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COASTAL SUSTAINABILITY ASSESSMENT OF THE SUNDARBANS USING THE CIRCLES OF COASTAL SUSTAINABILITY (CCS) FRAMEWORK: A COMPARATIVE ANALYSIS BETWEEN INDIA AND BANGLADESH

Thesis in: **English**

Supervisor:	Presented by:	Co-supervisor:
Alice Newton	**Ankur Deb**	**Purvaja Ramachandran**

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STATEMENT OF ORIGINALITY

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(Ankur Deb)

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"The social sciences, like much of biology but unlike most fields of the physical sciences, have to deal with structures of essential complexity, that is with structures whose characteristic properties can be exhibited only by models made up of relatively large numbers of variables."

~ Friedrich August von Hayek

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Abstract

The Sundarbans, part of the Ganges-Brahmaputra-Meghna (GBM) delta, comprises one of the largest continuous tracts of mangrove wetland areas in the world and faces an increasing threat from environmental and socio-economic problems like climate change and loss of livelihoods. These issues weigh on the millions of people who depend directly or indirectly on the services provided by the delta. The complications are further magnified by the transboundary nature of governance in the region shared between India and Bangladesh. The Circles of Coastal Sustainability (CCS) framework was utilized to analyze the coastal system using the four interdependent boundary domains of Environment and Ecology, Social and Cultural, Economics, and Governance and Policy. The Indian, as well as Bangladesh side, scored an overall Satisfactory score. But on a country-scale comparison, India looked more vulnerable than Bangladesh due to its poor sustainability scores on environmental grounds. The sustainability statuses and management needs differ for different indicators, but in general, there were more areas of concern as opposed to areas of no concern. The identified pressures on the whole biogeographic system included lack of efficiency and accountability of the government, intensification of cyclones, sea-level rise, coastal erosion, high poverty, lack of dignified and sufficient work, and the lack of basic amenities. But further ground-based due diligence is necessary. On an indicator level, a comparative analysis between the two countries showed that India scored poorly for the Environment and Ecology and Social and Cultural domains as compared to Bangladesh. Whereas the opposite is true for the Economics and Governance and Policy domains. The nature of the ecosystem due to its presence as a single biogeographic entity presents a burning need for joint co-operation through transboundary governance. Building on the elemental sustainability scores and the data repository compilation for Sundarbans, this study can act as an excellent starting point to inform bilateral collaboration and more effective transboundary governance between the two countries in the future.

Keywords: Sundarbans, transboundary governance, Coastal Circles of Sustainability framework (CCS)

1 Introduction

This thesis document is in partial fulfillment of the requirements of the *Erasmus Mundus* Masters in Water and Coastal Management (WACOMA). It focuses on the sustainability and management of the Sundarbans, a coastal wetland that forms a transboundary governance between India and Bangladesh.

1.1 Background

A coastal zone is the interface between land and water which forms dynamic zones of interaction between them through geomorphological and oceanographic factors. These are low-lying areas formed due to sedimentation during the Holocene period. In accordance with Voigt (1998), a coast is defined as a region that is between 60 and 200 kilometers from the shoreline and may include mangrove forests, tide flats, marshes, coastal floodplains, beaches, dunes, and coral reefs. Coastal zones include the natural ecosystems and socio-economic systems most at threat from the impacts of global environmental change (Ramesh et al., 2015), and hence, require a wholesome understanding. Humans have always been attracted to coastal zones because of their rich resources and the wide variety of ecosystem services they provide- the services contributing about 2.5 trillion USD to the global economy per year (Hoegh-Guldberg, 2015). The coasts of the world were home to more than 726 million people (>10% of the total population) in 2008 (Mondal and Tatem, 2012). Estimates of the coastal population can vary depending on the definition of the coastal zone used by different authors. But there is a general trend of increasing urbanization and population growth in the world's deltas, barrier islands, estuaries, and other coastal ecosystems over the last decades (LOICZ, 2002; Nicholls et al., 2007; Valiela, 2006), and is projected to keep growing. In fact, eight of the top ten largest cities in the world are situated on the coasts (Ramesh et al., 2015).

Consequently, human pressures on the coastlines have disproportionately increased. Urbanization on the coasts has many consequences- for example, deforestation and reclamation of land for settlements, change in the natural drainage patterns of coastal wetlands, and discharge of untreated wastewater, fertilizers, and other contaminants into coastal waters from activities like agriculture and industry. Other pressures may be in the form of engineering structures, such as damming and

diversion of rivers for regulating discharge, building walls and other engineering structures for protection against extreme events, and extractive activities like unsustainable harvesting of fisheries and other resources (LOICZ, 2002). Human activities also disrupt ecosystem services of coasts by altering the freshwater, sediment, and nutrient delivery systems (Nicholls et al., 2007). Increasing anthropogenic pressures have led to a sustained global loss of coral reefs, mangrove forests, salt marshes, and seagrass meadows.

Hence, it has become increasingly important to monitor and study the sustainability status of these sensitive ecosystems and take strong mitigation and adaptation steps for their revival. Coral reefs account for over 60% of all published research on coastal ecosystems, compared to 11–14 percent for each of salt marshes, mangrove forests, and seagrass meadows (Duarte et al., 2008). Salt marshes, mangrove forests, and seagrass meadows are relatively understudied, in terms of their interactions with human populations and resiliency for change. In this study, the focus is on mangrove ecosystems, especially on the Sundarbans forests and the multitude of management pressures it faces.

Mangroves, sea grasses, and salt marshes have the capacity to sequester carbon dioxide from the atmosphere, which is also known more specifically as 'blue carbon'. However, recent studies and carbon inventories have shown that mangrove ecosystems are more efficient in storing large quantities of carbon in their biomass and soil. Projections have shown up to five times more effective and up to a hundred times faster sequestration by mangroves as compared to terrestrial forests (Howard et al., 2014; Nellemann et al., 2009; Van Bochove et al., 2014). Moreover, mangrove ecosystems provide a myriad of other essential ecosystem services as well (Mitch and Gosselink, 2000; Salem and Mercer, 2012). These ecosystem services can include a range of direct benefits to the coastal population like employment and income through commercial fisheries (Blaber, 2007); rich source of raw materials such as timber, fuel wood, honey, medicinal plants, etc. (Barbier, 2007); tourism opportunities as an ecotourism destination; mineral extraction; and provides nutrients for fauna by exporting organic matter to the marine environment (Salem and Mercer, 2012). Mangrove ecosystems also provide several indirect benefits such as shore stabilization and erosion control through retention of soil in their root structure (Gedan et al., 2011), and shoreline protection for regions prone to hurricanes,

tsunamis, and storm surges (Badola and Hussain, 2005; Chong, 2007; McIvor et al., 2012. Additionally, mangroves are a major source of transportation through inter-canal or inter-river navigational routes (Nellemann et al., 2009), water purification agents, alongside being potential sources of important chemical compounds for insecticides and pesticides, and medicines (Saranraj and Sujitha, 2015).

Approximately 150,000 sq. km of mangroves exist worldwide (Spalding et al., 2010), down from more than 200,000 sq. km in the 1970s (Spalding, 1997). Coastal mangroves remain one of the most threatened ecosystems on the planet, being lost at a rate greater than coral reefs and tropical rainforests (Van Bochove et al., 2014). For instance, more than 5,000 sq. km of mangrove forest area were cleared in the last century in the Sundarbans to make way for human settlement (Das, 2015). 41.4% of the world's mangroves occur in South and Southeast Asia (Spalding, 1997), but are disappearing at a fast pace. Sundarbans is one of the most important mangrove forest ecosystems in this part of the world which needs further in-depth analysis.

The Sundarbans is a tract of halophytic mangrove forest ecosystem covering an area of approximately 10,200 sq. km straddling the coastal portions of the two countries of India and Bangladesh. It is arguably the largest continuous single stretch of mangrove forest remaining in the world with about 60 percent falling in Bangladesh (around 6017 sq. km) and 40 percent (4200 sq. km) in India (Dasgupta et al., 2020; Sánchez-Triana et al., 2014) (figure 1). It forms part of the bigger Ganges Brahmaputra Meghna (GBM) delta as the unique ecosystem of Sundarban receives freshwater flows from the tributaries and distributaries of the major rivers of Ganges, Brahmaputra and Meghna, and saline water from the Bay of Bengal. This results in the formation of a marginal to saline intertidal hydrological system environment which houses diverse plant and wildlife assemblages, and fisheries (Nishat et al., 2019). The Sundarbans holds international importance for its high biodiversity of flora and fauna that includes 528 species of vascular plants, 42 species of mammals, more than 300 species of birds, 58 reptiles, 9 amphibians, more than 320 species of fish, numerous species of insects, crustaceans, invertebrates, and mollusks, and diverse phytoplankton, fungi, bacteria and zooplankton (Habib et al., 2020; Danda et al., 2017; IUCN, 2015; Rahman et al., 2015; Sarkar et al., 2020; Sievers et al., 2020). It

also hosts many ecologically and economically important species of mangroves like *Heritiera, Excoecaria, Aegiceras*, *Rhizophora,* etc.

However, the Sundarbans stands at the forefront of climate change and the coastal population is exposed to climate hazards, including sea-level rise due to rising water levels and delta land subsidence (Akter et al., 2019; Becker et al., 2020; Brown and Nicholls, 2015; Sánchez-Triana et al., 2014), intensification of tropical cyclones accompanied by storm surges (Hazra, 2010; Sahana and Sajjad, 2019; Sahana et al., 2021), coastal and riverbank erosion (Ferdous and Rahman, 2019; Hasan et al., 2021; Kundu and Halder, 2018; Nishat et al., 2019), salinity intrusion and exposure due to seasonal low flow levels in rivers and upstream water diversion (Nishat et al., 2019), and arsenic contamination of drinking water (Nath et al., 2021; Ramesh et al., 2019). From the socio-economic perspective, the population living around the Sundarbans and dependent on its resources suffer from severe poverty. The average per capita income in the Indian part is USD 0.5 (Sánchez-Triana et al., 2014) per day and USD 0.9 per day in Bangladesh (Nishat et al., 2019). There are limited employment opportunities for the people. Agriculture (predominantly paddy crop) is the main economic activity, yet productivity and income levels through agricultural activities remain low due to factors like soil salinity, lack of freshwater availability, fragmentation of landholdings, etc. There is a high gender disparity in yearly livelihoods among men and women (Dasgupta et al., 2020). The literacy rate in the Indian part stands at 64% (Census of India, 2011) while it is 59% in the Bangladesh part (BBS, 2012). The socio-economic condition of the Sundarban-dependent people is further worsened by poor health conditions, inadequate water supply, and sanitation, absence of electricity in many places, and unreliable river-based transportation (Nishat et al., 2019; Dasgupta et al., 2020).

A review of the literature reveals the geographical limitations of previous studies, often restricted to a few mouzas, blocks, districts, or specific areas with available datasets, all within the boundaries of a country. There are a few country-wide analyses, alas very limited in their scope or management focus. The coverage of the aspects of the Sundarbans are ample- including biodiversity, spatial analyses, hydro-morphology, cultural history, social development, livelihoods, resource utilization, and policy. But there is a scarcity of attempts to understand the whole ecosystem of Sundarbans in its entirety. This is especially important for the

sustainability-based management studies of the ecosystem. Nishat et al. (2019), in their World Bank report, comprehensively studied and compiled all the scattered information about the two ecosystems of the two countries into a single report. This study, using the Circles of Coastal Sustainability (CCS) framework (developed by Alencar et al., 2020) as a science communication tool, attempts to gauge the variety of factors in the environmental, social, economic, and governance domains separately and score the overall sustainability of this mangrove ecosystem based on inter-linked indicators. Through country-specific investigations, the study also delves deeper to do an inter-country comparative analysis between India and Bangladesh with the aim to identify areas of concern and no concern for management focus.

1.2 The complexity of Sundarbans

The Sundarbans ecosystem is considered among the seven most globally important wetlands of the world (Nishat et al., 2019). Geographically, the undivided Sundarbans stretch extends approximately 260 km west-east along the Bay of Bengal from the Hugli River in India to the western segment of the Baleswar River in the Meghna River estuary in Bangladesh. Although it is celebrated for its rich ecological attributes, the Sundarbans are also threatened by multiple factors which are a combination of both, natural and human factors. Based on estimates, more than 40 percent of vertebrate species in the Sundarbans are at risk of extinction due to habitat loss itself, like the Bengal tiger and Gangetic dolphin (Sarker et al., 2016). The Sundarbans region suffers from coastal erosion in the whole southern part with maximum rates reaching 40 m/year in the west-central regions (Bandyopadhyay, 2019), predicted to increase and become the dominant loss driver in mangrove area by 2100 (Payo et al., 2016). Coastal erosion is caused by net sea-level rise (SLR) which has been increasing over the last 45 years (~3 mm/year) as compared to the global mean sea level (~2 mm/year) (Becker et al., 2020). Analyses of cyclonic events over the Sundarbans in the last 120 years also indicate a 26 percent rise in the frequency of high to very high-intensity cyclones (Singh and Singh, 2007).

The Sundarbans represent one of the most complex ecological and socio-political landscapes to manage. The mangrove forest ecosystem of the Sundarbans has often been seen as two separate ecosystems, ecologically, socio-economically, and

politically due to the presence of an international border shared between India and Bangladesh. Historically, the Sundarbans used to be a part of India as a whole and was managed as a single entity. But in 1971, during the partition of Bangladesh and West Bengal (India), the mangrove forest also got divided resulting in an artificially separated ecosystem. As a result, each country has its own set of laws and regulations concerning matters ranging from conservation to coastal issues to centralized schemes for socio-economic development to achieve objectives of the part of the forest which lies under their respective side of the borders.

There is recognition of Sundarbans' unique biodiversity, ecological importance, and the socio-economic dependency of its population. This has attracted conservation obligations under international conventions, treaties, and national laws. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) declared the critical parts of the forests of India and Bangladesh as World Heritage Sites in 1987 and 1997, respectively (Dasgupta et al., 2020). These are referred to as the Sundarbans West (Bangladesh), Sundarbans South (Bangladesh), Sundarbans East (Bangladesh), and Sundarbans National Park (India). The region is also internationally recognized and formalized under the Ramsar Convention as a Ramsar wetland. There are three national laws where the Governments of Bangladesh and India are committed not to allow hydrocarbon exploration, unsustained resource exploitation, and industrialization (source of pollution) in and around the Sundarbans. The Wildlife Preservation Act of 1974 to conserve animals and trees, the Forest Policy of 1994, the Forest Act of 2000, the Social Forestry Rules of 2004 and 2010, and the Bangladesh Wildlife Act of 2012 which prevents the killing or capturing of wildlife are some of the examples of management through national policy in Bangladesh. In the case of India, some of the national policies include the Wildlife Protection Act of 1972 which declares national parks and sanctuaries within the forest, and prohibits hunting and poaching of wild animals, and the Forest Conservation Act of 1986 which rules out the different types of pollutants, the Coastal Regulation Zone Notification (CRZ) of 1991 which regulates shrimp culture, and the West Bengal Marine Fishing Regulation Act of 1993 which regulates marine fishing.

The poor socio-economic status of the population, impending climate change risks, unregulated drives towards commercialization of natural products, and insufficient institutional coordination and capacity has led to inadequacy in the management of

the Sundarbans (Nishat et al., 2019). India and Bangladesh share some common challenges such as poverty and human development issues born out of poor health conditions, education levels, employment opportunities, inadequate infrastructure, and inadequate capacity of governments and communities. But each country also has its own individual set of specific challenges observed by following the focus and direction of national laws and policies. In Bangladesh, planning has typically focused on the physical resource, its status, and extent through management and conservation of the delta (IUCN, 2014a; IUCN, 2014b). There is very limited coverage of socio-economic issues of the forest-dependent people. On the contrary, in West Bengal, India, the Biosphere Reserve area includes the inhabited parts, and the programmes are aimed towards the interlinkages and dependency of the people on the forest resources. Indian decision-makers focus on community well-being, ecosystem conservation, and phased out-migration (Danda et al., 2011; Nishat et al., 2019).

This raises questions about the joint and country-specific sustainable management of the region. The divided governance presents more challenges as compared to benefits. One change or decision on one side of the border can reverberate into the other side due to the inter-linkedness of the ecosystem and lack of cross-communication. For example- the opening of the Farakka dam in West Bengal disrupted the freshwater flow to Bangladesh, impacting its agricultural and industrial production, fishing and navigation, human health and wellbeing (Bharati et al., 2011; Kawser and Samad, 2016). Some of the early joint actions include a five-year Memorandum of Understanding (MoU) on conservation of the Sundarbans where both countries agreed to conserve the biodiversity, particularly the Tiger; institutional mechanisms to deal with bilateral issues like the Joint Rivers Commission (JRC) and Joint Economic Commission (JEC), etc. (Nishat et al., 2019). But actions have been limited and the Sundarbans represent one of the least integrated parts of the world with regard to policy, trade, and infrastructure. Therefore, the shared region presents a strong opportunity for strategic cooperation, coordinated actions, and directional management between the two countries.

Delineating the areas of no concern and areas of concern, including all the different sustainability levels, might act as the first step towards a plan formulation. The Circles of Coastal Sustainability (CCS) is a holistic framework for socio-ecological

systems developed to assess the sustainability of the world's coastal zones at multiple scales based on indicators. CCS overcomes the criticisms associated with other coastal management frameworks through the utilization of four interdependent boundary domains for coastal quality: Environment and Ecology, Social and Cultural, Economics, and Governance and Policy, improving its usability for decision-makers and researchers. It was developed to be used in geographically different environmental contexts with pilot studies conducted in Spain (Alencar et al., 2020), south of Portugal, northeast England (Bryant and Elliott, 2021; unpublished report), and Arctic Canada. But the framework has neither been tested in a developing country context nor a transboundary region. This study attempts to utilize this framework to identify the unsustainable parts of this complex ecosystem on both sides of the border using the same indicators. The main sources of data have been derived from available literature and secondary sources like research papers and reports.

1.2.1 System definition and boundaries

This study considers the natural (uninhabited) area as well as the inhabited area where the population is directly or indirectly dependent on the resources from the Sundarbans forests. These people live on reclaimed land historically converted from mangrove forests. The area for the system is selected the same as that considered in the World Bank report (Nishat et al., 2019) for their study (figure 1). The total area of the system considered in the study covers a much larger area than the standalone mangrove forests due to the governance regime areas and resource dependency pattern of the local population.

On the Bangladesh side, the study area consists of the 6017 sq. km mangrove forest area protected as a reserve forest declared during the British period in 1875, also known as the Sundarban Reserve Forest (SRF), plus the area surrounding the periphery of the SRF with a 20 km wide radius called the Sundarban Impact Zone (SIZ) where the population dependent on the Sundarbans resides (IUCN, 2014b) (Figure 1). The SIZ also consists of the 10-km wide buffer zone of the Ecologically Critical Area (ECA) surrounding the northern and eastern boundaries of the SRF declared by the Environmental Conservation Act of 1995 with an approximate area of

1750 hectares. In the ECA, exploitation of natural resources is strictly regulated and resource procurement is done through permission from higher bodies. The population size living in the SIZ area is 2.7 million people (BBS, 2012). There are no settlements inside the Bangladesh Sundarban Reserve Forest (SRF). The Reserve Forest consists of six Wildlife Sanctuaries: Sundarban East, Sundarban South, and Sundarban West Wildlife Sanctuaries established in 1977, covering an area totaling 324 sq. km, and the three river areas of Chandpai, Dudhmukhi, and Dhangmari Wildlife Sanctuaries, established in 2012 for the protection of dolphins, covering a total area of 10.7 sq. km. The 20 km periphery of the inhabited Sundarban Impact Zone (SIZ) comprises parts of twenty Upazilas (sub-districts) belonging to five districts (Barguna, Pirojpur, Bagerhat, Khulna, and Satkhira).

On the western side of the international border, the Indian part of the study region is called the Sundarban Biosphere Reserve (SBR). The Biosphere Reserve in West Bengal was defined by the Ministry of Environment and Forests, Government of India (GoI) in 1989 consisting of a total area of 9630 sq. km. of the Ganga delta. The northern limits of the SBR is demarcated by the Dampier Hodges line of 1829-1830 (Danda et al., 2011). The Reserve includes approximately 4,260 sq. km of reserve forests and the rest is occupied by Sundarbans-dependent settlements and agricultural lands. A total of 4.5 million people live in this region (Census of India, 2011) with a population density of 1089.2 people per sq. km (Sanchez-Triana et al., 2014). The Indian Sundarban Biosphere Reserve is divided into three zones (Figure 1)-

1) The Core Zone is made up of protected areas that encompass around 40 percent of the reserve forest area, or about 1700 sq. km. This contains a 1330 sq. km National Park and 406 sq. km Sajnakhali, Lothian Island, and Holiday Island Wildlife Sanctuaries. It is a strictly no-entry zone with a focus on biodiversity conservation, bordered on the west by the Matla River and on the south by the Bay of Bengal.
2) Buffer Zone- It includes parts of the tiger reserve and the Sajnakhali Wildlife Sanctuary and borders the core zone from above. This is the sole zone where subsistence activities like fishing, crab, shell, and prawn seed collecting are permitted, but only with West Bengal Forest Department authorization.

3) Transition Zone- It is made up of reclaimed land where the Biosphere Reserve's population lives in an area that is currently used for settlements and agricultural grounds. This zone includes six administrative blocks in the North 24 Parganas district (Hingalganj, Hasnabad, Haroa, Sandeskhali - I, II, Minakhan) and thirteen blocks in the South 24 Parganas district (Canning - I, II, Basanti, Gosaba, Jaynagar - I, II, Mathurapur - I, II, Kultali, Patharpratima, Kakdwip, and Nam.

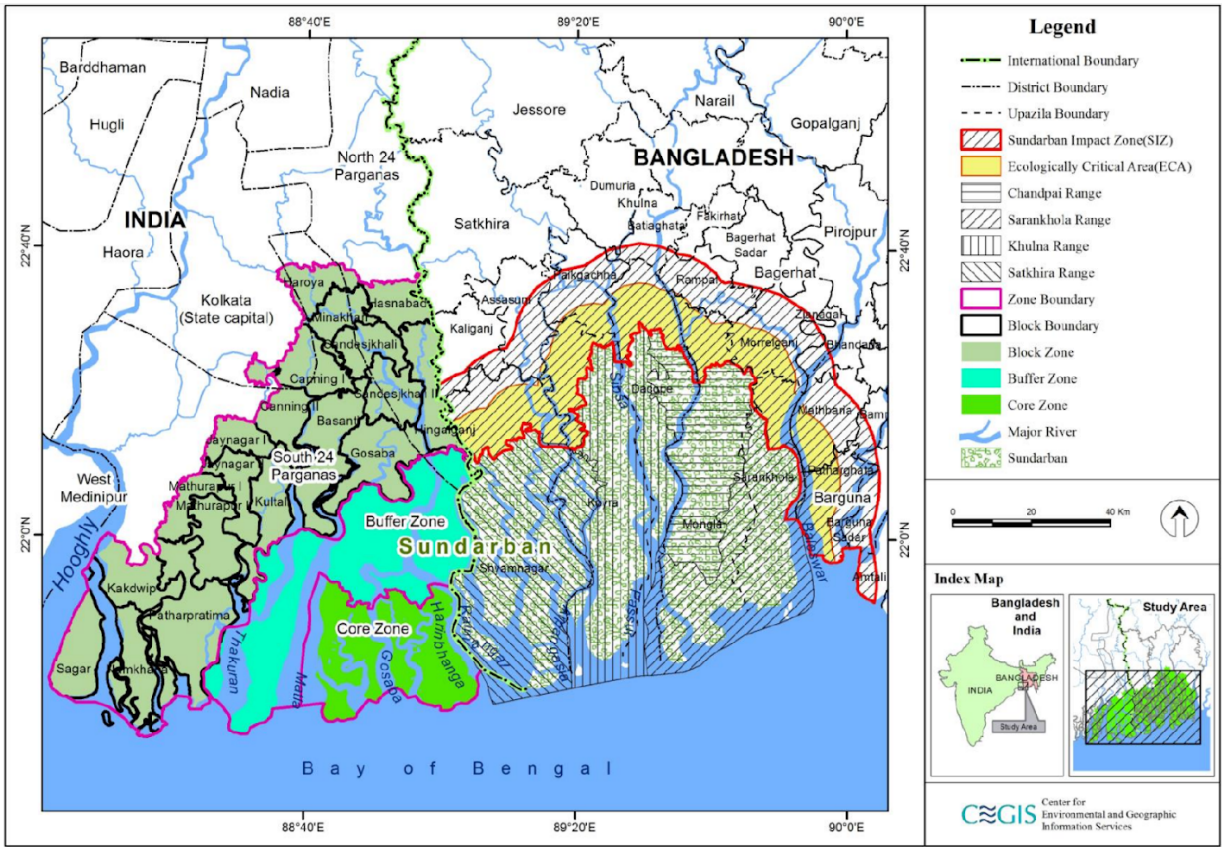


Figure 1- *The Sundarbans region and its land divisional arrangement for India and Bangladesh (from Nishat et al., (2019))*

1.3 Why is this study important?

The Sundarbans is a valuable ecosystem due to the plethora of ecosystem services it provides. According to studies, the Sundarbans mangroves generate services worth 456.32 USD to 1191.84 USD per hectare (ha) per year in Bangladesh (Haque and Aich, 2014), and the Sundarban Tiger Reserve in India delivers flow benefits worth 732 USD per ha per year (Verma et al., 2015). Valuation of ecosystem services

can play a significant role in policy formulation. But it doesn't consider the current status or the future direction of sustainability of the ecosystem. Understanding the sustainability status becomes important for reassessing valuation estimates and improving decision-making (Bherwani et al., 2020). There have been no documented frameworks implemented to evaluate the overall sustainability status of the Sundarbans as a whole. Through the use of CCS, this study establishes sustainability scores for the Environment, Social, Economic, and Governance domains of the system.

The Sundarbans is important for the local people, as well as for the fight for regional and global climate adaptation and mitigation measures. The net biosphere-atmosphere exchange of carbon in the Sundarbans has been estimated at 2.79 tonnes per ha per annum (Verma et al., 2015). As a result, they have been gaining global attention over the past few decades. It is a known fact now that climate change is going to reshape the global map due to coastal erosion and sea-level rise. But the impact will be disproportionately felt by developing countries and the coastal population living on low-elevation land (Ramesh et al., 2015). All the above criteria are fulfilled by the Sundarbans, and it forms a deadly cocktail of impending devastation from climate change in the future. The Sundarbans are sinking (Payo et al., 2016), and time is running out to take constructive actions. More than 7 million people living in the coastal region are reliant on the Sundarbans for their lives and livelihoods. This study is an attempt to compile a comprehensive dataset and a list of sources of literature covering the various aspects of sustainability for the Sundarbans (Annex I and footnote). Due to the lack of centralized repositories, there is always a gap between science and policy. This study tries the bridge the gap on the back of data-driven coastal sustainability analyses. The usage of CCS here aims to capture all the nuances associated with coastal-specific sustainability issues.

Another gap in the literature is the lack of comprehension of how interrelated the two artificially separated ecosystems of India and Bangladesh are. The gap is further expanded by both- negligent bilateral collaboration in the past, and the lack of plans to take meaningful steps towards better-integrated management in the future. Both the governments have shown good intentions towards meaningful partnerships to save the natural resources of the ecosystem through MoUs and trade pacts like Protocol on Inland Water Transit & Trade (PIWTT) but they have been fraught with

inaction and further due diligence. The backbone of this research involves an inter-country comparison to establish a holistic know-how of the similarities and differentiators between the sustainability statuses of the two countries. The end practical goal of this study is the integrated data-backed directional management of the Sundarbans through better collaboration and joint decision-making.

A spreadsheet consisting of the complete list of indicator-based analyses for the various sub-categories, categories, and their respective domains have been compiled. The spreadsheet contains a detailed analysis of these indicators and also includes notes on how each one has been scored. The list of sources/literature used is not exhaustive but might serve as an excellent starting point for future studies on the Sundarbans. It can be complemented with more on-ground bottom-up studies. The sheet can be accessed from here- https://bit.ly/3b57DUh (refer to Annex I and/or footnote).

2. Scope of Research

The Sundarbans is an ecologically sensitive ecosystem with impending threats from climate-change induced sea-level rise (Brown and Nicholls, 2015), increase in sea surface temperature (Hazra, 2010), coastal erosion (Nishat et al., 2019), and intensification of cyclones (Bandyopadhyay, 2019). More than 7.2 million people living in the region are directly or indirectly dependent on resources from the Sundarbans (Dasgupta et al., 2020; Sanchez-Triana et al., 2014). Additionally, the Sundarbans represent one of the most complex ecological and socio-political landscapes due to the transboundary governance between India and Bangladesh. It is well identified that Bangladesh and India must create conservation measures in a coordinated and cooperative manner (Nishat et al., 2019).

This study has the following objectives-

1. To assess the feasibility of CCS to be used to study the coastal environment of the transboundary nature of the Sundarbans
2. To create a data repository of literature sources covering all aspects of the Sundarbans ecosystem- Environmental, Social, Economics, and Governance.
3. To understand the effect of transboundary governance between India and Bangladesh on the sustainability of the Sundarbans

The aim of the study consists of-

Contribution to the global assessment using the CCS framework in a transboundary and developing country context for the Sundarbans.

The study has the following hypothesis-

The sustainability status of Sundarbans can be assessed on the basis of available secondary qualitative and quantitative literature for the defined elements of the Circles of Coastal Sustainability framework.

3. Methodology

There are multiple frameworks existing in the literature to assess issues like sustainability (James et al., 2015), human well-being (Raworth, 2012), or management-specific issues like marine litter (Mathews and Stretz, 2019). The DPSIR (Drivers–Pressures–State–Impact–Response) or the newer DAPSI(W)R(M) (where W refers to Welfare and M refers to Measures) framework links the socio-ecological system and the natural system for integrated marine management (Elliott et al., 2017). The Systems Approach Framework (SAF) encompasses the ecological, social, and economic components of coastal zones for integrated coastal zone management (McFadden et al., 2010). Ostrom's framework uses a generalized framework to analyze the sustainability of socio-ecological systems through an understanding of the mechanisms leading to improvement and deterioration (Ostrom, 2009).

But these frameworks either have very specific management focus hampering their utility, or they exclude one or most of the aspects of an ecosystem including the environmental, social, economic, and political elements (Alencar et al., 2020). There is a tendency for the majority of the frameworks to use an environmental focus, whereas very few of them include the policy aspect. For example, in the Large Marine Ecosystems (LME) framework, Mahon et al. (2009) noted the tendency for an indicator bias within the framework where the environmental or 'natural science' module received more attention than others. The Ocean Health Index (Halpern et al., 2015) does not include the governance and policies for analysis of the coastal zones. This study exclusively uses the Circles of Coastal Sustainability framework.

3.1 Circles of Coastal Sustainability (CCS) framework

The Circles of Coastal Sustainability (CCS) framework was developed by Alencar et al. (2020) as a science communication tool to rate the sustainability of coastal regions. It is a one-of-a-kind sustainability framework that also incorporates international policy goals such as the Sustainable Development Goals (SDGs), Aichi biodiversity targets, etc. The CCS framework aims to provide an unbiased overview of coastal sustainability rather than a singular view on one sector of coastline quality,

which has often been cited as a reflection of the non-holistic approach of current frameworks in use (Leach et al., 2013; Raworth, 2012). The specific focus of the framework also keeps a check on reducing the usage of indicators that might not be relevant to a coastal ecosystem.

The Circles of Coastal Sustainability framework is based on the Circles of Sustainability framework which has been used for urban planning of cities like Melbourne in Australia and New Delhi in India (James et al., 2015). The CCS framework has been adapted for use in coastal regions. CCS is built upon the concept of a 'dashboard', which is common to other frameworks like Planetary Boundaries (Rockström et al., 2009) and Ocean Health Index (OHI) (Halpern et al., 2015). The framework incorporates the 'triple bottom line' of sustainability including economic, social, and environmental elements of sustainability (O'Connor, 2006), and adds the politics and governance system into the mix. The CCS framework acknowledges the impossibility of assessing environmental issues without considering other spheres that it interacts with, such as the social, political, and economic spheres. This results in the formation of four independent boundary domains for the CCS: (i) Environment and Ecology (figure 2); (ii) Economics (figure 3); (iii) Social and Cultural (figure 4); and (iv) Governance and Policy (figure 5), with equal weighting. These domains form the basis of the framework and are used to cover all aspects of coastal quality as well as to meet the agenda of the Sustainable Development Goals, Paris agreement, Aichi biodiversity targets of the Convention on Biological Diversity (CBD) agreement. It envisions a global coast that will be sustainable in the long term and that nurtures socioeconomic and environmental growth equally.

Each domain of the framework is divided into five categories, which are further distributed amongst sub-categories. The sustainability of the various aspects of the region is based on finding the most appropriate indicator for each sub-category and scoring them. The context for each domain is further explained below.

3.1.1 The CCS Framework skeleton

I. Environment and Ecology domain

To assess the sustainability of the various aspects of the Environmental and Ecology domain, the following categories and their sub-categories have been considered. Consult figure 2 for the complete skeleton diagram.

1) Alteration of landscapes: Land, Sea and Shoreline
2) Ecosystem function: Biodiversity loss and Ecosystem services
3) Global environmental change: Sea level rise, Sea surface temperature and Coastal flooding
4) Shifts in hydrodynamics: Waves and Tides
5) Biogeochemical and physical flows: Nutrient leak, Pollution and contamination, Carbon, Freshwater cycles and Sediment cycles

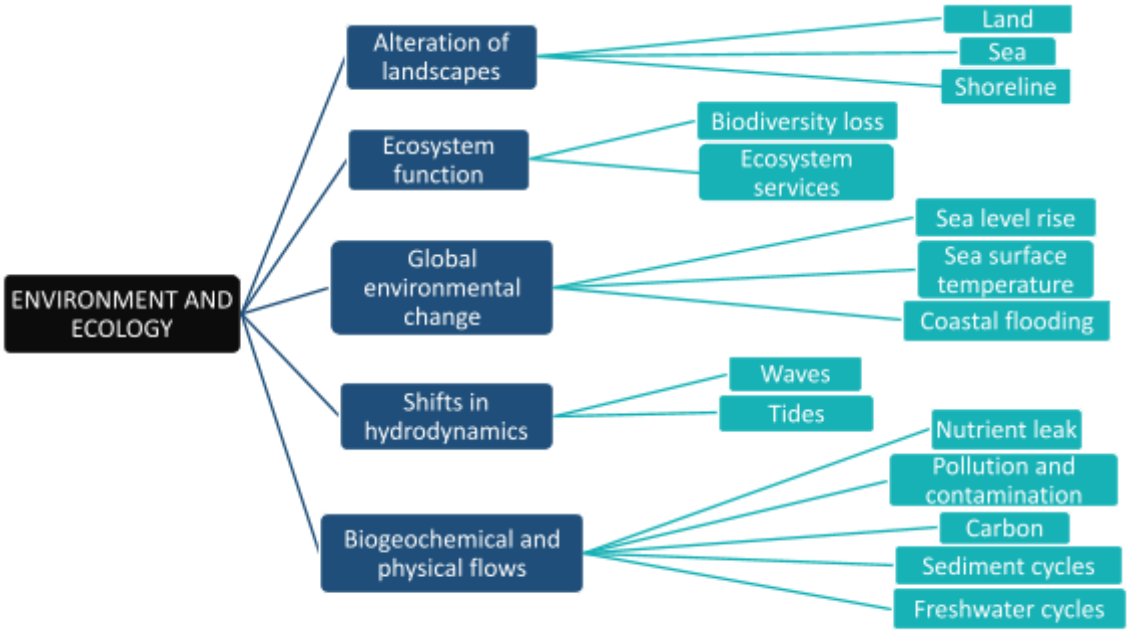


***Figure 2**- Environment and Ecology domain categories (in dark blue) and sub-categories (in light blue) (modified from Alencar et al., 2020)*

II. Social and Cultural domain

To assess the sustainability of the various aspects of the Social and Cultural domain, the following categories and their sub-categories have been considered. Consult figure 3 for the complete skeleton diagram.

1) Societal benefits: Goods and services and Water quality

2) Demographics: Population/Age/Structure/Trends, Migration and Immigration and Social class
3) Social wellbeing: Recreation and access, Food and water security and Health
4) Identity: Sense of place and Sense of self
5) Social resilience: Vulnerability and Education

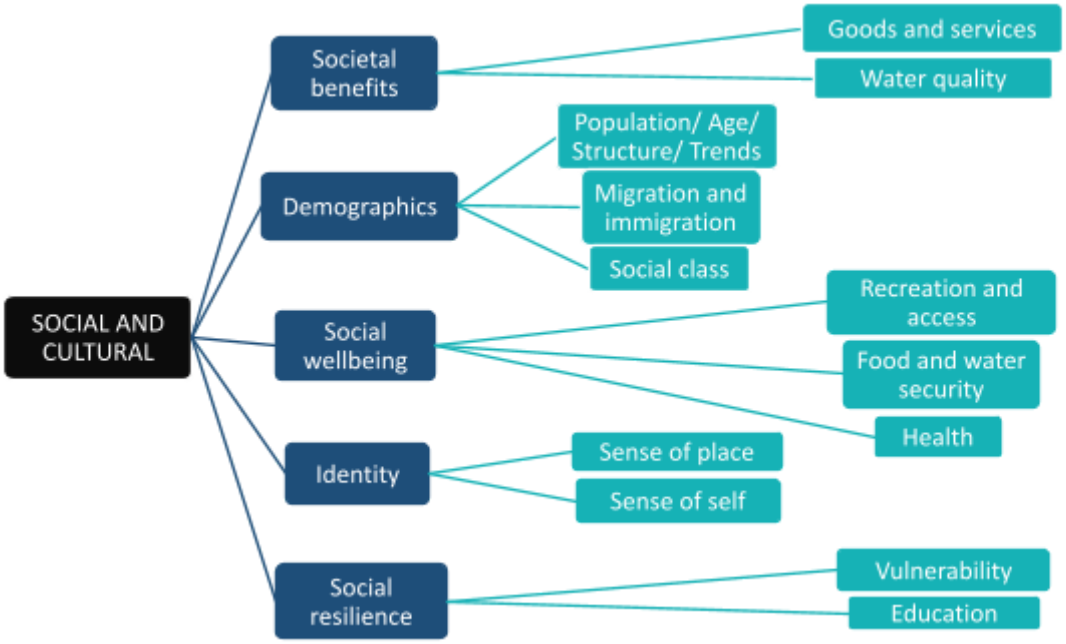


Figure 3- *Social and Cultural domain categories (in dark blue) and sub-categories (in light blue) (modified from Alencar et al., 2020)*

III. Economics domain

To assess the sustainability of the various aspects of the Economic domain, the following categories and their sub-categories have been considered. Consult figure 4 for the complete skeleton diagram.

1) Security: Livelihoods, Gender and Employment patterns
2) Infrastructure: Energy supply, Tourism, Transport and Access
3) Economic well-being: Equality, Income and Housing
4) Industry: Renewable sources and Extractive sources
5) Dependency: Dependency on coastal resources and Diversity of activities

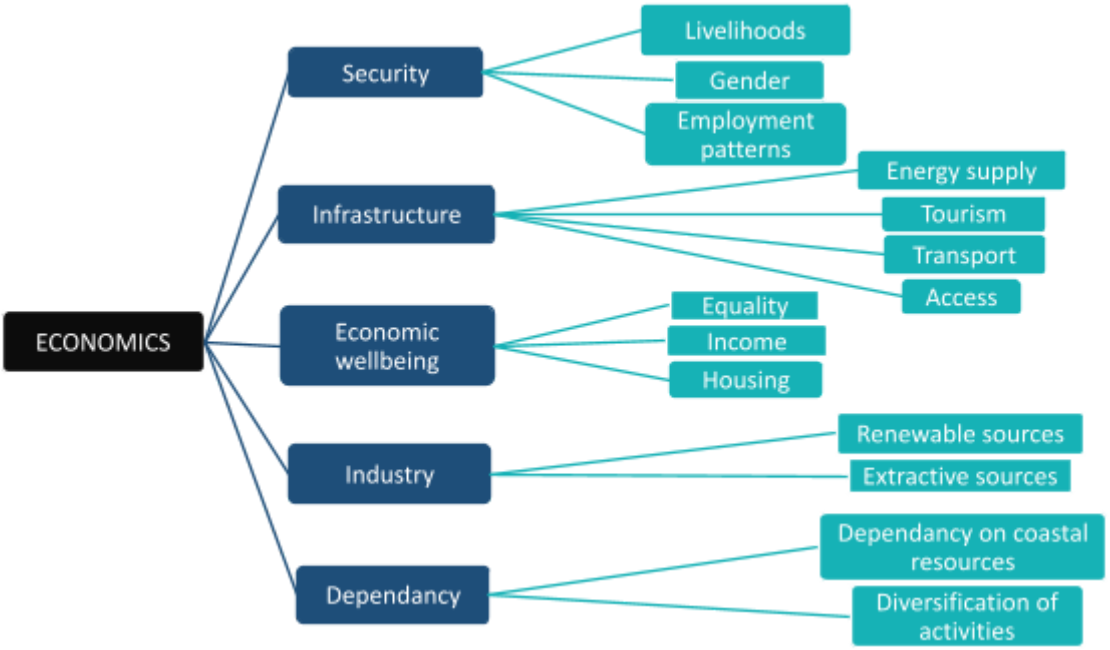


Figure 4- *Economics domain categories (in dark blue) and sub-categories (in light blue) (modified from Alencar et al., 2020)*

IV. Governance and Policy domain

To assess the sustainability of the various aspects of the Governance and Policy domain, the following categories and their sub-categories have been considered. Consult figure 5 for the complete skeleton diagram.

1) Organization: Civil and NGOs
2) Law and justice: Legislation, Efficacy and Enforcement
3) Representation and power: Effectiveness
4) Legitimacy and accountability
5) Resource management: Plans and Management

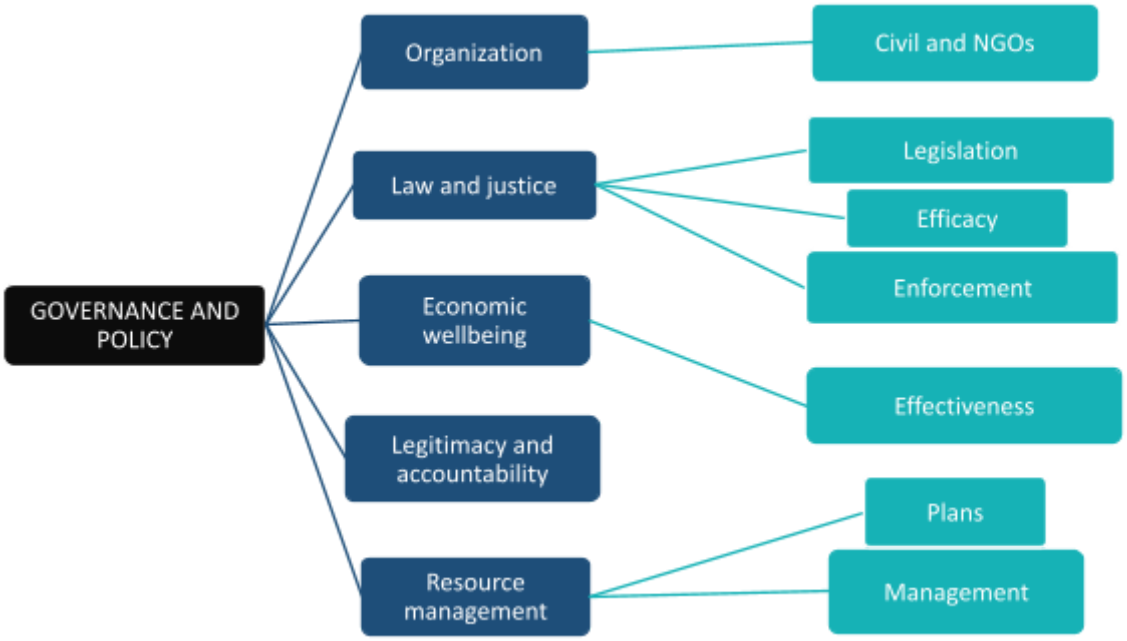


Figure 5- *Governance and policy domain categories (in dark blue) and sub-categories (in light blue) (modified from Alencar et al., 2020)*

3.1.2 The communication of CCS Framework

The actual utility of the domains, categories, and their sub-categories is derived from a set of qualitative or quantitative indicators, assigned specifically to the study region needs that lead to meaningful management actions for sustainability. The criterion of selection is dependent on the availability of data to support them and the ease of communicability of the information to managers, government agencies, and other stakeholders. The same indicators are used for both the countries for doing a fair comparison.

A 5-degree scoring system is followed to rate the sustainability levels: “Excellent” sustainability means 1 point and is colored Dark green; “Good” sustainability means 2 points and is colored Light green; “Satisfactory” sustainability means 3 points and is colored Yellow; “Poor” sustainability means 4 points and is colored Orange; “Bad” sustainability means 5 points and is colored Red (adapted from Alencar et al., 2020). Originally, the 5-degree color system of the CCS was based on the Water Framework Directive (Chave, 2001), and the CCS’ inside-out scoring followed the Planetary Boundaries mechanism (Rockström et al., 2009)- the further away from the center,

the poorer the sustainability. Here, the scoring has been adapted to show the level of sustainability only based on color, irrespective of the distance from the center. This is done to improve the visual output allowing for better scientific communication. Figure 6 shows the visual representation of the framework. All the indicators have the same weighting. An averaging method in the form of arithmetic mean is utilized for each category as well as the domains to attribute scores where the number of indicators are more than one for a category and for the five categories within each domain. Arithmetic averages allow perfect 'compensability' between indicators and have also been used to build the commonly used SDG framework index (Papadimitriou et al., 2019). An average score ending with .5 is bumped up to the next closest integer.

For the study region of Sundarbans, the scoring has been done based on available literature and guidance from local experts taking into consideration:

- Past activities that have caused changes or affected the current status

- Recent activities that try to worsen/manage/improve the condition

- The future direction it is headed based on literature and local expert guidance

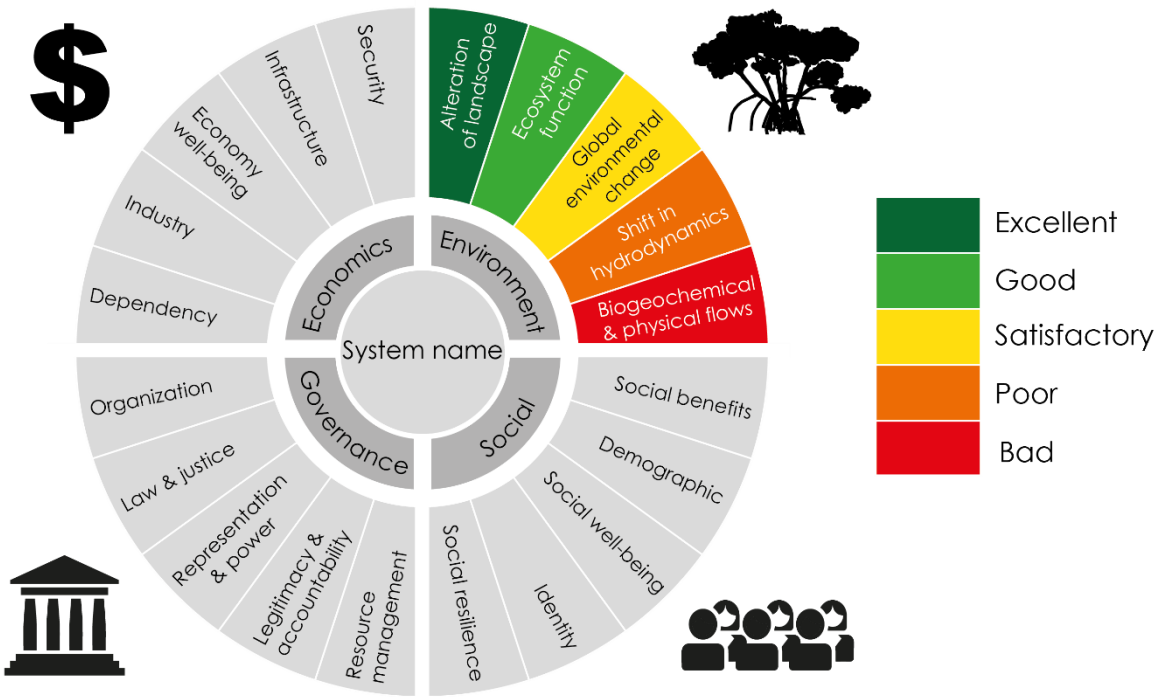


Figure 6- *Graphical representation of the Circles of Coastal Sustainability (CCS) framework (adapted from Alencar et al., 2020)*

3.1.3 Indicators used and their sources

Indicators at sub-category level for the domains of the CCS framework were assessed using data gathered from sources as cited in Tables 1, 2, 3, and 4 (Annex II) for Environment and Ecology, Social and Cultural, Economic and Governance and Policy domains respectively. The indicators used are the same for both countries to facilitate a fair comparison of the sustainability status of each sub-category and category. The chosen indicators are Sundarbans region-specific, and the sources used are mostly reports and published scientific papers. There is a scarcity of availability, accessibility, and the breadth captured by centralized information like census reports, government databases or surveys for both sides of the border in this region- something which needs to be addressed in the future.

4 Results

4.1 Overall sustainability

The averaged category-based sustainability scores of the CCS output for the Sundarbans is summarized in Table 5. The detailed analysis-based scoring can be consulted on the Google sheets, attached as a footnote and in Annex I. Figure 7 displays the CCS sustainability representations for India (Figure 7A) and Bangladesh (Figure 7B). Visually, the areas of concern (red and orange colors) and no concern (dark green and light green) can be easily identified in table 5 and figure 7. On initial observation, the quality of the coastal regions of both countries looks far from sustainable and there is a need for management intervention in most aspects of the ecosystem. None of the categories under any domain scored excellent (dark green color or a score of 1). This indicates at least some work is required in all domains of the framework for a shift towards a better future resilience of the system against the persistent pressures.

Based on the analysis, the least sustainable state was observed in the category of global environmental change (Table 5). It is an area of concern as the Sundarbans region faces threats from sea level rise (Payo et al., 2016), increasing sea surface temperature (Hazra, 2010), and increasing frequency of coastal flooding with the growing intensity of cyclones (Sahana et al., 2021). From a holistic outlook, India fared poorly as compared to Bangladesh in terms of an overall sustainability score because of a poor sustainability state in the Environment and Ecology domain (Figure 7). The Sundarbans are eroding and sinking, albeit at different rates in different sections. The western side, belonging to India, is facing the brunt of this impact as observed by multiple authors (Bandyopadhyay, 2019; Ferdous and Rehman, 2019; Kundu and Halder, 2018). The Indian side has also been experiencing higher salinity exposure due to the loss of connection of rivers flowing through the Sundarbans with the upstream rivers Damodar, Bhagirathi, etc. (Islam and Gnauch, 2011; Nishat et al., 2019). The implications are obvious- the biodiversity and ecosystem services that support the lives and livelihoods of coastal dwellers are at stake. The time frame for policy and action is only about three generations before 2100.

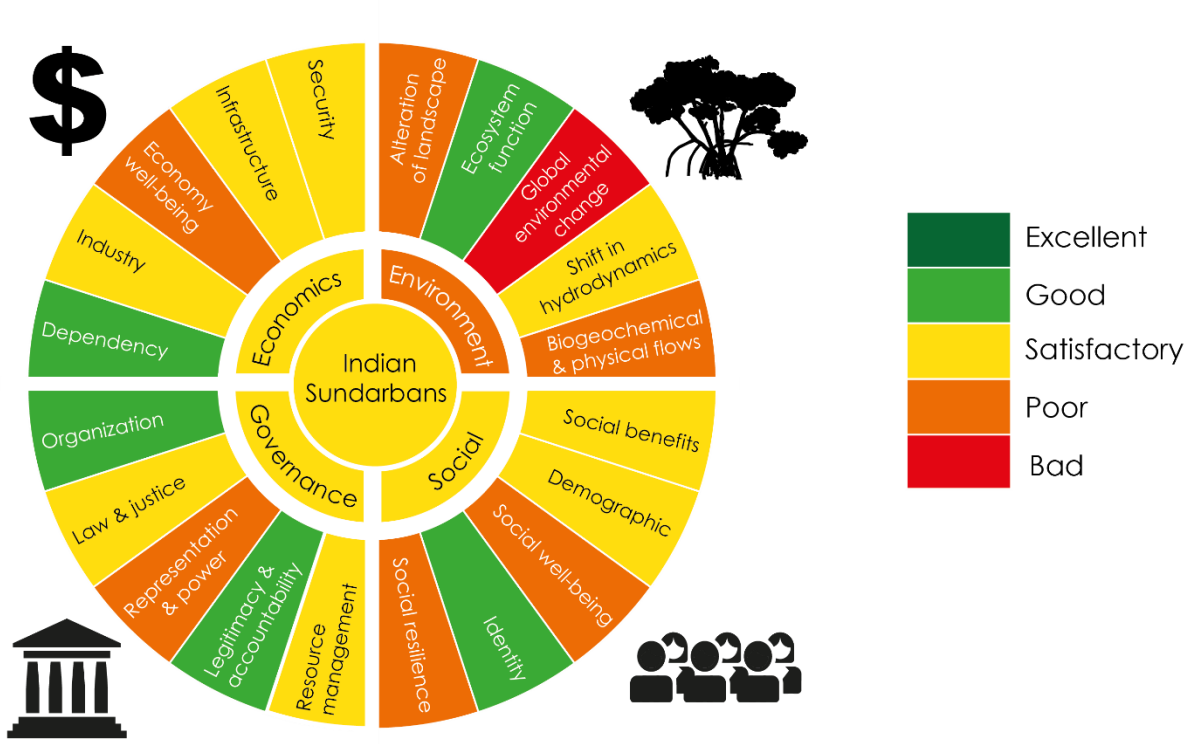
Both countries still have a high dependency on the Sundarbans for the livelihoods of the coastal population (CEGIS, 2012; Sanchez-Triana et al., 2014). The long-term sustenance of the local people is at stake and needs immediate attention. The obtained results from the study are explained in more detail in the following sections for each domain and subcategory separately:

Table 5- *The averaged sustainability category-based scores of India and Bangladesh under the four domains of Environment and Ecology, Social and Cultural, Economics, and Governance and Policy of the Circles of Coastal Sustainability framework*

Domain	Category	Scoring	
		INDIA	BANGLADESH
ENVIRONMENT AND ECOLOGY	Alteration of landscape	4 (Poor)	3 (Satisfactory)
	Ecosystem function	2 (Good)	2 (Good)
	Global Environmental Change	5 (Bad)	5 (Bad)
	Shifts in hydrodynamics	3 (Satisfactory)	3 (Satisfactory)
	Biogeochemical and physical flows	4 (Poor)	3 (Satisfactory)
SOCIAL AND CULTURAL	Societal benefits	3 (Satisfactory)	2 (Good)
	Demographics	4 (Poor)	4 (Poor)
	Social wellbeing	4 (Poor)	4 (Poor)
	Identity	2 (Good)	3 (Satisfactory)
	Social resilience	4 (Poor)	4 (Poor)
ECONOMICS	Security	3 (Satisfactory)	4 (Poor)
	Infrastructure	3 (Satisfactory)	3 (Satisfactory)
	Economic wellbeing	4 (Poor)	4 (Poor)
	Industry	3 (Satisfactory)	3 (Satisfactory)
	Dependency	2 (Good)	2 (Good)
GOVERNANCE AND POLICY	Organization	2 (Good)	3 (Satisfactory)
	Law and justice	3 (Satisfactory)	4 (Poor)
	Representation and power	4 (Poor)	4 (Poor)
	Legitimacy and accountability	2 (Good)	3 (Satisfactory)

	Resource management	3 (Satisfactory)	3 (Satisfactory)

A. India



B. Bangladesh

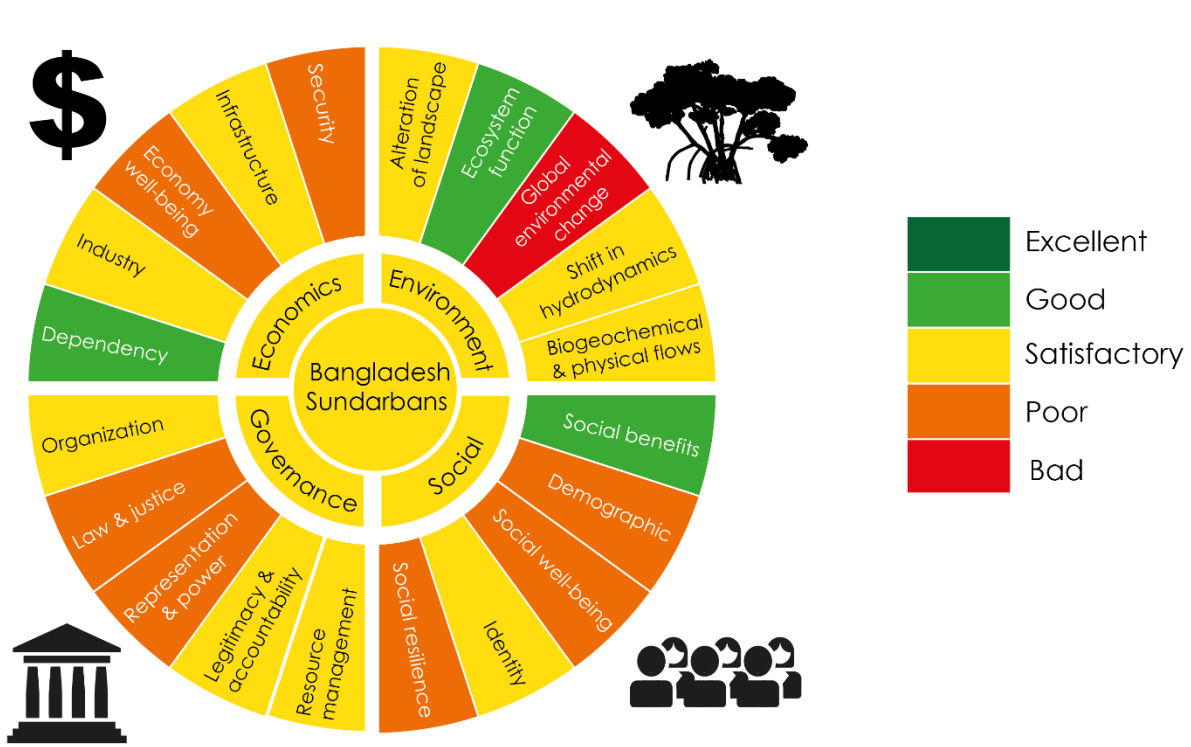


Figure 7- *The Circles of Coastal Sustainability framework output resulting from analysis of the Sundarbans of India (A) and Bangladesh (B)*

4.2 Comparative analysis between India and Bangladesh

The country-specific average scores for each category (Table 5) were assessed based on information from the sources mentioned in tables 1 to 4 for the domains of Environment and Ecology, Social and Cultural, Economics, and Governance and Policy respectively. Tables 6 to 9 show the sub-category analysis of the respective domains separately. These subcategories were analyzed and scored separately in the following sub-sections to deep dive into the comparative sustainability differences between the two countries. The categories with different sustainability scores were put under scrutiny, primarily focusing on the categories that underscore elements of vulnerability as well as elements that bear out resilience.

The human population residing in the Indian part lives within the Sundarban Biosphere Reserve (SBR) and the population in the Bangladesh part lives in the Sundarban Impact Zone (SIZ). Hence, to make the discussion less cumbersome, from here on, I-SBR represents the inhabited region of India and B-SIZ refers to the inhabited region of Bangladesh. In the case of the natural forest area, Sundarban Reserve Forest (B-SRF) represents the mangrove forest of Bangladesh, while on the Indian side it lies under the I-SBR region.

4.2.1 Environment and Ecology domain (refer to Table 1 and 6)

INDIA- 4	BANGLADESH- 4

This domain caters to the Sustainable Development Goals (SDGs) 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land)

I. Alteration of landscapes

INDIA- 4

BANGLADESH- 3

The category of Alteration of landscapes was divided into three sub-categories Land, Sea, and Coastline. The alteration of Land was assessed using the indicator-percentage change in mangrove cover and construction of embankments and boulders. Although, the last century saw more than 5000 sq. km of mangrove forests being cleared for reclamation purposes, including making space for human settlements, aquaculture, and agricultural lands (Das, 2015), there has been a complete halt on deforestation since the 1960s due to several protection measures undertaken by both the countries. The area of the forest has remained more or less constant, with minor changes due to factors, such as top-dying disease affecting H. Fomes species (Sarker et al., 2016), land cover erosion due to cyclones (Quader et al., 2017), and increase in area covered by water bodies (Jayanthi et al., 2018). There have been changes in the canopy closure, forest health, structure, and species composition of the forest, like an increase in the number of salt-tolerant species (Ghosh et al., 2016). But the overall area coverage has remained relatively consistent. As a result, the final score awarded was 3 for both I-SBR and B-SRF. The land is also affected by the construction of embankments and polders. The total length of the embankments in I-SBR has been found to be 3,638 km (Hazra et al., 2010). In Bangladesh, more than 129 polders have been constructed in the upstream areas of the Sundarbans, encompassing 13,000 sq. km of land, or about 44% of the total area in deltaic Bangladesh (Nishat et al., 2019). These were constructed in the late 1960s to protect the land from saline water and to increase crop production. This resulted in reduced tidal flows of the rivers. Auerbach et al. (2015) showed that polder construction resulted in a loss of 1–1.5 m of elevation inside the polders compared to neighboring mangroves, due to which they were scored 5 for both I-SBR and B-SRF. The average scores for Land alteration were calculated to be 4.

For the sub-category Sea, the indicator of sea ecosystems was used. There are no significant coral reef or seagrass ecosystems in the region and this area is relatively understudied. So, expert judgement was used to assess the sustainability of the indicator. Two important marine species of conservation interest- The gangetic dolphin and Irrawaddy dolphin have been threatened due to fishing pressures, shrinking of freshwater flow, and construction of upstream dams (Mansur et al.,

2014). Based on suggestions from experts, this sub-category was scored Satisfactory (a score of 3) for both regions.

The indicator of erosion and accretion was utilized to assess the Shoreline sub-category. The whole southern part of the Sundarbans is facing erosion (Bandyopadhyay, 2019). But the erosion rates and extent are different for I-SBR and B-SRF. Rate is maximum at the west-central section between the Saptamukhi and the Gosaba estuaries at 40 m/a, and gradually reduces west- and eastward, almost to reach zero on the west bank of the Baleswar. Southwest B-SRF (Mongla part) faces erosion (Hasan et al., 2019), while the eastern part has seen a net accretion (Ferdous & Rehman, 2019). Some islands in I-SBR have eroded by more than 40% like Jambudwip (Kundu and Haider, 2019). Considering all this, I-SBR scored 4 and B-SRF 3 for the sub-category.

II. Ecosystem function

INDIA- 2
BANGLADESH- 2

There were two sub-categories under the category of Ecosystem function, namely Biodiversity loss, and Ecosystem services. Biodiversity loss was assessed using the indicator of species diversity and abundance. The Sundarbans is an ecological paradise consisting of a variety of species of fishes, reptiles, birds, and mammals. Although it supports a diverse assemblage of rare and threatened global species, some of these species have been locally extirpated over the last century, including six mammal species Javan rhinoceros (CR), water buffalo (EN), swamp deer (VU), gaur (VU), hog deer (EN) and sambar (VU); one bird species Swamp francolin (VU); 2 reptiles Mugger (VU) and the Gharial (CR) (IUCN, 2017). There has also been a recurrent theme of a lack of a database and monitoring of species abundance and density except for commercially or nationally important species like Bengal Tiger or Irrawaddy Dolphin. Hence, a score of 3 was given to both I-SBR and B-SRF.

Mangroves provide regulatory services like protection from cyclones, which has been used as the indicator to investigate the sub-category Ecosystem services. The Sundarbans woods are thought to exchange 2.79 tonnes of carbon per hectare per year with the atmosphere (Ray et al., 2011). According to estimates, mangroves of

the Sundarban generate services worth between $456.32 to $1,191.84 per hectare per year in Bangladesh (Haque and Aich, 2014) and the Sundarban Tiger Reserve (STR) (approximately 1100 sq. km) in India provides flow benefits worth $732 per hectare per year (Verma et al., 2015). So, a score of 1 was awarded to both I-SBR and B-SRF.

III. Global Environmental change

INDIA- 5
BANGLADESH- 5

Global environment change consisted of three sub-categories of Sea level rise (SLR), Sea surface temperature (SST), and Coastal flooding. SLR impacts were assessed using net SLR (sum of the eustatic sea-level rise and delta subsidence). Over the last 45 years, the sea level in the delta has increased slightly faster (~3 mm/y) than the global mean sea level (~2 mm/y) (Becker et al., 2020). However, from 2005 onward, an acceleration in the SLR in the west of the delta was observed. SLR in the Bay of Bengal is predicted to be slightly higher (0.02 m) than the maximum global average estimates of 0.98 m or higher by 2100 from the 2000 baseline (Akter et al., 2019). Looking at these trends, both I-SBR and B-SRF received a sustainability score of 5.

The SST showed a rising trend at the rate of 0.0453°C/year during the period 2003-2009 (Hazra, 2010). This observed rate was in conformity with the estimated decadal rate of about 0.4°C to 0.5°C calculated by Singh (2002). Looking at the increasing SST trends, both I-SBR and B-SRF scored 5.

Coastal flooding was assessed using the indicator intensification of cyclones. The Sundarbans region, as a part of the bigger GBM delta, is facing an increased intensification of extreme events like cyclones. Analyses of cyclonic events over the last 120 years indicate a 26 percent rise in the frequency of high to very high-intensity cyclones over this time period (Singh and Singh, 2007). In the last 23 years, the Sundarbans have witnessed 13 ‘supercyclones’. The previous three years saw four of these cyclones- Fani (2019), Bulbul (2019), Amphan (2020), and Yaas (2021) (Kundu et al., 2021). The cyclone vulnerability and risk analysis of Indian Sundarbans showed that nearly half of the blocks are with very high to moderate

cyclone risk (Ali et al., 2020). Due to this intensifying trend of cyclones and other extreme events, a score of 5 was given to both I-SBR and B-SRF.

IV. Shifts in hydrodynamics

INDIA- 3
BANGLADESH- 3

Two sub-categories of Waves and Tides made up the category of Shifts in hydrodynamics. Sundarbans has a moderate wave climate with average wave heights of less than 0.5 m and 3–4 s wave periods. Wave height ranges from 0.1 to 0.6 m with a wave period of 5–7 s during the calm winter season, whereas these become 1.8–2.4 m and 12–14 s respectively during the rough summer session (Das, 2015). Both India and Bangladesh scored a Satisfactory score of 3.

In Sundarbans, the tidal cycle is semi-diurnal with minor diurnal inequality. The lowest tidal range is recorded at Hiron Point, the center of the Sundarbans. The range increases towards its westwardly and eastwardly flanks. Additionally, the tidal range also increases northward, up to 2.5 m, due to the increasing landward morphological constriction of the channels (Bandyopadhyay, 2019). The rising tide takes up less time in a cycle, causing the bi-directional tidal current to move quicker landward, turning estuaries into sediment sinks. Like the tidal range, the asymmetry also amplifies northward. A score of 3 was given for both sides of the border.

V. Biogeochemical and physical flows

INDIA- 4
BANGLADESH- 3

Five sub-categories were analyzed to rate the quality of Biogeochemical and physical flows- Nutrient leak, Pollution, and contamination, Carbon, Freshwater cycles, and Sediment cycles. Nutrient leaks were assessed using the indicators of increase in dissolved nitrate concentration and an increase in dissolved phosphate concentration. Although Sundarbans mangroves retain only 0.2% (8 × 106 mol) of the annual river flux of nitrogen (Ray et al., 2014), the net anthropogenic nitrogen input into the basin is considerably high. This is contributed by the high agricultural fertilizer inputs and other non-point sources, such as discharges from fishing vessels

(Banerjee et al., 2014). A study in India found dissolved nitrate concentration has increased by 9.49 µg at l^{-1}/decade in Diamond Harbour, 10.57 µg at l^{-1}/decade in Namkhana, and 5.98 µg at l^{-1}/decade in Ajmalmari (Mitra, 2020). In the case of dissolved phosphate concentration, concentrations have increased by 1.96 µg at l^{-1}/decade in Diamond Harbour, 2.11 µg l^{-1}/decade in Namkhana, and 0.92 µg at l^{-1}/decade in Ajmalmari during the period 1984 to 2009 (Mitra, 2020). Due to the unavailability of data from Bangladesh, the results were considered similar to India. Hence, nitrate (phosphate) indicators scored 4 (4) for India (Bangladesh). The average increase in nitrate and phosphate concentrations was given a score of 4 for both countries.

For the Pollution and contamination sub-category, arsenic contamination and plastic pollution were assessed. Arsenic has been a persistent contaminant in the Sundarbans region resulting in severe health issues recorded among the local population from arsenic-contaminated food and drinking water (Nath et al., 2021). But there is a lack of data on the same. So, based on expert judgement, a score of 3 was given to both I-SBR and B-SIZ. Ganges, Brahmaputra, and Meghna rivers are among the top ten global plastic waste carriers, transporting over 72,000 tonnes of plastics annually before emptying into the Bay of Bengal (Adyel and Macreadie 2021). As a result, both sides of the Sundarbans scored a score of 4. An average of the scores for arsenic contamination and plastic pollution came out to be 3.5 for both countries, which on further rounding off became 4.

The indicator carbon sequestration is used to assess the sub-category, Carbon. The net biosphere-atmosphere exchange of carbon in the Sundarbans has been estimated at 2.79 tonnes per hectare per annum (Verma et al., 2015), making the forest highly efficient for climate change mitigation. Hence, a score of 1 was given to both I-SBR and B-SRF.

For the assessment of Freshwater cycles, salinity exposure was used as the indicator. Salinity is a serious issue for the people living in the region, but the effect is more pronounced on the Indian side as compared to the Bangladesh side. The mangrove forest on the Indian side shows medium salinity (5-15 ppt) during the wet period (as opposed to <5 ppt on the Bangladesh side) but becomes high (>15 ppt) in the dry period (as opposed to 5-15 ppt in Bangladesh side) (Nishat et al., 2019).

Observing the high salinity levels and the disparity between the two sides of the border, I-SBR was scored 5, and B-SIZ was scored 4.

The Sediment cycles were assessed using coastal erosion as the indicator. The I-SBR coastline experienced more coastal erosion as compared to the B-SRF coastline. The western part of the Sundarbans for both countries suffered from more erosion, with the rates significantly higher for the Indian part. In India, according to Hazra et al. (2010), the total erosion over the last 30 years (1978-2008) is estimated to be 162.879 sq. km. During the period 2001-2009, the net loss of land due to erosion was 44.042 sq. km (Nishat et al., 2019). Similar studies in Bangladesh show that the average rates of erosion for the eastern and western parts of the Sundarban Impact Zone (SIZ) are 14 m/year and 15 m/year (Rahman, 2012). The threat from coastal erosion is predicted to increase greatly in the future due to multiple factors like SLR and anthropogenic factors. A sustainability score of 5 was given for India, while Bangladesh secured a 4.

Table 6- *List of subcategories and their respective sustainability scores under the Environment and Ecology domain for the Circles of Coastal Sustainability framework*

Domain	Category	Subcategory	Scoring	
			INDIA	BANGLADESH
ENVIRONMENT AND ECOLOGY	Alteration of landscape	Land	4	4
		Sea	3	3
		Shoreline	4	3
		Average	**4**	**3**
	Ecosystem function	Biodiversity loss	3	3
		Ecosystem services	1	1
		Average	**2**	**2**
	Global Environmental Change	Sea Level Rise (SLR)	5	5
		Sea Surface Temperature (SST)	5	5
		Coastal flooding	5	5
		Average	**5**	**5**

	Shifts in hydrodynamics	Waves	3	3
		Tides	3	3
		Average	**3**	**3**
	Biogeochemical and physical flows	Nutrient leak	4	4
		Pollution and contamination	4	4
		Carbon	1	1
		Freshwater cycles	5	4
		Sediment cycles	5	4
		Average	**4**	**3**

4.2.2 Social and Cultural domain (refer to Table 2 and 7)

INDIA- 3	BANGLADESH- 3

This domain caters to the Sustainable Development Goals (SDGs) 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-being), 4 (Quality Education), 6 (Clean Water and Sanitation), and 10 (Reduced Inequalities).

I. Societal benefits

INDIA- 3
BANGLADESH- 2

Within the Societal benefits category, two sub-categories were analyzed- Goods and services and Water quality. Nutrition from wild freshwater fish was used as the indicator for Goods and services. In coastal Bangladesh and India, fish are naturally abundant throughout the year and are more affordable than other animal-source foods. Given the high incidence of poverty in the region, wild freshwater fish is the main source of dietary protein and essential micronutrients for the millions of poor and extremely poor people (Dasgupta et al., 2020). As a result, a score of 1 was given to both India and Bangladesh.

Access to clean water was used as the indicator for Water quality. Contaminants in drinking water include arsenic and salinity. In India, the arsenic level ranges from 0.12-0.96 in several blocks of North 24 Parganas like Sandeskhali, Haroa, and Hasnabad which exceeds the WHO standards (Nishat et al., 2019). Water is not potable if its salinity exceeds 1 ppt. Salinity in deep tube-well water exceeds 1 ppt in 17 of 50 hamlets in Gosaba, Hingalgunj, and Patharpratima blocks of the reclaimed region in India (Dasgupta et al., 2020). In Bangladesh, arsenic level in almost all the areas in B-SIZ is negligible according to the WHO standard (Nishat et al., 2019). Projections show that progressive water salinization will lead to a significant decline in the availability of drinking water from river sources in the B-SIZ and freshwater zones will be completely lost in Khulna and Barguna districts during the dry season (Dasgupta et al., 2020). Because of the absence of arsenic contamination in Bangladesh, B-SIZ was scored 3, while I-SBR was scored a poorer 4.

II. Demographics

INDIA- 4
BANGLADESH- 4

Three sub-categories made up this section, this included Population/Age/ Structure/Trends, Migration and immigration, and Social class. Population demographic (density, male/female ratio, literacy rate) was used to assess the first sub-category. 4.4 million people live in I-SBR with an average density of 1089.2 people per sq. km (Census of India, 2011). This compares with a population density of 1,029 per sq. km in West Bengal, and 464 sq. km in India as a whole. 51.15% of the population is male, and 48.85% female. The literacy rate is 64.3% (Nishat et al., 2019). Approximately, 2.3 million people reside in the 20 km radius of B-SIZ, with a density of 560.3 people per sq. km. The population density of Bangladesh as a country is 1265 people per sq. km (www.worldometers.info). The population consists of 48% males and 52% females, and the literacy rate is 5% (BBS, 2011). Given the very high population density and slightly higher literacy rate, the population in I-SBR was given a score of 4, and B-SIZ was awarded a score of 3.

The sub-category Migration and immigration were assessed through population in-flows and out-flows. The population in the Indian part rose from 3.76 million in 2001 to 4.43 million in 2011, meaning an estimated 1.78% rise per year since 2001.

The population growth rate is higher than the average West Bengal growth rate due to high birth rates and migration inflows because of easy access to work, the retreat of embankments, restoration of ecosystems, and diversification of economic activities like tourism and aquaculture (Nishat et al., 2019). In Bangladesh, the population decreased from 2.33 million in 2001 to 2.30 million in 2011, showing an average drop of 0.13% per year due to out-migration (Danda et al., 2011). The migration is higher because of an increase in water salinity, exploitation of marginal and small farmers in shrimp farming occupation (Didar-Ul Islam et al., 2016), and natural calamities (Nishat et al., 2019). But both countries observe seasonal out-migration, especially the male population (Saha and Goswami, 2020). Taking all points into consideration, I-SBR secured a lower score of 4 while B-SIZ scored 3.

Social class was assessed based on the poverty levels of the population living in the Sundarbans. The average per capita income in the Indian part is USD 0.5 per day and USD 0.9 per day in the Bangladesh part (Nishat et al., 2019). Poverty in the Indian Sundarbans is acute with about 43% of households lying below the poverty line as compared to the national and state (West Bengal) average of 21.92% and 19.98% of households respectively (Sanchez-Triana et al., 2014). The extreme poverty levels of Bangladesh SIZ districts are also considerably higher at 42% as compared to non-SIZ upazilas (26%) (Islam, 2010). Looking at the high incidence of poverty, a score of 5 was given to both I-SBR and B-SIZ.

III. Social wellbeing

INDIA- 4
BANGLADESH- 4

The social well-being category consisted of the sub-categories of Recreation and access, Food and water security, and Health. To assess Recreation and access, access to nearby cities and ports was used. The remoteness of the region and complicated type of terrain including waterways and intertidal land makes the terrain not easy to navigate. On top of this, the inconvenient, time-consuming and non-consistent nature of the existing transportation system makes it non-ideal to access nearby cities and ports for the local people. For instance, in India, it takes at least 1.5 hours to travel from Kolkata to any of the other major centers, and at least 3 hours to get from Kolkata to Namkhana, the furthest city (Sanchez-Triana et al.,

2014). In Bangladesh, private operators do not have any fixed schedule of operation and no fixed time frame for the operation of private boats, and slow waterway vessels cause great distress to people by never reaching their destinations on time (Nishat et al., 2019). Hence, both I-SBR and B-SIZ were given a score of 4.

The sub-category Food and water security were assessed using two separate indicators of water security and food security (undernourishment). In India, more than 25% of households spend more than 30 minutes per day collecting water. In islands with no water sources, women travel long distances up to three to four hours daily to collect drinking and cooking water for their family (Sanchez-Triana et al., 2014). In Bangladesh, 23% of households have no access to safe drinking water (BBS, 2012) in the B-SIZ coastal districts. As a result, I-SBR and B-SIZ were given scores of 4. Malnutrition and anemia are wide-spread in the region. In India alone, the prevalence of anemia is 51.5%, mostly among pregnant women (Kalaivani and Premachandran. 2018); for children under the age of five, 21% are underweight and 38% are stunted (Fanzo et al., 2018). In Bangladesh, 39.6% of women of reproductive age suffer from anemia; for children under age five, 14.4% are underweight and 36.2% are stunted (Nishat et al., 2019). Looking at the grave situation for food and water security, both the indicators were scored 4 for both countries, the average totaling to 4 for both I-SBR and B-SIZ as a result.

To assess health, the indicator used was the presence of adequate healthcare facilities. The healthcare facilities are sub-standard at best. In India, the crude death rate in the Sundarbans is 7.6 against 6.3 for West Bengal as a whole (Kanjilal et al 2010). The sub-centers (SC) are adequate in number (4973 per sub-center) if one goes by the usual standard (5000 population per sub-center). The number of primary health centers (PHC), on the other hand, is inadequate (88,668 per PHC) by the same standard (30,000 per PHC). Inadequate facilities in addition to poor environmental conditions are responsible for 3,800 premature deaths and 1.9 million cases of illness every year, mainly among young children and women (Sanchez-Triana et al., 2014). In the case of Bangladesh, the districts of B-SIZ only have one Sadar Hospital, except for the Khulna district. According to government rules, there should be one union sub-center and one union family welfare center in each upazila. However, four out of all eleven upazilas had no union sub-centers (Nishat et al., 2019). Both I-SBR and B-SIZ scored 4 for this indicator.

IV. Identity

INDIA- 2
BANGLADESH- 3

Two subcategories formed the category Identity, these consist of Sense of place and Sense of self. In order to assess the sense of place, the indicator used was the number of tourists/year. The number of tourists visiting the Sundarbans every year has been gradually increasing every year in both India and Bangladesh. Tourism facilities such as resorts, parks, and transport facilities in the Indian SBR are more developed and available than on the Bangladeshi side and as a result, attract more domestic and international tourists. Tourists in India gradually increased from 60,000 per year in 2003-2004 to almost 160,000 per year in 2013-2014; while in Bangladesh, no. of tourists increased from 90,000 per year in 2005-2006 to 230,000 per year in 2011-2012, and then sharply dropping again to 100,000 visitors per year in 2013-2014 (Nishat et al., 2019; Sanchez-Triana et al., 2014). As can be observed clearly, India attracts more tourists due to better infrastructural facilities. As a result, I-SBR was scored 2, and B-SIZ was scored a lower 3.

Sense of self was assessed through cultural landscape and traditional knowledge. With all of its ethnicities, histories, myths, legends, beliefs, customs, rites, and traditional knowledge, the Sundarbans is a living museum brimming with traditional knowledge and linked livelihoods. The populaces in both parts share common natural and cultural landscapes- the threats and challenges, the living and coping, the livelihood and fatality, the rites and rituals. This is due to its shared history till 1971 when Bangladesh was partitioned as a separate nation. There was no quantitative information available in the literature for the indicator. So, both countries were given a score of 2.

V. Social resilience

INDIA- 4
BANGLADESH- 4

Two subcategories were used to assess Social resilience- Vulnerability and Education. To assess Vulnerability, the indicator used was social vulnerability. The

incapacity of individuals, groups, and societies to tolerate the negative effects of the various stresses to which they are subjected is known as social vulnerability (Adger and Kelly, 1999). The vulnerability gradient is high across the whole delta. The people living in the vicinity of the Sundarbans have very high poverty levels, and this is exacerbated by poor health conditions, limited employment opportunities with far more limited enterprise, inadequate water supply, and sanitation, absence of electricity in many places, difficult and primarily river-based transport, and very high risk of persistent cyclones, floods and embankment failures. The population also suffers from relatively low education levels, especially among women, making them vulnerable. Due to these, both countries were given the same score of 4.

The literacy rate of the population was used to assess the sub-category of Education. In India, the literacy rate is 64.3% as compared to 76.26% in West Bengal. Many children (5 years of age or older) go to school now due to government incentives whereas only 5% of adult fishers (+30 years) have five years of schooling (Census of India, 2011; Sanchez-Triana et al., 2014). In Bangladesh, educational infrastructure is lacking in the area. But the literacy rate in the associated districts is about 57%, ranging from 49% to 68%, which is partially higher than the national level of 51.8% as per the 2011 census (CEGIS, 2012). Concentrations of formal schools and higher educational institutes are scarce on both sides of the border. Thus, the numbers create a false sense of adequacy (IUCN, 2014b). The literacy rates are mediocre for both countries and hence, were scored a Satisfactory score of 3.

Table 7- *List of subcategories and their respective sustainability scores under the Social and cultural domain for the Circles of Coastal Sustainability framework*

Domain	Category	Subcategory	Scoring	
			INDIA	BANGLADESH
SOCIAL AND CULTURAL	Societal benefits	Goods and services	1	1
		Water quality	4	3
		Average	**3**	**2**
	Demographics	Population/Age/Structure/ Trends	4	3

		Migration and immigration	4	3
		Social class	5	5
		Average	**4**	**4**
	Social wellbeing	Recreation and access	4	4
		Food and water security	4	4
		Health	4	4
		Average	**4**	**4**
	Identity	Sense of place	2	3
		Sense of self	2	2
		Average	**2**	**3**
	Social resilience	Vulnerability	4	4
		Education	3	3
		Average	**4**	**4**

4.2.3 Economics domain (refer to Table 3 and 8)

INDIA- 3	BANGLADESH- 3

This domain caters to the Sustainable Development Goals (SDGs) 7 (Affordable and Clean Energy), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production).

I. Security

INDIA- 3
BANGLADESH- 4

Three sub-categories were used in order to assess Security: Livelihoods, Gender, and Employment patterns. Livelihoods were evaluated using the yearly and seasonal livelihoods indicators. According to data from the Census of India, a significant

percentage of people are engaged in seasonal or marginal livelihoods. For example, as a cultivator, 27% of people work on a seasonal basis; in the household industry, 59% of people are engaged on a seasonal basis. There was no data for seasonal livelihoods in the case of Bangladesh, so both the countries scored a 3 through consultation from experts and estimating similar conditions in both countries.

The subcategory Gender was gauged using percentage of employed women as the indicator. In India, out of all the rural working population who are employed in a yearly occupation, only 7.3% are cultivators, 8.7% in agricultural laborers, 41% are employed in the household industry, and 16% employed in other work are female. The percentage of women employed in a seasonal (marginal) occupation is significantly higher, showing that men are the primary bread-earners for their households (Sanchez-Triana et al., 2014). The seasonal livelihoods also pay lower. In the case of Bangladesh, a household survey of more than 1500 households consisting of 8000 people in the SIZ area was conducted by Adams et al. (2018) where they found that only a tenth of the number of women are working compared to men. The situation for women is far from ideal in both countries, but according to expert judgement, it is slightly better in India. So, a score of 3 was given to India and 4 to Bangladesh for this indicator.

Employment patterns were assessed through the exploitative and hazardous occupation indicator. Incomes of the more affluent households are six times higher than those of the poorest groups. Land ownership is also skewed, with only 51% of the population owning agricultural land (Islam and Chuenpagdee, 2013). Most of the fishers and resource harvesters suffer from long-term debt bondage and face exploitative relations with moneylenders. The poorest are also exposed to shocks which hamper livelihoods often leading to increased poverty. The poorest, due to their nature of work, also face other hazards like physical accidents during fishing and collection of resources from the Sundarbans, tiger attacks, attacks by criminal gangs, and illegal rent-seeking (ransoms, bribes). Due to these factors, both the countries scored 4.

II. Infrastructure

INDIA- 3

BANGLADESH- 3

Infrastructure covered the subcategories- Energy supply, Tourism, Transport, and Access. Energy supply was assessed through the indicator proportion of the population with clean access to energy. All villages in the I-SBR have access to electricity at least partly; of this, approximately 17% of the population has access to grid electricity. But 85% of these households face power cuts of 4 to 9 hours per day, and the remaining households face power cuts of between 9 and 14 hours per day. The remaining 83% of households without access to the grid depend largely on solar photovoltaic panels through off-grid solar energy, energy storage, and mini-grids, but maintenance costs for these are substantial. These provide 4 to 6 hours of daily power supply (Sanchez-Triana et al., 2014). The community's access to electricity in B-SIZ is limited to only 30-40% of the households. Introduction of solar energy facilities has been initiated. 60-70% of households depend on renewable sources of energy like solar power (Nishat et al., 2019). Both I-SBR and B-SIZ were scored 3.

The subcategory Tourism was evaluated using the indicator tourism infrastructure. The type of data used is the same as the indicator no. of tourists/year utilized for the sub-category Sense of place under the category Identity falling in the Social and cultural domain. As a result, the scoring done was the same- India securing a 2 and Bangladesh securing 3.

Transport was assessed by the transboundary goods navigation indicator. The cargo moved between India and Bangladesh during the year 2004–2005 along the protocol route was approximately 416,000 metric tons. Fly ash, granulated slag, gypsum, clinker, cement, manganese ore, food grains, wheat, rice, sugar, project cargo, and dried fish are among the exports to Bangladesh. The imports from Bangladesh include return project cargo, crushed bone, and hide. Although the volume of transit vessels has increased since 1995, there is a lot of room for improvement, which resulted in the Satisfactory score of 3 for both countries.

Access was judged on the existence of roads, waterways, ports, buses, railways, and airports. The data used for this indicator is the same as the indicator of access to nearby cities and ports used for the sub-category Recreation and access under the category Social wellbeing falling in the Social and cultural domain. So, the same score of 4 were given to both countries.

III. Economic wellbeing

INDIA- 4
BANGLADESH- 4

Economic well-being consisted of three sub-categories, these included Equality, Income, and Housing. To assess Equality, the GINI index (a measure of the distribution of income across a population) for India and Bangladesh was used as an indicator. A GINI coefficient of 0 expresses perfect equality, where all values are the same (that is everyone has the same income). A Gini coefficient of 100 expresses maximal inequality among values. India has a GINI coefficient of 35.7 as per 2011 data. Bangladesh has a GINI index of 32.4 as of 2016, which are both mediocre values, therefore resulting in the scores of 3 for both countries.

Income was evaluated using the indicator of income sources and levels. All the people residing in I-SBR and B-SIZ live in rural areas with an estimated 60% of people not being able to meet basic daily nutritional requirements (Dasgupta et al., 2020). Agriculture is the main occupation, but the main crop of paddy is seasonal and the income from that is not sufficient, so people have to find other jobs during the rest of the year. Seasonal livelihoods are high for both countries. In Bangladesh, the average income for male household heads varies from 8,508 BDT (Bangladesh Taka) a month to 7,207 BDT a month. For women, the average income varies from 6,447 to 3,532 BDT (Adams et al., 2018). The bottom line is that the poverty levels are very high in the region due to low-income levels and people struggle to make ends meet. Therefore, both I-SBR and B-SIZ were scored 5.

To assess Housing, the indicator used was no. of members living in each household. In India, the average household size was 4.47 in 2011, down from an average household size of 6.9 people in 2001 (Census of India, 2011). In Bangladesh, 28% of households have 4 members, 24% have 5 members, 16% of households have 6 members and 14% have 3 members, bringing the average to 4 to 5 members in each household, similar to India. Even though the per-house occupancy is not very high, one thing to note is the size of these houses. The houses are generally very tiny and made with poor quality materials, increasing vulnerability to natural disasters. Due to all these factors, a score of 4 was given to both countries.

IV. Industry

INDIA- 3
BANGLADESH- 3

To assess this category, two subcategories were used, Renewable sources and Extractive sources. Ecotourism was used as an indicator for Renewable sources. There was a dearth of information available for this indicator. Only a tiny percentage of people are employed in the tourism sector. The sector is also seasonal in nature. But the Sundarbans has a strong ecotourism destination potential in the future, given that it constitutes the world's largest continuous mangrove forest and is inhabited by the Royal Bengal Tiger. So, a score of 4 was given for both the countries.

Extractive resources were assessed using the indicator fisheries and aquaculture. In the Sundarbans, there are a variety of fishing activities which include coastal fisheries, estuarine and riverine fisheries, riverside prawn-seed and shrimp-fry collection, shrimp farming, prawn post larvae (PPL) catching, crab, mollusk, oyster, and shells collection and several freshwater aquaculture variants, brackish water aquaculture, like that of Bagda shrimp. Brackish water aquaculture has been gaining prominence since the eighties and has become one of the important livelihood generators in the region (Nishat et al., 2019). Considering the similar prevalence of fisheries and aquaculture in India and Bangladesh, a score of 2 was given to both.

V. Dependency

INDIA- 2
BANGLADESH- 2

This category consisted of the sub-categories Dependency on coastal resources and Diversification of activities. To assess the first sub-category, dependency on Sundarbans coastal resources was used as an indicator. Almost all the population directly or indirectly depends on the Sundarbans for livelihood. The dependence on Sunderbans may be a direct one through fisheries and aquatic resources, non-timber forest products or wood collection, or an indirect dependence through agriculture and brackish water aquaculture. The Bangladesh part of Sundarbans provides employment for over 700,000 people directly working as 'jaleys' or fishermen,

'bawalis' or woodcutters, 'mouals' or honey gatherers, shrimp fry collectors and nipa-leaf (Nypa fruticans) and thatching grass (Imperata spp.) collectors (Islam, 2010; Nishat et al., 2019). Some 50,000 people from around the Sundarban enter the forest every day for their livelihood. In India, the livelihood of nearly 2 million people is linked with the Sundarbans, which mainly include fishing, crab collection, honey and beeswax collection and allied activities (Singh et al., 2010). Looking at the dependency, the highest score of 1 was awarded to both.

Diversification of activities was evaluated using the livelihood diversification indicator. In India, 60% of the working population primarily depends on agriculture, with more than 75% of the inhabited land used for agriculture (Sanchez-Triana et al., 2014). In Bangladesh, over 80% of the gross area is being used for cultivation (CEGIS, 2012). Agriculture is the primary livelihood, followed by aquaculture and fisheries. Some other types of livelihoods include a variety of fishing activities like coastal fisheries, estuarine and riverine fisheries, riverside prawn-seed and shrimp-fry collection, shrimp farming, crab, mollusc, oyster and shells collection and several freshwater aquaculture variants; non-Timber Forest Products (NTFPs) collection- honey and wax procurement, Golpata and Hental leaves collection, oyster, nal khagra, ulu ghas and maila ghas; timber harvesting; and livestock and poultry. The two countries were given a Satisfactory score of 3 for this indicator.

Table 8- *List of subcategories and their respective sustainability scores under the Economics domain for the Circles of Coastal Sustainability framework*

Domain	Category	Subcategory	Scoring	
			INDIA	BANGLADESH
ECONOMICS	Security	Livelihoods	3	3
		Gender	3	4
		Employment patterns	4	4
		Average	**3**	**4**
	Infrastructure	Energy supply	3	3
		Tourism	2	3
		Transport	3	3
		Access	4	4

		Average	**3**	**3**
	Economic well-being	Equality	3	3
		Income	5	5
		Housing	4	4
		Average	**4**	**4**
	Industry	Renewable sources	4	4
		Extractive sources	2	2
		Average	**3**	**3**
	Dependency	Dependency on coastal resources	1	1
		Diversity of activities	3	3
		Average	**2**	**2**

4.2.4 Governance and Policy domain (refer to Table 4 and 9)

INDIA- 3	BANGLADESH- 3

This domain caters to the Sustainable Development Goals (SDGs) 16 (Peace, Justice and Strong Institutions) and 17 (Partnerships for the Goals).

I. Organization

INDIA- 2
BANGLADESH- 3

The organization only consisted of one subcategory Civil and NGOs, and the indicator used to assess this was the existence of collective action groups. According to expert judgement, a large number of NGOs and self-help groups have come together in the past few years to help include people in decision-making. The trend is positively inclined more towards India than Bangladesh. These agencies or groups build storm protection shelters, water supply systems, and infrastructure for solar energy, among other things. India scored 2 and Bangladesh scored 3 for this category.

II. Law and justice

INDIA- 3
BANGLADESH- 4

This category consisted of three subcategories including Legislation, Efficacy, and Enforcement. The Legislation was judged on the existence of legislation to rule over coastal and related resources. In both countries, each component of the ecosystem (like water, fisheries, vegetation, etc.) is governed by a different legal regime. Laws and institutions rarely include cross-cutting issues and are often confined within sectoral boundaries. This is made worse by a disjointed legal system and contradictions in laws and regulations (Allan et al., 2013). Some examples from Bangladesh include Bangladesh Wildlife Act 2012 which prohibits the killing or capturing of wildlife; Bangladesh acceded to CITES in 1982 which bans the use and export of tigers and other threatened species, or their body parts. Some examples from India include the Wildlife (Protection) Act, 1972 which prohibits hunting and poaching of wild animals; the Environment (Protection) Act of 1986 is a comprehensive law that offers protection from all forms of pollutants; the Forest (Conservation) Act of 1980 places restrictions on the use of forest land for non-forest activities. Due to the large variety of legislations implemented, both countries were awarded a score of 2.

Efficacy was judged using regulatory quality and effectiveness indicators. In Bangladesh and India, there is a national and international concern for conservation, political support, and significant resource flows. Despite this, a combination of exposure to disasters and natural stresses, increasing population pressure, and insufficient institutional coordination and capacity have led to inadequate management. Forest management in Bangladesh essentially only focuses on the reserve forest. There are a few uncoordinated activities by government and non-government agencies, but no real initiative has been taken to manage and develop the surrounding areas which house the population dependent on the Sundarbans so far. Planning and management have typically focused on the physical resource, its status, and extent. SBR in India, consisting of uninhabited National Park as well as inhabited areas, has a few programmes and initiatives by the government, non-government, and research agencies focusing on the entire

SBR. Socio-economic issues affecting forest change, dependency, and interlinkages on forest resources are better addressed in India as compared to Bangladesh. Also, there is a Sundarban Development Authority in India that looks after local issues. So, based on research and expert opinion, SBR in India was scored 3, and SIZ in Bangladesh was scored a poorer 4.

Enforcement was judged using transboundary governance. The Ganges Treaty was signed between the two countries in 1996. Also, in 2011, the Governments of Bangladesh and India signed a five-year Memorandum of Understanding (MoU) on the conservation of the Sundarbans, and a protocol for the conservation of the Tiger in the Sundarbans. A Joint Working Group on the Conservation of Sundarbans comprising officials from both countries was set up to implement the activities under the MoU. In spite of all this, very limited collaboration has actually taken place. So, based on expert judgement, both were scored very poorly with scores of 5.

III. Representation and power

INDIA- 4
BANGLADESH- 4

Effectiveness was the only sub-category under this category. The indicator voice and accountability in environmental issues was used to evaluate effectiveness. Based on research and expert opinion, both the country governments have taken some steps in the past to include the local people in management steps for the benefit of the people, but they have been sparse, uncoordinated, and with no follow-ups. In general, there is an unwillingness to include local people in management decisions. Management is basically top-down with very limited participation from the people. So, scores of 4 were given to both India and Bangladesh.

IV. Legitimacy and accountability

INDIA- 2
BANGLADESH- 3

Democratic task allocation among agencies and departments was used as the indicator to assess Legitimacy and accountability. It didn't have a sub-category. Bangladesh only has one agency, the Forest Department responsible for

Sundarbans conservation. While in India, there are several agencies at the state and national levels. According to the opinion of experts, both countries have allocated duties for separate departments and agencies. But the Indian part has a better spread distributed among central and state agencies. As a result, the Indian part was scored 2 and the Bangladesh part was given a score of 3.

V. Resource management

INDIA- 3
BANGLADESH- 3

Resource management consisted of two subcategories including Plans and Management. Plans were judged according to the sectoral policies and plans. On both sides of the international border, the sectoral policies and plans have tended to be short-term and sector-specific, following the mandate of the formulating ministries or departments, while clearly lacking integration across relevant issues including the cross-cutting issues. There is a clear need for a framework to allow coordination among the sectoral approaches from a climate change perspective by setting sectoral priorities and identifying key sectors for immediate attention. While success can be attributed to wildlife and forest conservation regulations, other sectors have lacked proper management. Hence, both countries were given a score of 3.

Management was judged using the environmental management indicator. In Bangladesh, the Sundarban is managed through three wildlife sanctuaries where any sort of resource harvesting is illegal. Additionally, the entire reserve forest is subject to a felling moratorium. Fishing is banned in the sanctuaries which are 23% of the total area of the Sundarbans. In India, the Project Tiger and the coastal zone are federally managed, and the national park, inhabited areas, and the wildlife sanctuaries are under the forest departments of the state of West Bengal, which have varying degrees of control in different parts. Additionally, the secretariat of the biosphere reserve, which is the custodian of the entire 9630 sq. km of the Indian Sundarbans, is headed by a director. Based on expert opinion about this indicator, both were given a score of 2.

Table 9- *List of subcategories and their respective sustainability scores under the Governance and Policy domain for the Circles of Coastal Sustainability framework*

Domain	Category	Subcategory	Scoring	
			INDIA	BANGLADESH
GOVERNANCE AND POLICY	Organization	Civil and NGOs	2	3
		Average	**2**	**3**
	Law and Justice	Legislation	2	2
		Efficacy	3	4
		Enforcement	5	5
		Average	**3**	**4**
	Representation and power	Effectiveness	4	4
		Average	**4**	**4**
	Legitimacy and accountability	Task allocation	2	3
		Average	**2**	**3**
	Resource management	Plans	3	3
		Average	**3**	**3**

5. Discussion

5.1 Overarching discussion

The framework of Circles of Coastal Sustainability (CCS) was used to assess the sustainability of the Sundarbans region through the inclusion of the social, political and economic spheres on top of addressing the environmental issues of the area. The Sundarbans is a complex coastal system with many intricacies and interlinked elements- natural as well as human. To understand the complications associated with the system, an analysis using a framework that delves deep into multiple coastal elements of the system was essential. Through the preliminary investigative lens of CCS, the associated risks were identified for both the ecosystems and included inefficiency and lack of accountability of the government, intensification of cyclones, sea-level rise, coastal erosion, and delta subsidence. Socio-economic pressures include high poverty levels, persistent lack of basic services such as healthcare services, dignified work, and proper transportation. These pressures are particularly high for the most vulnerable population, estimated to be 1 million by modelers (IUCN, 2014a). India scored a lower sustainability score overall among the two countries. This was a result of a Poor (score of 4) rating for India as compared to the Satisfactory (score of 3) rating of Bangladesh as the environmental and ecological degradation stood out like a sore thumb for India. Whereas, both countries were given equal sustainability ratings (Satisfactory or a score of 3) for the Social and Cultural, Economics, and Governance and Policy domains.

Some of these notable weaknesses of the system are known and have been attracting global concern, like the fast-sinking and eroding islands of the Sundarbans. On the other hand, some of the elements do not get this kind of attention like the necessity of an efficient and functioning transboundary governance between India and Bangladesh for future-proofing of the at-risk population. In this study, the comparative analysis between the two countries clearly highlights the similarities as well as differences between the two artificially separated ecosystems when it comes to the state of sustainability. There is undoubtedly a need for joint action between their governments for a sustainable future. There are many examples where the actions taken in one country directly affects the other, like for

example, the repercussions faced by Bangladesh due to the opening of the Farakka dam in India (Kawser and Samad, 2016).

The Delta Vision 2050 (IUCN, 2014a; IUCN, 2014b), through the idea of a climate emergency, proposes the development of a functional bilateral alliance between India and Bangladesh to address “environmental security issues”. The Members of Parliament (MPs) of India and Bangladesh also agree on the necessity of a joint platform to preserve the Sundarbans through sharing of good-practices and experiences (Chowdhury, 2015). In September 2011, India and Bangladesh signed a memorandum of understanding (MoU) on conservation efforts in the Sundarbans, but very limited actionable outcomes have materialized (Thakur, 2019). A Joint Working Group on the Conservation of Sundarbans comprising officials from both countries was set up in 2016 to implement the activities under the MoU, but again that has been followed by a sincere lack of actions (Nishat et al., 2019). Cooperative activities through adaptive capacities are visibly lacking on the ground. This study relied on secondary datasets for its holistic analysis of the Sundarbans. In turn, it also resulted in the compilation of a data repository of literature sources for future studies.

To tackle the dangers of global environmental change, some climate adaptation strategies have been proposed, like “managed retreat” which intends rehabilitation of these 1 million people from vulnerable areas to northern parts. This is a top-down approach and might be misguided without due consideration of the coastal population’s needs (Bhattacharyya and Mehtta, 2020). Although intentions of protecting the socio-economically poor people are well directed, it is not clear whether the vision for the delta accommodates the concerns of the islanders: where they will move to, what they will do there, and whether they want to move. Plus, the proposed plans are yet to be formalized and formulated into a plan. As the seas keep rising continuously and the tides keep swelling in the Sundarbans, the go-to adaptation strategy for Sundarbans has been to raise the houses higher above the ground and grow the embankments a few inches taller. But as the cyclones become more intense with time, the embankments keep getting toppled. The prevalent approach to Sundarbans policy that is currently being used, which includes building embankments, forcible separation of people and nature, and longer-term proposed managed retreat, does not take seriously the various realities, desires, and

especially multifaceted vulnerabilities of the people this policy will affect. For most areas, mitigation measures have more or less become redundant against the backdrop of a sinking Sundarbans.

There is no doubt a lot of work needs to be done to protect the pristine nature of this spectacular ecosystem as well as to protect the homes, livelihoods, and wellbeing of the Sundarbans' dependent population. Bilateral research initiatives, such as this study, are necessary to inform joint action for sustainable development and conservation of the Sundarbans landscape. Understanding the importance of a multi-agency approach that facilitates integrated working in collaboration with the Ministry of Environment and Forests (MoEF) in Bangladesh and the Ministry of Environment, Forest and Climate Change (MoEFCC) in India is essential for on-ground implementation. Identifying specific needs and priorities for the respective governments can help assist in setting up a framework for cooperation. An Indo-Bangladesh platform of technical and social experts in close contact with the government ought to be set up for collective learning which can result in collaborative activities. Both the countries need to work together towards a common vision for the Sundarbans, fueled with national interests, including economic development, security, and concerns and needs of the local population for better binding, actionable agreements. To overcome the challenges associated with the joint implementation of activities, Nishat et al. (2019) suggests addressing three key challenges: a) building consensus, b) building institutions for joint management; and c) identifying and catalyzing the processes necessary to mobilize institutions. The results from this sustainability study and the repository can act as a starting point for future work.

There will never be a time for a complete and comprehensive analysis of the Sundarbans. It might be underwater by then. Research efforts need to be well-directed and address the articulation of the institutional and financial arrangements to operationalize the instruments for the betterment and enhancing technical cooperation between the two countries. A domain-specific discussion is done below-

1) In the Environment and Ecology domain, as has been noted in the previous sections, the whole Sundarbans ecosystem faces high stress from global

environmental change in the form of sea-level rise of the Bay of Bengal and delta land subsidence, increase in sea surface temperature, and coastal floods caused by extreme events in the coastal region. The system shows some resilience in ecosystem function due to the plethora of ecosystem services provided by the forest ecosystem and some control over the loss of biodiversity as compared to the past destruction rate. India displays a show of poorer sustainability in natural landscape alteration and biogeochemical and physical flows because of a higher rate of shoreline change and modified freshwater and sediment cycles respectively.

2) For the Social and Cultural domain, Bangladesh shows resilience in societal benefits for the local people benefiting from better water quality comparison. While India shows resilience for the identity of the population benefiting from a better sense of place. Within this domain, the elements of demographics, social wellbeing, and social resilience of the coastal population all suffer from poor sustainability due to multiple pressures. Vulnerability, health, food and water security, recreation, and access are among the daily stressors faced by the population living in the coastal zones of Sundarbans. These are exacerbated by the poor social class of the people. Additionally, migration (seasonal and non-seasonal) of people to bigger urban areas is becoming worrisome.

3) In the Economics domain, the ecosystem shows vulnerability for some elements, resiliency in some, as well as mediocre sustainability for others. The economic well-being of the people suffers the most due to very low income from professions and poor housing conditions. The coastal population is heavily dependent on the coastal resources for their livelihood and wellbeing, but the diversity of activities is sub-par. The economic industry relying on renewable sources also needs attention. Furthermore, infrastructural needs in terms of access and linkages can be improved in the future.

4) Within the Governance and Policy domain, representation and power clearly lacks any focus which can be observed by the poor effectiveness. Despite good legislative policies, enforcement of laws and justice is not taken seriously on either side of the border. There is also scope for improvement in implementing plans for resource management.

5.2 Comparative analysis between India and Bangladesh

The Sundarbans ecosystem exists as a single, continuous, naturally occurring system. But it has been artificially divided due to the partition of Bangladesh into a separate nation in 1971, resulting in divided governance between India and Bangladesh. Conservation efforts have also followed along with this socio-political division. Due to this, the sustainability levels of the different aspects of the system are not the same for the two countries (Table 10). The differences may be or may not be because of the artificially imposed international border. This study focuses on finding the contrasting differences in sustainability ratings of the different elements. It doesn't intend to point out the inefficient management or blame the respective government agencies. The comparative differences in sustainability are an interplay of multiple factors and any constructive comments on the same are beyond the scope of this study due to: 1) The recent partition of the two countries (1971) which doesn't allow sufficient time and data for a constructive comparison between the before and after scenarios; 2) The sheer size of the ecosystem which probably contains many micro-ecosystems with different issues requiring separate analysis; 3) The lack of sufficient publicly available information about various factors of sustainability which deems a fair comparison irrelevant; 4) The requirement of a more comprehensive in-depth analysis including the local people (bottom-up) and decision-makers (top-down) in the studies.

On a closer look at table 10, India scored poorly for all indicators under the Environment and Ecology, and Social and Cultural domains as compared to Bangladesh. However, it is completely opposite to the elements of the Economics and Governance and Policy domains. Here, Bangladesh scores poorly in comparison. Even though the differentiating indicators are not representative of the whole domains, there is still a clear trend of different sustainability statuses for the various domains. This is also not an exhaustive comparison, but clearly, there is a pattern that needs to be capitalized on. Indian decision-makers should focus on environmental conservation and improving the social coefficient of the local population. On the contrary, Bangladesh should allocate more resources in correcting the economic wellbeing of the people through better policies, legislation, and accountability.

The side-by-side comparison, through the use of CCS, demonstrates both the elements with the same sustainability statuses as well as different sustainability statuses. But this analysis is not the final product for directional management. The secondary sources used for this study lacked the comprehensive bottom-up assessment required to take into consideration the needs of the people. For better collaboration and joint decision-making between India and Bangladesh, there is a need to increase the scope of the studies. This will ensure the inclusion of the wide array of elements impacting the needs of a system and its local population. Reiterating, this study has the potential to become an excellent preliminary assessment or even a wealthy resource of information upon which future studies can build upon. But it is not to be taken as a standalone assessment of the Sundarbans.

Table 10- *List of indicators where the Indian Sundarbans was scored differently for its sustainability than Bangladesh Sundarbans under the Circles of Coastal Sustainability framework (CCS)*

Indicator	Scoring	
	India	Bangladesh
1. Erosion and accretion	4	3
2. Salinity exposure	5	4
3. Coastal erosion	4	3
4. Percentage of population with access to clean water	4	3
5. Coastal population, its density, male/female ratio and literacy rate	4	3
6. Population in-flows and out-flows	4	3
7. Number of tourists per year	2	3
8. Percentage of women employed	3	4
9. Tourism infrastructure	2	3
10. Existence of collective action groups	2	3
11. Regulatory quality and effectiveness	3	4
12. Democratic task allocation among different agencies and departments	2	3

CCS output- https://bit.ly/3b57DUh

5.3 CCS framework analysis

This study brings forth the usability of the CCS framework at different scales and regions. The CCS is a relatively new framework developed by Alencar et al. (2020) aimed at studying the different states of sustainability of a coastal ecosystem. It has been back-tested on other ecosystems in the developed world context like Spain and UK but lacked the implementation in a developing country context. Through this study, the framework showed its applicability for wider usage, including coastal wetlands lying in developing countries. It is an effective communication tool to bridge the gap between science and policy through the inclusion of the multivariate elements of the system in an easy-to-understand format. The CCS fills the niche of a lack of frameworks for use-case, particularly in coastal contexts. More generalized frameworks might not be able to address the coastal specific issues which are proactively covered through CCS.

The backbone of this study consisted of both- the testing of the framework in a transboundary context, that is the Sundarbans, and the comparison of sustainability between the two countries of India and Bangladesh. CCS proved to be an efficient tool for projecting comparison results for the artificially separated ecosystem. It clearly displays similarities as well as differences through the usage of similar sustainability indicators for both (Table 5 and Figure 7). Color-coded science communication is especially useful for this purpose. The framework allows the data-backed sustainability communication, but further due diligence is necessary to identify collaboration and joint decision-making pathways. It can be an excellent tool to initiate dialogue between the two countries. But it fails to harmonize a co-developed management strategy between them.

There are also other shortcomings of the framework like it fails to consider the elements present outside the ecosystem, in this case, the river catchments and the polluting nature of the large nearby cities of Kolkata (India) and Dhaka (Bangladesh). In the literature, for some indicators, different authors found contrasting results. This may be due to- 1) the usage of different methodologies for the same study, and 2) the differing research foci. As a result, the results might be skewed. This can be avoided by doing scuttlebutt on the ground or research focus based primary research. The framework can benefit greatly by forming a mechanism to better

understand the interlinkages and inter-connectivity between the different elements of the system. The framework is also reliant on information for multiple factors to judge the overall sustainability. This becomes difficult in the case of secondary research such as this one.

There is also a requirement for a more quantitative or defined scoring system. The sustainability scores given for the different indicators were solely based on available secondary datasets and discussion between the researcher and other experts of the area. This, sometimes, also led to disagreements. The final scores of the categories and domains were obtained by averaging using an arithmetic mean for the indicator scores. This is similar to the method used in calculating SDGs (Papadimitriou et al., 2019). The averaging method of scoring employed in the framework might be skewing the final results of the domains due to the non-consideration of bad performing outliers (the elements scoring on the extreme end of the sustainability spectrum). Using geometric mean for scoring can be explored further for future studies. In general, averaging of any type doesn't allow the in-depth discussion required to present the differently performing sustainability areas because of the issue of 'compensability' (Papadimitriou et al., 2019). This is more true for the arithmetic mean as compared to the geometric mean. It rules out the nuanced analysis necessary for actionable science communication which might have an effect on the final scores. Additionally, expert opinion was necessary from both sides of the border to avoid bias. In this study, due to the limited scope, only experts from India were consulted for the scoring. Although, the combined efforts have been to reduce bias and represent both the systems as truthfully as possible. But future studies can incorporate experts from both sides of the border before allocating the final scores.

6 Final comments

6.1 Dissemination and exploitation of results

The Sundarbans is a dynamic area with many complexities. The complexities have been broken down into separate elements for a thorough intra- and inter-country sustainability analyses using a simple 5-degree scoring mechanism. CCS proved to be an effective tool to study the coastal environment of the Sundarbans which included, both the inhabited area and natural protected forests. This was a clear demonstration of the applicability of the framework for wider use cases. The inter-country assessment between the two countries of India and Bangladesh allowed a nuanced analysis of the artificially separated ecosystem. A data repository was compiled in the process for future use.

The dissemination and exploitation of the results are expected to be done in the form of concurrent or collaborative activities between the two countries. The pressure areas were identified in this study which has the potential to become areas for collaboration. The difference in transboundary governance was explored in detail through the use of CCS and a research paper is in preparation for the dissemination of results. This use-case of CCS for the transboundary coastal environment for Sundarbans was recently presented at the Sustainability Research and Innovation (SRI) Congress 2022 in South Africa as part of the Future Earth Coasts organization outputs. It will also be part of Future Earth Coasts conferences and events through posters and oral presentations for communication on multiple scales. The results from this transboundary research can be further exploited by the initiation of similar full-scale collaborative research in other parts of the globe.

6.2 Way forward

The future scope of this study has been divided into four points of implementation. The list is based on the visualization of the Sundarbans across Bangladesh and India as a single biogeographical entity and the possibility of using CCS for bilateral research cooperation for the sustainable development of the ecosystem.

1) There is a need for more ground surveys to include the local population in research and decision-making. This will allow an improved bottom-up understanding of the system and all-encompassing policy formulation.
2) The Circles of Coastal Sustainability framework can be improved through a more quantitative and nuanced scoring mechanism.
3) This research identified the pressures faced by the system. Using these results, actionable transboundary strategies between India and Bangladesh can be orchestrated through selective awareness spreading.
4) The collaboration between the two countries can be improved through the identification of associated stakeholders and institutional actors for building joint platforms and joint integrated management strategies.

7. Conclusions

The Circles of Coastal Sustainability framework was a comprehensive tool to assess the sustainability of the coastal Sundarbans. The framework was weighted equally between environment, social, economic, and governance factors giving a unique perspective. The framework also acted as an efficient tool for science communication with different colors demarcating different levels of sustainability- dark green for Excellent; yellow for Satisfactory; and red for Bad. The major challenge facing the whole landscape is the global environmental change where both the nations scored the poorest in terms of sustainability. There are also other pressures that plague the region, such as lack of employment, intensification of cyclones, accelerated sea-level rise, and coastal erosion. The brunt of these effects is faced by the coastal population and is exacerbated due to the high poverty levels and lack of public services such as proper healthcare, sufficient housing, and work opportunities. The framework also highlights the resilient areas. The results from the analysis present opportunities to adapt and mitigate through directional management. For example, India needs to focus on environmental and social issues, while Bangladesh needs to allocate more resources towards tackling the governance and economic related problems. One such strategy proposed is the need for an improved collaborative transboundary governance between the neighboring countries India and Bangladesh through future planning and policy formulation towards sustainability. Future needs include the identification of stakeholders and institutional actors for joint integrated management strategies.

This paper can be considered as a first step or a platform to inform further research by including local people and improving collaboration between agencies. It fulfilled the bigger goal of understanding the state of the system through secondary research. It also formed a data repository for a one-stop destination for literature sources. The study clearly shows the pressures facing the system. The question is not “if” the danger is real, instead, the focus should be on “how” to tackle the complexity of the system. The need for joint transboundary governance has never been more important, and the limelight is on this fast-sinking, ecologically diverse mangrove ecosystem called the Sundarbans.

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Annex I

Spreadsheet for detailed analysis of the sustainability for the Sundarbans region at the Domain, Category and Sub-category levels under the Circles of Coastal Sustainability framework (CCS)-

https://docs.google.com/spreadsheets/d/1VkXFozR0RfftVLyc_CoUV715q9pFflyC6E4TLWR7e-w/edit?usp=sharing

(shortened form- https://bit.ly/3b57DUh)

Annex II

Table 1- *Indicators and data sources used for the Environment and Ecology domain for the Circles of Coastal Sustainability framework*

Category	Sub-category	Indicator used	Data sources
Alteration of landscapes	Land	1 Percentage change in mangrove cover	Das, 2015 Ghosh et al., 2016 Islam et al., 1997 Jayanthi et al., 2018 Kumar et al., 2021 Quader et al., 2017 Sarker et al., 2016 Thakur et al., 2020
		2 Reclamation of land	Auerbach, 2015 Hazra et al., 2010 Nishat et al., 2019
	Sea	Sea ecosystems	Expert judgement Mansur et al., 2014
	Shoreline	Erosion and accretion	Bandyopadhyay, 2019 Chaudhuri et al., 2020 Ferdous and Rehman, 2019 Hasan et al., 2021 Kundu and Halder, 2018

			Nishat et al., 2019 Payo et al., 2016
Ecosystem function	Biodiversity loss	Species diversity and abundance/ Endangered species	Expert judgement Habib et al., 2019 IUCN, 2017 Sarkar et al., 2019 Sievers et al., 2020
	Ecosystem services	Regulatory service like protection from cyclones, carbon exchange etc	Haque and Aich, 2014 IUCN, 2014a Ray et al., 2011 Verma et al., 2015
Global environmental change	Sea level rise	Net sea level rise	Allison, 1998 Akter et al., 2019 Becker et al., 2020 Brown and Nicholls, 2015 Ramesh et al., 2019 Danda, 2010
	Sea surface temperature	Sea surface temperature	Hazra, 2010 Singh, 2002
	Coastal flooding	Intensification of extreme events	Ali et al., 2020 Bandyopadhyay, 2019 Hazra et al., 2002 Kundu et al., 2021 Sahana et al., 2021 Singh and Singh, 2007
Shifts in hydrodynamics	Waves	Waves	Das, 2015
	Tides	Tides	Bandyopadhyay, 2019
Biogeochemical and physical flows	Nutrient leak	1 Increase in dissolved nitrate concentration	Chanda et al., 2001 Mitra, 2020 Ramesh et al., 2019 Ray et al., 2014 Swaney et al., 2015

		2 Increase in dissolved phosphate concentration	Mitra, 2020
	Pollution and contamination	1 Arsenic contamination	Expert judgement Nath et al., 2021
		2 Plastic pollution	Adyel and Macreadie, 2021
	Carbon	Carbon sequestration	Nishat et al., 2019 Verma et al., 2015
	Freshwater cycles	Salinity exposure	Islam and Gnauck, 2011 Nishat et al., 2019 Sarkar et al., 2013
	Sediment cycles	Coastal erosion	Hazra et al., 2010 Nishat et al., 2019 Rahman, 2012 Sánchez-Triana et al., 2014

Table 2- *Indicators and data sources used for the Social and cultural domain for the Circles of Coastal Sustainability framework*

Category	**Sub-category**	**Indicator used**	**Data sources**
Societal benefits	Goods and services	Nutrition from wild freshwater fish	Dasgupta et al., 2017 Dasgupta et al., 2020
	Water quality	Access to clean water	BBS, 2012 CEGIS, 2012 Dasgupta et al., 2020 Nishat et al., 2019
Demographics	Population/Age/ Structure/Trends	Population demographic (density, male /female ratio, literacy rate)	BBS, 2011 Census of India, 2011 Nishat et al., 2019 Anonymous, 2022 (www.worldometers.info)
	Migration and immigration	Population in-flows and out-flows	BBS, 2012 Danda et al., 2011

			Didar-Ul Islam and Bhuiyan, 2016 Nicholls et al., 2020 Nishat et al., 2019 Saha and Goswami, 2020 Statistical Handbook of West Bengal, 2010-2011
	Social class	Poverty levels	Islam, 2010 Islam and Chuenpagdee, 2013 Nishat et al., 2019 Sanchez-Triana et al., 2014
Social wellbeing	Recreation and access	Access to nearby cities and ports	Mangroves for the Future, 2015 Nishat et al., 2019 Sanchez-Triana et al., 2014
	Foods and water security	1 Water security	BBS, 2012 Dasgupta et al., 2020 Nishat et al., 2019 Sanchez-Triana et al., 2014
		2 Food security (undernourishment)	BBS, 2012 Dasgupta et al., 2020 Fanzo et al., 2018 Kalaivani and Premachandran, 2018 Sanchez-Triana et al., 2014
	Health	Presence of adequate healthcare facilities	Kanjilal et al., 2010 Nishat et al., 2019

			Sanchez-Triana et al., 2014
Identity	Sense of place	No of tourists/ year	Nishat et al., 2019
	Sense of self	Cultural landscape and traditional knowledge	Nishat et al., 2019
Social resilience	Vulnerability	Social vulnerability	Adger and Kelly, 1999 Dasgupta et al., 2015 Dasgupta et al., 2020 Nishat et al., 2019
	Education	Literacy rate of population	CEGIS, 2012 Census of India, 2011 IUCN, 2014b Nishat et al., 2019

Table 3- *Indicators and data sources used for the Economics domain for the Circles of Coastal Sustainability framework*

Category	**Sub-category**	**Indicator used**	**Data sources**
Security	Livelihoods	Yearly and seasonal livelihoods	Census of India, 2011 Expert judgement Nishat et al., 2019
	Gender	Percentage of employed women	Adams et al., 2018 Census of India, 2011 Dasgupta et al., 2020 Expert judgement Nicholls et al., 2018 Nishat et al., 2019
	Employment patterns	Exploitative and hazardous occupation	Islam and Chuenpagdee, 2013 Nishat et al., 2019
Infrastructure	Energy supply	Proportion of population with	Sanchez-Triana et al., 2014 Nishat et al., 2019

		access to electricity	
	Tourism	Tourism infrastructure	Nishat et al., 2019
	Transport	Transboundary goods navigation	Nishat et al., 2019
	Access	Existence of roads, waterway, ports, buses, railways, airports	Nishat et al., 2019
Economic wellbeing	Equality	GINI Index	World Bank data (https://data.worldbank.org/indicator/SI.POV.GINI?locations=BD-IN)
	Income	Income sources and levels	Adams et al., 2018 Census of India, 2011 Dasgupta et al., 2020 Sanchez-Triana et al., 2014
	Housing	No of members living in each household	Adams et al., 2016 Adams et al., 2018 Sanchez-Triana et al., 2014
Industry	Renewable sources	Ecotourism	Dasgupta et al., 2020 Expert judgement Nishat et al., 2019
	Extractive sources	Fisheries and aquaculture	Dasgupta et al., 2020 Nicholls et al., 2020
Dependency	Dependency on coastal resources	Dependency on Sundarbans and its resources	CEGIS, 2012 Islam, 2010 Mallick et al., 2021 Nishat et al., 2019

			Sanchez-Triana et al., 2014 Singh et al., 2010
	Diversification of activities	Livelihood diversification	Nishat et al., 2019

Table 4- *Indicators and data sources used for the Governance and policy domain for the Circles of Coastal Sustainability framework*

Category	**Sub-category**	**Indicator used**	**Data sources**
Organization	Civil and NGOs	Existence of collective action groups	Dey et al., 2016 Expert judgement Haq et al., 2015 Nishat et al., 2019 Sahana-Triana et al., 2014
Law and justice	Legislation	Existence of legislation to rule over coastal and related resources	Allan et al., 2013 Dey et al., 2016 Expert judgement Haq et al., 2015 Nishat et al., 2019 Sahana-Triana et al., 2014
	Efficacy	Regulatory quality and effectiveness	Dey et al., 2016 Expert judgement Haq et al., 2015 Hoq, 2007 Nishat et al., 2019 Roy and Allam, 2012 Sahana-Triana et al., 2014
	Enforcement	Transboundary governance	Dey et al., 2016 Expert judgement Haq et al., 2015 Nicholls et al., 2020 Nishat et al., 2019 Sahana-Triana et al., 2014

Representation and power	Effectiveness	Voice and accountability in environmental issues	Dey et al., 2016 Expert judgement Haq et al., 2015 IUCN, 2014b Nishat et al., 2019 Roy and Allam, 2012 Sahana-Triana et al., 2014
Legitimacy and accounting		Democratic task allocation among agencies and departments	Dey et al., 2016 Expert judgement Haq et al., 2015 IUCN, 2014b Nishat et al., 2019 Sahana-Triana et al., 2014
Resource management	Plans	Sectoral policies and plans	Dey et al., 2016 Expert judgement Haq et al., 2015 Salehin et al., 2018
	Management	Environmental management	Dey et al., 2016 Expert judgement Haq et al., 2015 Nishat et al., 2019 Sahana-Triana et al., 2014