water, garbage, and sewage. Nonetheless, the available port-reception facilities are very poor and underutilized. These facilities may be enhanced in order to ensure

compliance with the MARPOL regulations through enhancing the infrastructure, making sure these facilities operate 24/7 and modernizing the system of tracking waste. Through this, illegal discharge of marine waters may be avoided and an environmentally friendly maritime transport will be enhanced (Islam & Tusher, 2023).

Introducing Environmental Risk Assessments (ERAs) to Maritime Projects. The majority of coastal developmental projects in Bangladesh including expansion of seaports, power plants & installations, and industrial plants are developed without consideration of an inclusive nature of the risks to the environment. ERAs can be required in all maritime projects to recognize the possible sources of pollution and address the mitigation measures when the project is developed. The government may formulate different ERA guidelines on marine ecosystems and establish an open review process by involving independent individuals (Mahmood & Hasan, 2022).

Tapping the Blue Carbon Ecosystems as a Method of Controlling Pollution. Blue carbon ecosystems - such as mangroves, salt marshes, and sea-grasses not only store blue carbon but also trap pollutants and filter sediments, provide shoreline stabilization. Bangladesh needs to make it a priority to restore and increase such ecosystems, especially Sundarbans and Saint Martin's Island, as natural buffers of pollution. Rewarding community-based afforestation schemes, as well as incorporating blue carbon in national climate plans will provide a natural solution to ocean pollution

Implementing “Pollution Taxes” on High-Risk Marine Activities. An environmental tax or pollution tax may be used as a deterrent against high marine pollution activities -like shipbreaking, trawler activities, and construction along coastline and may also be used as a source of revenue. Funds collected may be set aside in a Marine Environmental Protection Fund to undertake clean-up activities, scientific study and training local people. Norway and other countries such as New Zealand have successfully employed such fiscal tools and they could be applied to suit the conditions in Bangladesh (Ahmed & Rahman, 2022).

Promoting Green Shipping through Incentives and Regulations. The shipping industry of Bangladesh, especially the older ships, is a major cause of marine pollution resulting in oil spillages, discharges of ballast water as well as exhausts. Green shipping can also be promoted by ensuring that ships are upgraded in line with international feet with regard to emissions and waste emissions. This transition can be hastened by incentives of lower port tariffs on compliant vessels,

soft loans and even expedited clearance on vessels having eco-certification. The International Maritime Organization (IMO) green standards must be imposed with supervision on the part of the Department of Shipping (Chowdhury, 2021).

Utilizing Citizen Science and Community Reporting Apps. In environmental monitoring, citizen science has been realized to be efficient. Bangladesh may come up with mobile applications that the fishers, tourists, and coastal neighbors can use to report cases of oil spills, plastic clutter, or illegal dumps. Upon verification, such data can be fed into government databases and immediately prompt action. With the help of incentives and training programs, higher rates of participation could be ensured especially in the outlying coastal regions (Rahman & Saha, 2023).

Conclusions

The Bay of Bengal which is known as an ecologically rich and a strategic location continues to be the focal point of social and economic as well as regional environmental health of Bangladesh. Nevertheless, the coastal and marine ecosystem has been under serious threat due to the rising rates of marine pollution which affects millions of people. The sources of pollution that were present in the ocean over time include industrial effluents, untreated sewage, plastic wastes and agricultural runoffs, which have contributed to the noticeable loss as well as the long term ecological changes. These pressures have de-stabilized important ecosystems such as mangroves, estuaries, coral beds and sea-grass meadow destroying biodiversity and natural coastal defenses.

Also linked to these sources of pollution is degradation of coastal biodiversity. The most vulnerable include iconic and endangered species like Irrawaddy dolphin, olive Ridley turtles and the economically important Hilsa fish. Vegetation plant life such as mangroves and submerged aquatic vegetation has got stressed due to the contaminants, alteration of salinity and siltation. These deaths affect the supply chain of foods, decrease the resilience to climate-related risks and compromise fisheries among other nature-based livelihoods. Turning to the coastal belt in turn the community being vulnerable to disasters, food insecurity and loss of income are more intensified.

With the existing policy instruments, mitigation has not been possible due to the limitation in terms of enforcement, coordination and the institutional capacity. The fragmentation of implementation, and as well as the overlaps of jurisdiction have not resulted in meaningful change brought about by the Coastal

Zone Policy (2005), the Bangladesh Environment Conservation Act (1995) and the various laws on fisheries. Resource requirements, time lag in monitoring facilities, and unskilled manpower have been some of the common issues held by the environmental regulatory agencies. In addition, the implementation of coastal development activities is often conducted without proper environmental impact evaluation and thus becomes unsustainable in the long run.

It is also evidenced by the absence of any public awareness and participation of the stakeholders. The participation of society in the preservation of the marine and coastal environment is very low, even though these societies are directly affected by the natural resources. Low participation levels in conservation activities are related to poor understanding of the causes of pollution, lack of livelihood option, and the limited support by institutions. This is further enhanced by a failure of incorporating scientific findings into the process of local and national planning which brings about a gap between the knowledge and the policy actions.

There is an urgent need to change the situation strategically in order to revert the ecological deterioration and ensure marine biodiversity. Creating a centralized marine legal structure aimed at the management of marine pollution would centralize the existing initiatives and provide introductions to tentative accountability processes. Improvement of institutional capacity through specific training, investment in newer technologies of monitoring, as well as inter-agency coordination is necessary. An increased focus on coherent and responsive decision-making may be achieved through developing a more centralized coastal and marine governance body.

Financing clean infrastructure like green sewage treatment, better waste processing and clean ports would decrease pollution at point of origin. Agricultural and industrial runoff could be solved by promotion of organic farming and good regulation of aquaculture. Marine Protected Areas (MPA) where vulnerable species could be provided with protective places would create an incubator and promote the restoration of new habitats. Local communities must be enrolled in the conservation projects by offering incentives, participatory planning, and educational programs in an effort to develop stewardship on the lowest level.

It will help in the long term sustainability by paying further attention towards scientific research and data driven policymaking. Evidence-based governance will be achieved by incorporating Geographic Information Systems (GIS) and remote sensing and marine spatial planning. This might be filled by

partnership with academic institutions, non-governmental organizations and international agencies that might combine their capacities to create innovations. In addition, maintaining consistency of national plans with the international agenda like the Sustainable Development Goals (in particular SDG 14: Life below Water) will increase funding prospects and policy consistency.

The regional collaboration across the Bay of Bengal plays an important role too. Several of the marine pollution issues are trans-boundary in character with the necessity of coordinated tracking, information-exchange, and coordinated rules. The proper involvement in regional processes such as BIMSTEC and cooperation with neighbor countries in the mitigation of various types of pollution, biodiversity sustainability, and sustainable development of marine ecosystems can establish the stronger and more resilient Bay of Bengal region. Cooperation of such kind would not only lead to better environmental results but also help toward stability in geopolitics and in the economic development.

Coastal biodiversity preservation is a national mandate at Bay of Bengal. Not only is it important to keep marine ecosystems intact because of their inherent ecological worth, but also because of their absolute necessity in providing sustenance, food security and resilience to climate change. The political will, scientific progress, institutional reform, and general involvement of people will determine how these ecosystems are governed sustainably. An integrative, inclusive, and futuristic approach would align the ecological equilibrium, and, by doing so, make the blue economy the source of long-term prosperity and environmental security.

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