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RISK FACTORS ASSOCIATED WITH DESTRUCTION OF SUNDARBANS MANGROVE FOREST, BANGLADESH: A REVIEW FROM CLIMATE CHANGE PERSPECTIVE

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Abstract

Sundarbans mangrove forest is the largest continuous mangrove track of the world which is shared by Bangladesh and India. The Sundarbans reserved forest of Bangladesh constitutes around 51% of the country's protected area and more than 3 million people depend on its resources. But the forest is under threats by anthropogenic interventions and climate change. The objective of this paper is to synthesize published works on the impact of climate change on Sundarbans. This paper is based on the desktop review of relevant literature focused on the impact of climate change on Sundarbans. Snowball sampling method was used to select relevant literature. This article conceptualizes from the spatial and temporal point of view. Along with the anthropogenic pressure, climate change has sped up the annihilation of Sundarbans though increasing level of salinity, decreasing freshwater supply, irregular rainfall and sea level rise. The frequency and severity of landfalls of cyclonic storms over the coastal zones increased in the last couple of decades. Projection suggests that one-meter rise in sea level is enough to make Sundarbans disappear from the map of Bangladesh. Comprehensive conservation measures need be taken at the local, regional, national and international level to protect the world's largest mangrove forest.

Keywords*: Sundarbans reserved forest; impact of climate change; sea level rise; Bangladesh.*

Introduction

Mangroves include the provision of a large diversity of timber and non-timber forest products; protect coastal zone against strong winds, waves and water currents; conserve biological diversity, such as endangered amphibians, birds, mammals and reptiles; provision of habitat, spawning grounds and nutrients for fishes and shellfishes; and protect coral reefs sea-grass bed and shipping lanes against siltation [1]. The densely populated climate fragile country, Bangladesh has shared the world's largest mangrove forest with India. Around 38% of the world's mangroves are found in Asia of which 19% are located in Indonesia [1]. Although most of the mangroves occur in small patches in different deltaic habitats, the Sundarbans Mangroves Forest (SMF) is the largest continuous mangrove forest in the world [2-4]. The SMF is divided between Bangladesh (also known as Sundarbans Reserve Forest) and India (also known as Sundarbans National Park). The Sundarbans is recognized as United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site (798th) for its unique ecosystem, and a Ramsar site (560th) for its importance as an internationally

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significant wetland [1, 5]. An area of 1,397km^2 of Sundarbans forest land is considered as World Heritage Site under the Ramsar Convention [6, 7].

During the Mughal Period (1203-1538), the northern boundary of Sundarbans extended from Hatiagarh (south of Diamond Harbour of West Bengal, India) to Bagerhat district (erstwhile southern part of Jessore, Bangladesh) and to Haringhata alongside the southern portions of Khalifatabad, Satgaon and Sirkars. The area of SMF was mapped in 1764, after obtained proprietary rights the East India Company in 1757 [8]. Between 18th and 19th century, the boundary of the Sundarbans extended inland to a distance of 60 miles and towards the Bay of Bengal about 170 miles expanding from the estuary of the Hoogly and Meghna River [9]. Between 1830 and 1875, a large portion of the forest cleaned out. In 1869, the Forest Management Division established its jurisdiction over the Sundarbans [8]. In 1875-76, under the Forest Act 1965 (Act VIII of 1965), the Sundarbans was declared a Reserved Forest [8].

The boundary of the reserve forest of the greater Khulna district, comprising of Khulna district, Bagerhat district and Satkhira district [10], did not undergo any major change since 1876, except small-scale deforestation in the last part of 19th century and the beginning of 20th century [11]. After the partition of the Indian subcontinent in 1947, the Sundarbans has been divided between Bangladesh (erstwhile East Pakistan) and India.

The Sundarbans Mangroves Forest extends over southwest coastal districts (Bagerhat, Khulna and Satkhira district) of Bangladesh and southeastern coast of West Bengal in India [12]. The present area of this mangrove forest covers an area of about 10,000km^2 in the southwest region of Bangladesh and West Bengal of India [2, 4, 12 -16]. Around 62% of this forest cover is located in Bangladesh [2, 4, 14] while rest of the forest cover (38%) is in India [4, 7, 14, 17]. The Sundarbans Reserved Forest (SRF) is now situated at the southern periphery of Ganges delta [2-4] which is bounded by Baleswar River on the east and Harinbanga River (international boundary with India) on the west [13, 18] (Figure 1). In Bangladesh, the Sundarbans reserved forest covers approximately 6017km^2 [7, 19] which is around 4.07% of the total land area [20] and over half of all reserve forest area of the country.

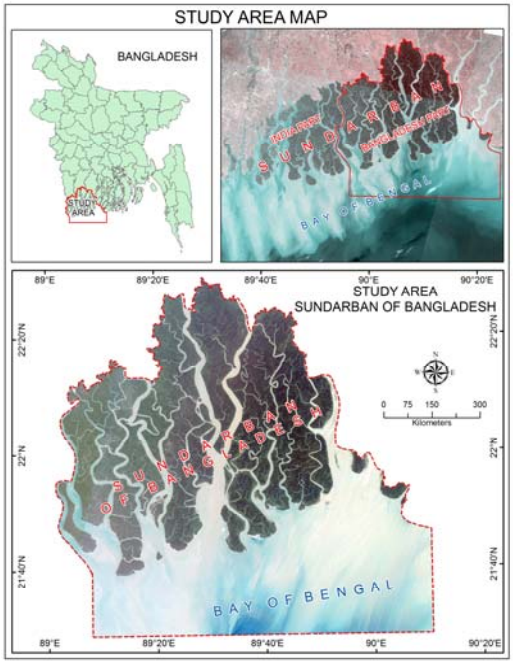

Fig. 1. Location of Sundarbans Reserved Forest in Bangladesh

The Sundarbans mangrove forest is the largest productive mangrove forest of the world [14, 21]. It supports a diverse unique ecosystem and a large number of plants and animals species [14]. The notable faunal species are Royal Bengal Tiger, spotted deer, dolphins, and many more [10, 14]. The estuaries and waterways hold a rich source of marine biodiversity, which is of great value both ecologically and economically. This forest also has a rich floral diversity [14] including Sundari (*Heritiera fomes*), Gewa (*Excoecaria agallocha*), Golpata (*Nipa fruticans*), Passur (*Xylocarpus mekongensis*), Goran (*Ceriops decandra*), and Keora (*Sonneratia apetala*). The role of Sundarbans in the environmental process is also significant. This forest is playing a vital role to maintain a balance and protect coastal wetland ecosystems of the Bengal Basin. It also acts as a natural protection for the lives and properties of coastal communities from tropical cyclones and storm surges [13-14, 16]. It is also the largest source of forest resources of the country. It offers livelihoods for millions of frontier population [13, 14], (around 18% of total households of impact zone) including fishermen, honey collectors, woodcutters, fuelwood collectors, shell collectors, etc [10, 14]. Sundarbans reserve forest is the richest and most economically valuable natural forests of the country. It constitutes more than half (about 51%) of the total reserved forest of the country and shares about 50% of the total forest revenue [7, 22, 23]. Several manufacturing factories are grown surrounding this forest as it provides raw materials for industries. In addition, thousands of poor coastal communities engage in generating their income [14] through harvesting non-wood forest resources, like, honey, medicinal plants, wax and many more. It produces a variety of crabs, fishes and shrimps. The forest serves as the largest carbon asset pool of the country [24].

Worldwide mangrove forest is under threat [14]. In 2005, the estimated area of mangrove forest in the world was 152,000km^2 that decreased from 188,000km^2 in 1980 [1]. Sundarbans is also under threats because of anthropogenic interventions, such as human encroachment, shrimp farming, crab farming, frontier agriculture, pollution, and above all lack of awareness. The land use of Sundarbans is likely to be altered directly or indirectly by anthropogenic interventions. This anthropogenic pressure on Sundarbans has been increasing in manifolds over the last few decades. Along with those anthropogenic stresses, another dimension of pressure has recently been imposed on Sundarbans in the form of climate change. It is true that Sundarbans has a highly fragile ecosystem [14] and its delicate balance [25] may be adversely affected if these pressures are not dealt with. On this background, the objective of this paper is to synthesize the observed and projected impact of climate change on Sundarbans reserve forest in Bangladesh.

Methodology

This research was based on a review of published literature mainly focused on the impacts of climate change on Sundarbans Reserve Forest in Bangladesh. Snowball sampling method was applied to identify potential literature. The potential articles and reports were identified by Google search engine. Climate change, Sundarbans and Bangladesh were used as keywords to find journal articles and reports. After removing duplication, irreverent articles and reports, 9 journal articles, 11 reports, 7 conference papers and 5 books included in this study (Fig. 2). In addition, 8 relevant references included manually for this study. The language of all those articles and reports was English.

Results and discussions

Climate change and Bangladesh

Climate change is the biggest challenge for the humanity. The intensity, frequency and severity of climatological disasters have increased in recent years. Climate change may alter the disaster risk by increasing risks related to weather, sea level rise and temperature and rainfall

variability. The funnel-like geographical shape of Bangladesh is recognized as one of the most climate vulnerable countries of the world. The coast of the country is a global hotspot for tropical cyclones. The coastal area represents around 32% of country's total geographical area [10] and about 10% of the country's total land lies 1m above the mean sea level (MSL). The coastal zone is divided into three distinct geo-morphological zones- eastern, central and western coastal zones [26]. Ganges tidal plain is located in western portion that lies below 1.5m MSL. The erosion and accretion are very much active in the central zone. The Sundarbans mangrove forest is situated in the southwestern zone where erosion is comparatively low but salinity and tidal flooding is high.

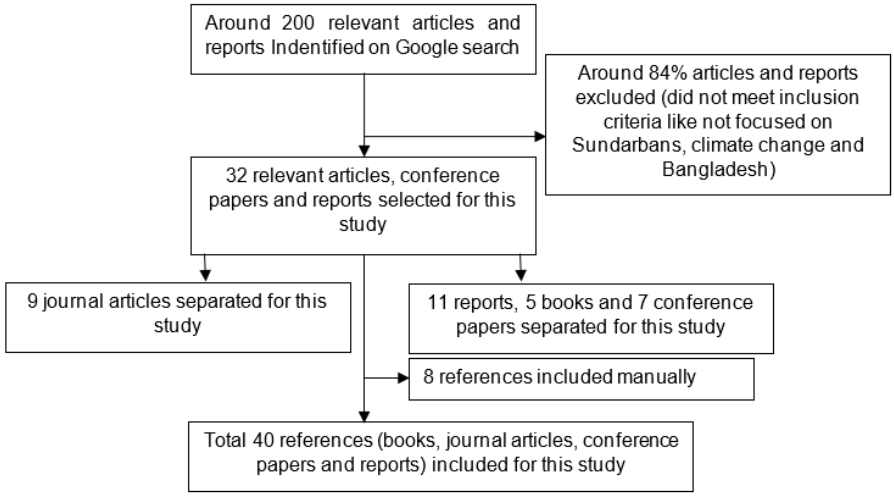

Fig. 2. Process of literature review for this study

The impacts of climate change are now visible in Bangladesh as extreme temperature, irregular or excessive precipitation, and increased frequency of extreme events like cyclones, droughts, floods [27]. The mean monsoon and winter temperature of Bangladesh will increase by 0.7°C and 1.3°C respectively by 2030 (based on the general circulation models) [28]. Climate change will also hamper the precipitation pattern through increasing likelihood of monsoon precipitation (May to September) and decrease dry season precipitation (December to February) [27]. The frequency of formation of tropical cyclones and increase in sea surface temperature are correlated. Generally, cyclones are formed in the deep sea if the temperature of the sea surface reaches a threshold value of around 27°C [3, 29]. The sea level along the coast of the country is increasing at about 3 mm per year and temperature of the sea surface is showing an increasing trend [29]. Interpolation suggested that 10 cm rise in sea level could inundate 2500 km^2 (about 2% of total land area) and 100 cm can inundate 25000 km^2 (about 17.5% of total land area) land of the country [29]. This increase in sea level would result salinity ingression in the coastal zone as well as the mainland of the country.

Observed impact of climate change on Sundarbans

The occurrence and development of mangrove forest depend on distinct environmental factors including temperature, precipitation, sedimentation, level of salinity, ocean current, freshwater flow, and so on [2]. Intergovernmental Panel on Climate Change (IPCC) predicted that climate change will probably deteriorate the state of tropical forest ecosystems [30]. Sundarbans mangrove forest is the innocent victims of climate change in several ways. The notable impacts in the form of sea level rise, increased frequency and severity of the cyclonic

storm, irregular rainfall, salinity ingression, and so on. Those changes will have a definite adverse impact on Sundarbans, and the lives and livelihoods of the frontier population.

Sundarbans serves as a barrier to the tropical cyclones and storm surges [10, 14]. The numbers of cyclone formations in the Bay of Bengal are increasing [4]. Sundarbans is the immediate path of tropical cyclonic storms formed in the Bay of Bengal. Between 1876 and 1964, there was only one severe cyclone over North Bay of Bengal with a wind speed of more than 200 km/h, but during 1965 to 2010 (45 years) it was 9 [31]. Among them, 7 severe cyclones were landfall within 20 years (between 1991 and 2010). Cyclone Sidr was the most devastating that landfall on 15th November 2007 with an average wind speed of 223 km/h, causing more than 3000 casualties [32]. It caused serious destruction to the forest, such as trees were uprooted and broken down, thousands of animals died, saline water flushed into the forest causing freshwater scarcity for biotic species. The other notable one was cyclone Aila (landfall on 25th May 2009) that endangered lives and livelihoods of millions of coastal communities [32]. After those back to back cyclones, the impact of climate change has become more pronounced in the southern coast of the country.

Around 233 km^2 the forest lost due to coastal erosion between 1973 and 2010 [33]. Under certain scenarios of sea-level rise and net subsidence, the Sea Level Affecting Marshes Model (SLAMM) model projected that erosion may be the dominant loss driver to 2100 and the estimated net mangrove area losses (relative to the year 2000) would be 81km^2 - 178km^2, 111km^2 - 376km^2 and 583km^2 - 1393 km^2 with the sea level rise scenario of 46cm, 75cm and 148cm respectively and subsidence of ±2.5 mm/year [34].

The freshwater flow in Sundarbans depends on upstream river flow [14]. The largest perennial distributary of the Ganges River was Gorai River that supply freshwater for the southwestern region of Bangladesh [3]. This river also carries freshwater for Sundarbans. However, the water flow of Gorai River has declined since 1975 after the commissioning of Farakka barrage by India, about 190 km upstream of the Gorai mouth [3, 7, 18, 25]. The purpose of diverting the Ganges water through the Hoogly River was to navigate the Kolkata port [3, 27] in India. After that, the dry season discharge of the Ganges River or the Padma River in Bangladesh decreased dramatically. Around 7 out of the 15 distributaries are now nearly dead while 8 others are flowing timidly [35]. Since 1988, the dry season flow (November to April) of Gorai River has been completely disconnected from the Ganges flow [7, 14, 27]. The rivulets and creeks of the forest also play a vital role to flush away the saline water and maintain a balance between fresh and saline water [3]. Freshwater flow through the rivers helps to flush the salinity off from the forest floor. This chronic disturbance of freshwater flow change salinity regime [4]. The decrease in water flow encourages sedimentation that block different channels and further periodic or permanent inundation around the forest could be observed.

On the basis of salinity, the Sundarbans Reserve Forest is divided into 3 zones such as strong saline zone (25-30 parts per trillion [ppt]), moderately saline Zone (15-25 ppt) and less saline zone (5-15 ppt) [36]. The level of salinity of the forest increases from eastern zone to western zone [7, 14], and the density of vegetation cover growth and canopy closure reduces [4] from eastern zone to western zone. Moreover, growth and height of different mangrove species in the forest depend on the level of salinity [14]. For example, Sundari trees grow in the low saline zone (5~10 ppt), Gewa trees in the moderate saline zone (10~25 ppt) and Goran trees in the strong saline zone (over 25 ppt) [14]. The Sundarbans have already affected by increasing salinity. There is a strong correlation between the top dying disease of Sundari trees and the consequence of increasing salinity over a long period of time [4, 37]. Sundari trees are being perished by the outbreak of top-dying disease [10, 14]. Top-dying diseases of Sundari trees are endemic where the numbers of pneumatophores (breathing roots) are significantly less [38]. The intensity and speed of spread of the top dying disease have increased after cyclone Sidr. The development of undergrowth species also depends on salinity, for example, the rich

diversity of undergrowth is an indication of healthy mangrove forest in the low saline zone, whereas, poor diversity and stunted growth of undergrowth represent ill mangrove forest of strong saline zone [2]. Moreover, the surface water temperature has increased 0.5°C per decade over the past three decades (1980 and 2007) in the (Indian) Sundarbans which was higher than the globally observed warming rate of 0.06 °C per decade [39].

Projected impact of climate change on Sundarbans

Sundarbans is going to lose its richness and diversity. This forest is now in a premature transitional stage as a result of human interventions particular changes in hydrological flow from the upstream [14]. This anthropogenic interfere would be accelerated by climate change and sea level rise in the next 50 years [21]. The National Biodiversity Strategy and Action Plan for Bangladesh (2005) have clearly predicted that by 2050 the many changes may observe to Sundarbans: such as, freshwater mangroves will replace by saline water mangroves; decline total mangrove area, biodiversity and timber production; and increase mesophytic vegetation area and use of non-timber forest products [21].

Sea level rise is also a serious threat to the forest. Inundation and ingression as a result of sea level rise may create adverse impacts on Sundarbans and its ecosystem services. Sundarbans will be submerged by the sea level rise. Around 15% of the forest will go underwater as long as the sea level rise by 10cm, 40% by 25cm, 75% by 45cm and will be lost forever under 100cm sea level rise [29].

Due to the impact of climate change, valuable species like Sundari trees will be replaced by less valuable Goran trees and Gewa trees [3 - 4, 14, 29]. Estuarine fish species could reduce their diversity and richness as long as the breeding ground of Sundarbans and other coastal wetlands decreased. Saline water will move in inland (in deltas) a result of sea level rise. This may lessen freshwater habitat although habitat for estuarine fish can increase [29].

The study of Center for Environmental and Geographic Information Services (CEGIS) found that the suitable area for Sundari tree and Gewa tree will be decreased by 45% and 7% respectively by 2100 with 88cm SLR from the base year 2001(Table 1) [36]. This change in floristic composition in Sundarbans may hamper the wildlife diversity of the forest and that it may lead to the gradual extinction of the forest. Moreover, the gross merchantable timber volume per unit area of Sundarbans will decline with the increased level of salinity in soil and river [40].

Table 1. Suitable area of Sundari and Gewa trees under different sea level rise scenarios (Source: CEGIS, 2006)

Year	Suitable area (ha)	
	For Sundri	For Gewa
2001 (Base)	80489	59027
2050 (under 32 cm SLR)	69571	58992
	(-14%)	(-0.06%)
2100 (Under 88 cm SLR)	43884	55021
	(-45%)	(-7%)

The impact of climate change on Sundarbans will be more evident during the dry season. The seasonal salinity distribution of the forest will also be affected by the climate change. The highest level of salinity will increase during monsoon season (average 4 practical salinity units [psu]), followed by winter season (average 2.4 psu), post-monsoon season (average 1.8 psu) and pre-monsoon season (average 1.7 psu) for the 2080s, compared to baseline condition during 1991-2010 [41]. The temperature rise in winter may speed up evapotranspiration rate from the forest [25]. A decrease in precipitation will affect freshwater flow through the forest which also directly hinders evapotranspiration systems. This will hamper the normal growth of fresh water-loving species [29]. These combined effects of the above scenarios will further promote salinity ingression into the forest regime and its adjacent land boundary. The existence of current

mangrove depends on the quality of forest environment. The biodiversity of Sundarbans would be deteriorated due to the unfavorable forest environment.

Conclusions

Climate change is not now assumption which is already turned out in the earth. Impact of climate change in south-western coast of the country is reality nowadays. The Sundarbans Reserved Forest is well conserved, and no major changes observed during 1980 to 2005 [1]. However, due to overexploitation, the total merchantable volume of Sundari tree and Gewa tree have been decreased by 40% and 45% respectively compared to 1959 inventory [10]. Along with this anthropogenic pressure, climate change creates another threat to the forest in the form of top-dying disease.

The impact of climate change on Sundarbans is a thought-provoking issue among the communities and policy makers. Increase in sea level and salinity level, and shrinking in biological diversity and reserve forest area will loop back with the sustainable resource harvesting from the Sundarbans. Millions of frontier communities are directly engaged to collect resources from the forest as a means of their livelihoods. The SRF depended livelihoods are going to be endangered due to the shrinking of livelihoods opportunities. As a result, people will search for alternative livelihoods opportunities. This may responsible for a mass migration from the periphery of Sundarbans because of the impact of climate change on a single forest.

Coastal zone was affected by two devastating cyclones in 2007 (cyclone Sidr) and in 2009 (cyclone Aila). These two cyclones endangered lives and livelihoods of coastal communities. Thousands of families from Koyra and Dacope upazila were displaced on nearby embankments, roads or collective centres after cyclone Aila [42]. Many people seasonally migrated from their locality for livelihoods and to some extend dependency of some people on Sundarbans increased. Therefore, climate-induced extreme events may speed up poverty trap in Sundarbans locality that may further increase dependency on Sundarbans. The vicious cycle of human poverty and impact of climate change on Sundarbans can play a crucial role to the depletion of Sundarbans forest resources. Hypothetically, if the government of Bangladesh develops strong policies and takes effective and efficient legal measures to conserve Sundarbans from anthropogenic interventions, even Sundarbans will further be degraded because of climate change [43].

The SRF plays a significant role in the south-western coastal communities. But the forest is being degraded day by day. Therefore, comprehensive conservation measures need be taken at the local, regional, national and international level to protect the world's largest mangrove forest, Sundarbans. Finally, trans-boundary river management is urgent to protect Sundarbans from human-induced climate change impacts.

References

[1] Food and Agricultural Organization (FAO). **The world's Mangroves 1980-2005**, Food and Agricultural Organization, Rome, Italy, 2007.

[2] S. H. Rashid, R. Böcker, A. B. M. E. Hossain, S. AA. Khan, *Undergrowth species diversity of Sundarban mangrove forest (Bangladesh) in relation to salinity*, **Berlin Institute Landschafts-Pflanzenökologie Univ. Hohenheim, 17**, 2008, pp. 41-56.

[3] S. Agrawala, T. Ota, A .U. Ahmed, J. Smith, M.V. Aalst, **Development and climate change in Bangladesh: focus on coastal flooding and the Sundarbans**. Organisation for Economic Co-operation and Development, Paris, 2003.

[4] A. Ghosh, S. Schmidt, T. Fickert, M. Nüsser, *The Indian Sundarban mangrove forests: history, utilization, conservation strategies and local perception*, **Diversity**, **7**(2), 2015,

pp. 149-169.
[5] UNESCO World Heritage Centre (UNESCO-WHC), **The Sundarbans**, http://whc.unesco.org/en/list/798 [accessed on 10. 10. 2017]
[6] J. K. Choudhury, M. A. Hossain, **Bangladesh forestry outlook study. Asia-Pacific Forestry Sector Outlook**, Food and Agriculture Organization, Bangkok, 2011.
[7] M. S. N. Islam, A. Gnauck, *Threats to the Sundarbans mangrove wetland ecosystems from transboundary water allocation in the Ganges basin: A preliminary problem analysis*, **International Journal of Ecological Economics & Statistics**, **13**(9), 2009, pp. 64-78.
[8] R. Khan, *Wildlife of the Sundarban*, **Sundarban Rediscovering Sundarban The Mangrove Beauty of Bangladesh** (Editor: R. Khan), Nymphea Publication, Dhaka, 2013, p.36.
[9] B. Barua, *The Beauty and Vulnerability of the Sundarban*, **Sundarban Rediscovering Sundarban The Mangrove Beauty of Bangladesh** (Editor: R. Khan), Nymphea Publication, Dhaka, 2013, p.28.
[10] M. S. Iftekhar, M. R. Islam, *Managing mangroves in Bangladesh: A strategy analysis.* **Journal of Coastal Conservation, 10**(1-2), 2004, pp. 139-146.
[11] S. Tabassum, **Everything You Wanted to Know about the Sundarbans,** International Union for Conservation of Nature and Natural Resources, Dhaka, Bangladesh, 2000.
[12] Z. Hussain, G. Acharya, ***Mangroves of the Sundarbans. Volume 2***, IUCN, Bangkok, 1994.
[13] C. Giri, B. Pengra, Z. Zhu, A. Singh, L. L. Tieszen, *Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000*, **Estuarine, coastal and shelf science**, **73**(1), 2007, pp. 91-100.
[14] L. D. De Lacerda, ***Mangrove ecosystems: function and management***, Springer Science & Business Media, New York, 2002.
[15] M. Spalding, M. Kainuma, L. Collins, **World Atlas of Mangroves**, Earthscan, UK, 2010.
[16] M. K. Ghosh, L. Kumar, C. Roy, *Mapping Long-Term Changes in Mangrove Species Composition and Distribution in the Sundarbans*, ***Forests***, **7**(12), 2016, p. 305.
[17] K.M. Alam, *Integration of Socio-economic and Ecological Data in Conservation and* Management of Floral Diversity in the Sundarbans, **Proceedings of the National Workshop on Mangrove Research and Development,** 15th -16th May 2001, Chittagong, Bangladesh Forest Research Institute.
[18] A. Aziz, A. R. Paul, *Bangladesh Sundarbans: present status of the environment and biota*, **Diversity**, **7**(3), 2015, pp. 242-269.
[19] N. A. Siddiqi, *The Importance of Mangroves to the People in the Coastal Areas of Bangladesh*, **Proceedings of VII Pacific Science International Congress, International Society for Mangrove Ecosystems**, Tokyo, Japan, 1994
[20] Bangladesh Bureau of Statistics (BBS), **Statistical pocketbook of Bangladesh-2013,** Bangladesh Bureau of Statistics, Dhaka, 2014.
[21] Ministry of Environment and Forests (MoEF), **National Biodiversity Strategy and Action Plan for Bangladesh,** Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh, 2005.
[22] K. M. Islam, **A study of the principal marketed value chains derived from the Sundarbans reserve forest**, Integrated Protected Area Co-management, Dhaka, Bangladesh, 2010.
[23] M. S. Shah, K. A. Huq, S. M. Rahman, **Study on the conservation and management of fisheries resources of the Sundarbans,** Integrated Protected Area Co-Management (IPAC), Dhaka, Bangladesh, 2010.
[24] Multidisciplinary Action Research Center (MARC), **Socioeconomic studies on the Sundarbans reserved forest**, Food and Agricultural Organization, Dhaka, Bangladesh, 1995.

[25] A. Nishat, *Climate Change Impact and the Sundarban*, **Sundarban Rediscovering Sundarban The Mangrove Beauty of Bangladesh** (Editor: R. Khan), Nymphea Publication, Dhaka, 2013, p.36.

[26] M. R. Islam, **Where land meets the sea: a profile of the coastal zone of Bangladesh**, University Press Ltd, Dhaka, Bangladesh, 2004.

[27] S. Dasgupta, F. A. Kamal, Z. H. Khan, S. Choudhury, A. Nishat, *River salinity and climate change: Evidence from coastal Bangladesh*, **Policy Research Working Paper 6817**, World Bank, Washington, D.C., 2014.

[28] A.U. Ahmed, M. Alam, *Development of Climate Change Scenarios with general Circulation Models*, **Vulnerability and Adaptation to Climate Change for Bangladesh** (Editors: S. Huq, Z. Karim, M. Asaduzzaman, F Mahtab), Kluwer Academic Publishers, Dordrecht, 1998, pp. 13-20.

[29] World Bank, **Bangladesh: Climate Change & Sustainable Development,** Rural Development Unit, South Asia Region of World Bank, 2000.

[30] Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers' in Climate Change 2007: Mitigation*. **Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,** (Editors: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer), Cambridge University Press, U, 2007.

[31] International Resources Group (IRG), **State of Bangladesh's Forest Protected Areas'2010**, Integrated Protected Area Co-management, Dhaka, Bangladesh, 2012.

[32] Forest Department (FD). **Integrated resources management plans for the Sundarbans (2010-2020), vol.1,** Forest Department, Ministry of Environment and Forests, Dhaka, Bangladesh, 2010.

[33] M. M. Rahman, *Time-series analysis of coastal erosion in the Sundarbans mangrove. International Archives of the Photogrammetry,* **Remote Sensing and Spatial Information Sciences, 39**(B8), 2012, pp. 425-429.

[34] A. Payo, A. Mukhopadhyay, S. Hazra, T. Ghosh, S. Ghosh, S. Brown, R. J. Nicholls, L. Brichen, J. Wolf, S. Kay, A. N. Lázár, A. Haque, *Projected changes in area of the Sundarban mangrove forest in Bangladesh due to SLR by 2100,* **Climatic Change, 139**(2), 2016, pp. 279-291.

[35] S. A. Haq, *Impact of climate change on 'Sundarbans', the largest mangrove forest: ways forward,* **Proceedings of the 18th Commonwealth Forestry Conference;** 28th June– 2nd July, 2010, Edinburgh International Conference Center, Scotland, UK.

[36] Center for Environmental and Geographic Information Services (CEGIS), **Coastal Land Use Zoning in the South-west: Impact of Sea Level Rise on Landuse Suitability and Adaptation Options**, Center for Environmental and Geographic Information Services, Dhaka, 2006.

[37] A. Rahman, *Diseases and Disorders of Tree Species in the Sundarbans and Their Management.* **Proceedings of the National Workshop on Mangrove Research and Development,** 15th -16th May 2001, Chittagong, Bangladesh Forest Research Institute, pp. 86-97.

[38] S. Islam, *Healing of the Sundarbans following Sidr,* **The Daily Star,** Dhaka, Bangladesh, 28 December 2007.

[39] A. Mitra, A. Gangopadhyay, A. Dube, A. C. Schmidt, K. Banerjee, *Observed changes in water mass properties in the Indian Sundarbans (northwestern Bay of Bengal) during 1980–2007,* **Current Science, 97**(10), 2009, pp. 1445-1452.

[40] D. R. Chaffey, F. R. Miller, J. H. Sandom, **A forest inventory of Sundarbans, Bangladesh**. Overseas Development Administration, Land Resources Development Centre, Surrey, England, 1985.

[41] M. A. Hussain, A. K. S. Islam, M. A. Hasan, B. Bhaskaran. *Changes of the seasonal*

salinity distribution at the Sundarbans coast due to impact of climate change. **Proceedings of the 4th International Conference on Water & Flood Management (ICWFM),** 4th -5th October, 2013, Institute of Water and Flood Management of Bangladesh University of Engineering and Technology, Dhaka, Bangladesh.

[42] S. H. Mondal, *The Critical Links between Socio-Demographic Dynamics of Sundarbans Impact Zone and Forest Resource Depletion, Bangladesh: A Review*, **Eurasian Journal of Science & Engineering, 2***(1*), 2016, pp. 41-52.

[43] S. H. Mondal, P. Debnath, *Spatial and Temporal Changes of Sundarbans Reserve Forest in Bangladesh*, **Environment and Natural Resources Journal**, 15(1), 2017, pp. 51-61.

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