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Climate Change Impacts on Mangrove Forests in South Asia: A Systematic Literature Review

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Abstract: *In South Asia, mangrove forests are found along the coasts of India, Bangladesh, Pakistan, and Sri Lanka. The region's coastal residents rely on the woods as key providers of products and services, and they also support critical ecological processes. Mangrove forests have survived long-term erosion events despite attests worldwide confirming past episodes of local and regional intervention, primarily in reaction to sudden rapid rising sea levels. The objective of this systematic literature review is to assess the impact of climate change on mangrove forests in South Asia, changes in temperature, rainfall, and increase in CO_2 concentration are also contemplated. The systematic review design was adopted for conducting this study. The articles for this review were searched through the keywords; "mangrove", climate change" "impacts of climate change", impacts of climate change on mangroves", and "south Asia". The scrutiny process was comprised of three steps. Firstly, 440 articles were identified through keyword searches. Secondly, 277 articles were removed through title analysis. Finally, 100 articles were selected for this review after a screening of the abstract and body of the paper. Through qualitative analysis and descriptive statistics, the analysis was completed. The finding reveals that the area of mangrove forests in South Asia is in the region of 1,187,476 ha which represents 8% of the total worldwide. Mangrove forests are particularly vulnerable to sea-level rise. The main reasons for the change in forest management are similar throughout the region, although specific factors may be concentrated in specific areas. All of these interact to determine the spatially variable resilience of populations to climate change impacts because mangroves vary in type and geographic location. Mangrove Southeast Asian forests account for about 6 to 8% of the world's total and are located along the coasts of Bangladesh, Sri Lanka, India, and Pakistan. These forests provide important environmental goods and services for biological ecosystems and the functioning of densely populated coastal populations. Forests are threatened by both natural and anthropogenic forces. Deforestation causes reduced freshwater runoff and reduced alluvium flow.*

Keywords: Climate change, mangrove forest, mangrove ecosystem, ecosystem services, sea level rise.

1. Introduction

Mangroves, which live at least horizontally at the land-sea interface, serve as climate change sentinels. (Pham et al., 2018). Mangrove forests, which are still plentiful in Southeast Asia, are among the most vulnerable ecosystems, and they are vanishing as a result of climate change and human activity (DasGupta & Shaw, 2013). Their marine habitat is physically and geologically effective, and it is these forces, which are constrained by changing temperature and environmental conditions, that continue to shape mangrove forests over time (V. Burkett & Davidson, 2012; Davis Jr & FitzGerald, 2009). In the face of environmental instability, mangroves have demonstrated community resilience and god-like ecological stability (Lewis & Conaty, 2012). Their survival is due to a combination of key features that result in ecosystems with both terrestrial and marine organisms, as well as high nutrient turnover rates, which makes architectural designs highly efficient in terms of facilitating and enhancing recovery from natural and anthropogenic disasters (Bohonak & Jenkins, 2003; Hiscock et al., 2004; Holl, 2020). Mangroves are vital nursery and breeding places for brushes as well as many other semi-terrestrial and marine creatures. They are also a renewable source of food for traditional medicine and wood for fuel (D. Alongi, 2009; King & Brown, 2011). Nonetheless, these woods have been delivering environmental services that contribute significantly to human well-being by minimizing the impact of coastal erosion and catastrophic events such as cyclones and tsunamis (Wells & Ravilious, 2006). In other words, if there is a market failure and, by definition, the market provides less system services (Liebowitz & Beckman, 2020). Researchers all across the world believe that the existence of mangrove forests is imperiled due to habitat fragmentation (P. L. Biswas & Biswas, 2020).

Effects on mangroves, particularly human influences on mangroves, including climate change, have gained a lot of attention recently, partly because these forests are being deforested at a rate of 1% to 2% annually, which implies that the majority of the woods will likely disappear within this times (D. M. Alongi, 2015; Sayer & Whitmore, 1991). Despite the high rate of destruction in developing nations with high poverty rates and population increase, mangroves continue to serve an essential role in human sustainability and livelihoods (Debrot et al., 2020). These forests are under stress and pressure from multiple angles, including sea level rise, resource exploitation, and climate change, all of which are exacerbated by a weak governance framework, resulting in the destruction of these ecosystems (Chapin III et al., 2010). Under these conditions, communities' ability to provide ecosystem services for the local and global communities is fast dwindling (R. Watson et al., 2019). Furthermore, the mangrove ecosystem services are expected to vanish totally within the next 100 years (Kuenzer & Tuan, 2013). Coastal mangroves are highly vulnerable to the effects of climate change over 2 degrees Celsius, primarily in areas of tropical and subtropical distribution, which can be predicted to encounter some of the harshest effects of climate change (Beaumont et al., 2011; Wang & Gu, 2021). On the other hand, the oceanic are exposed to a variety processing of caused by variations in sea level, such as storm surges, which are brief fluctuations in sea level (Karim & Mimura, 2008). Mangrove flora already occurs within an active intertidal habitat, and several species already exist sensitive to relatively minor changes in biological circumstances that are at or near the physical boundaries (Jennerjahn et al., 2017).

Several portions of the tropical and subtropical shorelines of South and South Asia are densely forested with highly productive mangrove forests (Polidoro et al., 2010). These mangroves are geographically classified as Indo-Malayan they are regarded as the most protected and oldest mangrove habitats in existence (DasGupta & Shaw, 2013). Its area was more than 6.14 million acres in 2009, and it is known to contain approximately 40.4% of the world's mangroves (Teutli-Hernández & Herrera-Silveira, 2018). The region's increasing need for mangrove acreage is challenged by unsustainable fish production, wastewater mixing, and changing landscapes (Lee et al., 2014), because the entire Eco zone is straddled by developing country political boundaries, the pattern of mangrove exploitation varies substantially due to competing economic priorities (Cochrane, 2021), Similarly, conservation and rehabilitation measures vary greatly depending on the country's sociopolitical landscape (Jungwirth et al., 2002). South Asian forests have long provided vital products

Providing services to the coastal inhabitants and ecosystem, such as storm protection, coastal stability, and ground water recharge (Ernstson et al., 2010).

The ecological significance of the mangrove forest ecosystem emerges in the marine environment established between the east coast and the intertidal environment of the shoreline, and the dynamic changes (Duke et al., 2021). Mangrove forests are critical for sustaining and improving ecological services that benefit both local and global societies (Getzner & Islam, 2020). As a result of these unique circumstances, only a small number of countries support biodiversity hotspots (Hanson et al., 2009). An environmental assessment research assesses the values of mangrove forests ability to serve in order to further highlight the economic worth of mangrove forests (Gunawardena & Rowan, 2005). Following the 2004 Indian Ocean tsunami, mangrove recovery and conservation activities gained prominence (Attavanich et al., 2015). Yet, identifying the complex ecosystem of mangroves is crucial to planning and implementing successful restoration techniques (S. R. Biswas et al., 2009). Mangroves provide genetically diverse ecosystems of aquatic and terrestrial fauna and flora that are economically, ecologically, and socially important to human societies all over the world, both directly and indirectly (Vo et al., 2012). Growing economic and human pressures in many tropical coastal areas have resulted in more unsustainable ecological development (Creel, 2003; C. D. Field, 1995). This knowledge is critical since coastal development is under threat from natural disasters and climate change, such as tsunamis and typhoons (Marois & Mitsch, 2015). Although research has proven that these woods can preserve lives and property during tsunamis, there have also been counterarguments presented (Chandra Giri et al., 2015).

According to recent research, Asian mangrove forests are among the most carbo-rich in the tropics, with a carbon content of 1.023 Mg of carbon factor, more than 51% of which is preserved in organically abundant soil (Maiti & Chowdhury, 2013). The purpose of this review is to critically assess the impacts of climate change on the mangrove ecosystem in south Asia, in addition to sea-level rise with a unique view of their oceanic nature, changes in the temperature, salinity, and rainfall pattern are the main focus.

2. METHODS

To conduct the systematic literature review employed in this study, this paper recommended reporting for reviews as well as meta-analyses. This approach is a published guideline that provides a process-based flow for researchers to study and interact with a wide range of validated resources, and it has also been adopted by certain researchers. The methodology procedure is divided into two major parts. First, the current literature on the topic of observation was reviewed and selected for collection for a paper, as well as those available for qualitative analysis. Second, relevant data relating to the problem statement was extracted and entered into a data sheet.

2.1 Setting

The study includes Bangladesh, Pakistan, India and Sri Lanka coastal areas, Mangroves are found in each country's specific coastal enclaves. Although, about 95% of mangroves in Pakistan are concentered near Sind province's Indus Delta, by the Arabian Sea. India mangrove is found in 4500 square kilometers with most of it on the east coast while only more than owing to the existence of rich resources on the west coast, 14% delta, the mangrove is found in the Andaman and Nicobar Islands. Most of them are found in East Bengal, mangroves occur in the Sundarbans in Bangladesh, protected forest are found in the Southeast’s Chittagong region, and in the nor0central region. Due to natural and anthropogenic forces, the main reasons for the change in forest management are the same throughout the region, but may dominant in certain areas and certain time.

2.2 Studies Selection

Conducting systematic literature reviews and meta-analysis the guidelines and observed reporting preferences for statements of literature that included the following five-steps methodology. (1) Identification of keywords, questions, (3) selecting eligibility criteria, (4) selecting studies according to criteria, (5) Included syntheses.

2.3 Search Strategy

This analysis was done in a bibliographic database, which is considered the most reliable in combination with Scopus. A number of studies have extensively compared the two databases, showing Scopus has wider coverage than the web of science, given the large number of findings, the inclusion criteria were limited and papers written in English were chosen, with grey literature being excluded. Search terms were honed and more searches were done based on the parameters. A total of about 400 articles were chosen and sent for screening, clearly reviewed for eligibility, and following the screening procedure about 100 were selected for qualitative analysis. Hence, the number of articles that conformed to these criteria was limited. A PRISMA flow chart in Figure 1 summarizes the overall process described in this phrase.

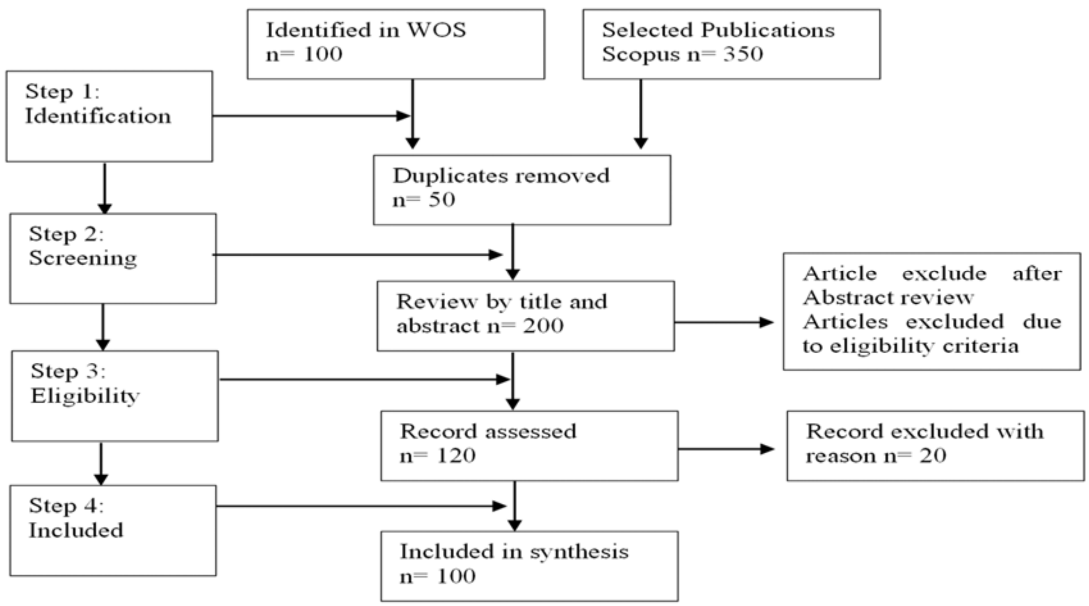


Figure 1 PRISMA flow chart

2.4 Data Extraction

Appropriate selection of studies as well as adequate data extraction for analysis is another important point. After selecting a sample of papers, manual data were extracted and summarized in a matrix of the absolute parameters. Based on the specific investigated area, the selection of climatic zone was done according to the koppenGeiger classification system.

1. RESULT

3.1 Impacts of Climate Change On Mangroves in South Asia

Mangroves have a variety of origins and effects on climate change, including carbon dioxide emissions, rising temperatures, rising sea levels, increasing and decreasing rainfall, changes in storm intensity as well as distribution (J. Ellison, 1994). Climate change can affect the components of the mangrove ecosystem in both positive and negative ways, and the effects of climate change can interact with one another (Ward et al., 2016). Species-specific reactions to the repercussions have an impact on how severe they are at the species level climate change, whereas they are more likely to be regulated through extensive environmental conditions at the habitat scale (Bellard et al., 2012). Despite the fact that climate change affects many components of the mangrove ecosystem, two markers of climate change impacts are the system's area extent and vegetation biomass, both of which are internationally well-suited (Gilman et al., 2008), This is related to the study of geographical patterns of climate change (Bryan-Brown et al., 2020).

Table 1 Predicted impacts of climate change on mangroves forest in South Asia

Climate Change	**Processes Impacted**	**Possible Effects**	**References**
Modifications to Ocean Circulation Patterns	▪ Gene flow ▪ Scattered	▪ Changes in community structure	(Lovelock & Ellison, 2007) (Kennedy, 1995)
Increase in Air And Sea Temperature	▪ Photosynthesis ▪ Respiration ▪ Productivity	▪ Reduced low-latitude production and enhanced high-latitude productivity over the winter	(Ficke et al., 2007) (Boisvenue & Running, 2006)
UVB Radiation	▪ Photosynthesis ▪ Morphology ▪ Productivity	▪ A few important effects.	(Teramura & Sullivan, 1994) (Kataria et al., 2014)
Sea Level Rise	▪ Productivity ▪ Forest cover ▪ Recruitment	▪ Loss of forest by the sea. ▪ Migration toward landward depends on sand grains and other factors and human changes in the landscape. ▪ Salt loss and Salt flats.	(Isdell et al., 2020) (Schaeffer-Novelli et al., 2016)
Enhanced CO2	▪ Biomass allocation ▪ Photosynthesis ▪ Respiration ▪ Productivity	▪ Productivity increases but it is limited and depends on other factors.	(Poorter & Nagel, 2000) (McGuire et al., 1995) (Pattison et al., 1998)
Rising Waves	▪ Recruitment ▪ Sedimentation	▪ Forest cover changes, depending on whether the cost is increasing or decreasing.	(Lovelock & Ellison, 2007) (J. C. Ellison, 2010)
Decrease in Rainfall	▪ Reduced groundwater ▪ Reduction in sediment supply ▪ Salinization	▪ Decrease in surface elevation above sea level	(Alam, 1996) (Hughes, 2004) (Kundzewicz & Doell, 2009)
Extreme Storm	▪ Reduced sediment retention ▪ Forest growth ▪ Recruitment reduced ▪ Subsidence	▪ Reduce forest cover ▪ Retreat to mangrove land.	(Lovelock & Ellison, 2007) (Gilman et al., 2008)
Decrease in Humidity	▪ Productivity ▪ Photosynthesis	▪ Damage of surface advancement comparative to sea level ▪ Retreat to mangrove land.	(Lovelock & Ellison, 2007) (Pennings & Bertness, 2001)

		▪ Mangrove invasion of salt marshes and freshwater wetlands. ▪ Mangrove invasion of salt marshes and freshwater wetlands	(J. C. Ellison, 2000) (McKee et al., 2012)
Increase in Rainfall	▪ Fewer saline habitats ▪ Increased sedimentation ▪ Enhanced groundwater ▪ Productivity	▪ Maintain altitude above sea level ▪ Increased productivity ▪ Restoration of surface elevation	(Lovelock & Ellison, 2007) (Krauss et al., 2014) (K. Rogers et al., 2005)

According to climate change forecasts, much of the world's landmass will face diminished air and drainage as a result of the mudslide (Dehn et al., 2000). The photosensitivity, growth, and reproductive productivity of commercial areas are affected by less rainfall; hypertrophication poses a serious risk; and salt and hypersaline plates have the potential to replace mangroves in Table 1(Sarkar, 2018). In arid and semi-arid climates, a shortage of rainfall concerns the survival of felt (Ifejika Speranza et al., 2010). These forests are home to tide-influenced geochronological systems with limited freshwater flow. Drought, in combination with other climate change stresses, has resulted in biomass loss and substantial housing damage (Committee, 2019).

3.2 Increase in Temperature

A 2°C increase in temperature has varied effects on mangroves; Mangrove biomass and production increase at the plant size until the maximum temperature is attained (Friess et al., 2022), Because mangroves are restricted to the forest in latitude along some coastlines, temperature's impact on parameters like mangrove biomass, anticipated to be highest in latitude (Clough, 1993). Increasing temperatures in arid locations increase water vapor loss, reducing host plant growth and survival (Fuhrer, 2003). High evapotranspiration rates also cause mangrove deterioration under irrigated settings, resulting in shifts in species dominance and biotic stress (Bassi et al., 2014). In terms of ecosystems, increasing temperatures are connected with diminishing mangroves and higher temperature latitudes (Wu et al., 2018). Mangroves are thriving in salinity communities at high latitudes in both the northern and southern hemispheres as temperatures rise and frost episodes decrease (Saintilan et al., 2014). In the photosynthesis scenarios in Table 1, productivity decreases when the temperature rises above the peak temperature for photosynthesis and when the leaf temperature rises above 37–40°C (Carter et al., 2021). Furthermore, rising temperatures increase evaporation rates, which can lead to soil salinity, decreasing forest extent and productivity (Mulholland et al., 1997).

3.3 Sea Level Rise

Mangrove habitats are particularly vulnerable to the effects of climate change due to sea-level rise vulnerable to changes in salinity and abundance during submergence (Ward et al., 2016). Longer floods can result in a shift in the species mix and the loss of plants on the seaward margins, which can have a detrimental effect on ecosystem services and productivity (see table 1) (Gedan et al., 2009), because mangroves are constrained to confined intertidal zones, fast sea-level rise is one of the most crucial climate change aspects affecting their long-term survival (D. M. Alongi, 2018). Mangroves are prone to floods and lateral erosion as sea levels rise (Cahoon et al., 2021). The mangroves may have maintained contact with the moderate rate via a variety of physical and spatial structures related to sea-level rise, and may have corresponded to the breadth of space (Steckler et al., 2022). A variety of monogenic and disturbance processes, such as the addition of microbial depositions and the buildup of sediment from the valley or its coastal sources, contribute to the formation of vertical habitats (Prentice et al., 2020). To preserve and improve surface elevations that are impacted by other climate processes, the biogenic system has relied mostly on subsurface effort generation (Driscoll et al., 2013). Yet, the great majority of the world's protected oceans, as well as biological processes and monitoring systems, demonstrate that current and future sea-level rise dynamics are heavily driven by larger coastal sediment load (Lindeboom, 2002).

3.4 Changes in Precipitation

The IPCC forecast in 2013 that dramatic changes in rainfall are occurring worldwide, with significant regional variance, which will be exacerbated by variability in India (Hao et al., 2018), which will have an impact on both evaporation and transpiration rates Changing Rainfall patterns are probably going to affect the distribution and growth of mangrove forests, particularly in mangroves nearing their tolerance limits. For example, extreme changes in rainfall can alter climate and salinity in some systems over months, though this does not occur well between them (Ward et al., 2016). Less rainfall and greater evaporation increase soil salinity, resulting in less loss and hyper salinity in the maritime zone (Srivastava & Jefferies, 1995). In Table 1, mangroves in high-rainfall locations are more productive and diversified than those in low-rainfall areas because heavy rainfall promotes mangrove development and mitigates the effects of saline stress (Lovelock et al., 2009). Worldwide, there is a relationship between mangrove canopy height and temperature, rainfall, and maybe storm frequency (Simard et al., 2019). Rainfall increases precipitation, which encourages productivity growth and enhances the flow of fresh water in the channels (Elexander & Dunton, 2002). However, heavy rains can push the shoreline and cause flooding, and it can even be washed away during monsoons (Brakenridge et al., 2017).

3.5 Changes in Cyclone

At 2°C, it is anticipated that the peak of violent wind gusts and storm-driven rain will be significantly higher than at 5°C as the cycle develops (Zimmerman et al., 2001). Mangroves are vulnerable because more than half of the world's mangrove forests are found in storm-prone areas, where they are uprooted and destroyed, resulting in the loss of above-ground biomass and vegetation as well as large, long-term altitude reductions (Table 3) (Macintosh & Ashton, 2002). Large-scale and longer-duration antagonistic, furthermore, regimens can affect the level in the course of a storm occurrence and may suggest future sensitivities, but this varies depending on the scale involved (Ellis et al., 2004). The cumulative effect of previous storm damage is linked to mangrove degradation and other landscape-level problems with beach erosion. In the case of a future storm event, beaches in the following locations will sustain the most damage (Figure 2). Empirical comparisons reveal that being closer to the course of the cyclones causes more damage to the falls, even if the higher the cyclone frequency, the greater the damage inflicted by low-grade damage (Barbier, 2015). Extended durations of rain can also cause major damage throughout the group's region, including higher-energy streams and storm surges connected with storms, as well as the deback of dwellings owing to extremely high water levels (Ciavola & Coco, 2017). Although storms can benefit mangroves in specific circumstances, sediment cores eroded by the shoreline are deposited within the mangrove ecosystem, offering an interesting subsidy that can boost rising sea levels and has been helping to bring the gulf in line with rising sea levels over time (Barbano et al., 2009).

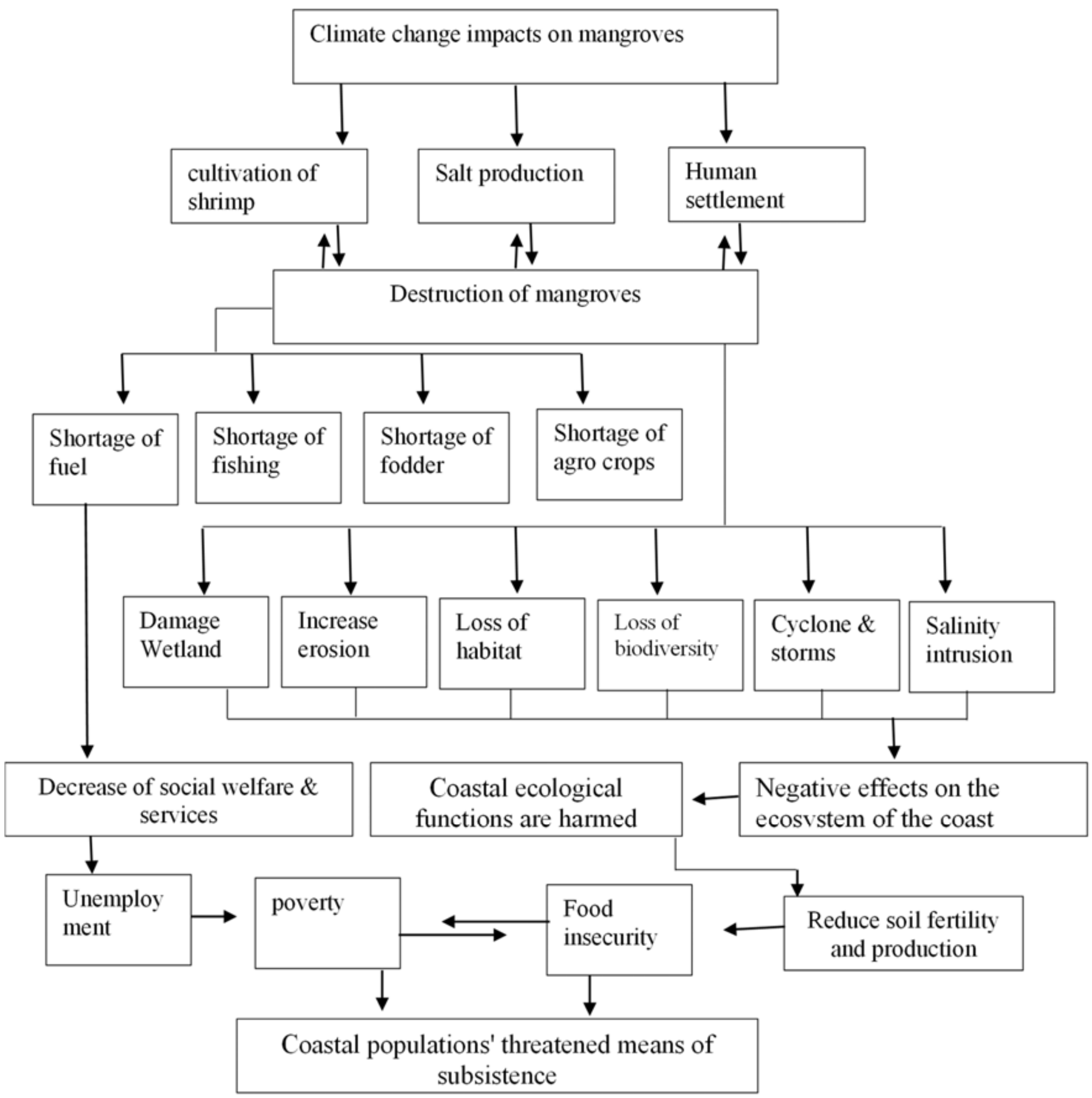
3.6 Hydrodynamic Energy Changes

It is estimated that wave energy on the shore would grow due to warming along the world's coastlines and increased wave height in the Indian Ocean's mangrove regions (Sheppard et al., 2005). This results in the chopping and thinning of mangroves, which can further hinder vegetation growth (Stuart et al., 2007). The winter index is higher when the North Atlantic Oscillation is in a positive cycle, the time of increased wave energy is cut short, resulting in damage over a wide variety of conditions

(Castelle et al., 2018), Waves can leave behind material on the beach, destroying buildings and causing drowning and the death of mangroves (Leonardi et al., 2018).

3.7 Climatic Oscillations Variability

Climate change is having an impact on the frequency and intensity of certain climate cycles, such as the global El Nino Southern Oscillation (Cai et al., 2021). There is compelling evidence that marine water is having an influence on mangroves, and that delays in both the frequency and severity of El Nino events are raising Mangrove demise (Friess et al., 2022). Increases in climate variability and many other climate change conflicts are projected to increase rainfall; nonetheless, even with the intensity it is at now, waves have already seen significant quantities of climate change (Haines et al., 2006), The size and extent of this event directly increased the involvement of mangroves in climate change and subsequent climate change reports, which may be significant given the volume and quantity of ENSO episodes anticipated to grow (C. B. Field et al., 2012). Yet, given the ambiguity in the mechanism relating ENSO variation to climate change, the attribution remains questionable (Hegerl & Zwiers, 2011).



Source: (Shafi Islam, 2014)

Figure 2 Impacts of climate change on mangroves in South Asia

Since mangrove destruction is underway and most forests are predicted to disappear within this century, human impacts on mangroves, especially climate change, have garnered a lot of attention recently (Mitra, 2013). The loss of mangroves as a result of human settlement reduces our supply of fuel, fish, and agricultural crops. In addition, there is a risk of cyclones and strong winds, all of which have negative effects on the coastal ecosystem and increase the risk to our coastal population through social welfare, employment, and port growth. Mangroves continue to be crucial to human sustainability and means of subsistence in emerging countries with high rates of poverty and population expansion, despite their high rates of destruction (Figure 2) (Ferreira et al., 2022). Since most mangrove plants and related organisms are positioned on the ragged border between land and water, they are often resistant to most environmental changes. Mangroves are essential habitats and breeding grounds for a wide range of estuarine and semi terrestrial animals, such as fish, crabs, birds, mammals, reptiles, and many more (Arceo-Carranza et al., 2021).

3.8 Spatial Distribution of Climate Change Impacts on Mangroves

South Asia has 852,606 hectares of mangroves, accounting for 6% of the overall global (Chandra Giri et al., 2015). The largest areas of mangroves in Bangladesh are Gujarat and the Andaman and Nicobar Islands. India's Sundarbans Miani Hor and the Indus Delta, Pakistan's Balochistan coast, Batticaloa, Trincomalee, and Puttalam Lagoon In Sri Lanka, the Dutch Bay-Portugal Bay complex is completed (Chandra Giri et al., 2015; Luther & Greenberg, 2009).

Table 2 Distribution of mangrove forests in South Asia

Country	**Mangrove area (in ha)**	**Loss**	**Gain**	**Percentage of Global Total**	**References**
Bangladesh	411,487.0	16179.4	6575.4	3.2	(Shedage et al., 2019)
India	343,065.2	58020.7	2965.7	2.7	(Parthasarathi et al., 2019)
Pakistan	411,487.0	17691.6	44230.7	2.6	(Chandra Giri et al., 2015) (Shedage et al., 2019)
Sri Lanka	21,437.1	243.5	0.0	0.2	(Shedage et al., 2019)

The extent of mangroves diminishes with increasing latitude, save in South Asia around latitudes 20º N to 24º N (Chandra Giri et al., 2015). The majority of the mangroves in this region are restricted to subtropical region as compare to tropics (Chandra Giri et al., 2015; Hyde & Lee, 1995). Over-harvesting, predominantly urban development, conversion to agriculture, and other factors such as mining, urban pollution, and natural disturbances are all major drivers of forest loss (Tran & Shaw, 2007).

3.8.1 Indus Delta, Pakistan

It is regarded as one of the most vulnerable big deltas in agriculture due to the loss of freshwater, which presently irrigates an area of 181,000 square kilometres (Hamerlynck et al., 2010). The Indus delta mangroves do not fully understand the impact of reduced freshwater flow due to conflicting estimates from various stakeholders such as the Sindh forest department, the International Union for Conservation of Nature (IUCN), the Sindh costal authority, and the Wild Wide Fund for Pakistan (Sayied, 2007). The previous data on the change described in the based on the findings of various one-time evaluations, Indus Delta undertaken over time by various institutions (Salik et al., 2016). The country's eastern border's inter-table zone and western border's higher sea zone have both seen significant degradation of mangrove trees. The degradation of the coastal zone can be understood in the perspective of reduced freshwater discharge from the Indus river (Beg, 1995). Other main sources of Indus Delta mangrove damage includes excessive fishing for fuelwood and the use of camels for grazing, as well as vehicle loss and logging (Qureshi et al., 2011). Changes in river flow have been proposed as another factor for the rise in minnow survival in various studies (Matthews & Zimmerman, 1990).

3.8.2 Goa, India

On India's west coast, the Mandovi-Zuari Estuarine Complex in Goa is home to one of the biggest mangrove forests. (Misra, 2015). Visual analysis of the data has identified regions along rivers where mangroves have increased; these rivers are primarily bordering patches with short strips interspersed among them (Cochard et al., 2008). Despite the fact that mangrove regions are expanding, woods are being threatened by increased urbanization, which leads to increased encroachment in neighboring area (C Giri et al., 2008). Agricultural, mining, and mangrove conservation on public lands for human occupancy and industrial reasons all contribute to degradation (GOA, 2000). The passage of barges, which causes harm to these plants, is another reason of loss in mangrove vegetation (SM Islam & Bhuiyan, 2018).

Table 3 Factors affecting mangroves forest vulnerability

Vulnerability	Local Conditions	Description	References
Most vulnerable	Low rainfall island	• Low growth rate as well as peat are particularly vulnerable to sea-level rise as they are vulnerable to drought and erosion.	(Feller et al., 2015) (E. Watson et al., 2014)
	Lack of rivers	• Lack of freshwater. • Lack of sediments.	(Feller et al., 2015) (O'Reagain et al., 2005) (Mwamburi, 2003)
	Sleep topography	• When sea-level rises, cannot move inland.	(Feller et al., 2015) (Herzfeld et al., 2011) (Jamieson et al., 2012)
	Area Subsiding	• Sea-level rise and flooding.	(Feller et al., 2015) (V. R. Burkett et al., 2002)
Least vulnerable	River rise mangrove	• The most productive mangroves habitat due nutrient attentiveness.	(Feller et al., 2015) (D. M. Alongi, 2008a)
	Mangroves move landward	• As sea-level rise, there is an opportunity to expand inland.	(Feller et al., 2015) (McLeod & Salm, 2006) (Woodroffe et al., 2016)
	Mangroves in remote areas	• Landward migration is not prevented by limited anthropogenic disasters and coastal communities.	(Feller et al., 2015) (Gilman et al., 2006)

As a matter of course, there are many other factors that can affect mangroves, some of which have been discussed in Table 3. Based on these studies, I have identified mangrove forests as the most vulnerable to sea level rise, composed mainly of red and white species, with carbonate-based surficial geologies.

3.8.3 Sundarbans (Bangladesh and India)

The Sundarbans mangrove forest straddles the border between Bangladesh and India, stretching from the Hooghly River in India to the Baleshwar River in Bangladesh. Sundarbans mangrove forests declined by 1.4% between 1970 and 2018 (Das et al., 2020). These forests have provided millions of Bangladeshis and

Indians with the benefit of coastal protection (Hoq, 2007). In light of connected classification and the mangroves' dynamic nature ecosystems, this change is negligible (Chandra Giri et al., 2007). Because of the higher a change between mangroves and other types of vegetation, there is mostly used for encroachment removal, erosion enhancement, and temple restoration, and because growth and regeneration in the Sundarbans continue to compensate This process has increased the land and mangrove forests, making up a significant portion of the erosion loss (Lahiri-Dutt & Samanta, 2013). The Ganges, Brahmaputra, and Meghna The forest is traversed by rivers and is linked by an intricate network of mangroves, channel mudflats, and tidal rivers (table 3) (K. G. Rogers & Goodbred, 2014).

2. DISCUSSION

Mangrove communities worldwide are expected to be significantly affected by physical processes related to climate change (D. M. Alongi, 2008b). This review focuses on the impact and level of understanding of extreme regional development in mangrove communities in terms of safeguarding biodiversity (Ward et al., 2016). Sea-level rise is not regionally benign and is more likely to occur in areas with abundant or steady coastal productivity and huge marine deposits, such as the Amazon basin and the Parnaiba delta (Foti et al., 2012). At the cognitive level of mangroves, estimating climate change distributions is difficult (GAARD, 2019). Certain mangrove ecosystems are likely to undergo larger climate change consequences, Additionally to being a global hub for current human pressure, particularly in Southeast Asia due to sea-level rise and increased energy use (Goldberg et al., 2020). Other tropical regions such as South Asia, East Asia, South America, and Southeast Africa are likely to face fewer climate change consequences in the future, but these regions are particularly concerned about the implications of climate change (Niles et al., 2015).

The ability of mangroves to adapt to climate change is affected by a variety of variations in the processes causing climate change, which together make up the net geographical distribution of favorable and unfavorable influences on mangroves (Ward et al., 2016). A single shift in the climate effect can possess both negative and positive consequences. For instance, nitrogen subsidies can also promote biomass growth whereas storms can significantly reduce biomass in disturbed settings and mangrove biomass while also preventing biomass growth by creating canopy gaps. Similarly, increased rainfall may increase plant biomass globally but negatively affect local vegetation a table 1 (Zeppel et al., 2014). The overall severity of the affects meant that the local distribution altered the consequences (Cheung et al., 2009). Increases in precipitation and temperature, on the other hand, will have a relatively minor global climate influence because their effects will be limited to local latitudes, notably in the subtropics, which are the warmest or driest climatic zones (Polade et al., 2014).

The intensity of these consequences may also be determined by the interaction of various Effects of climate change may include sea level rise and periodic alteration, and sea-level increase may harm the coast's mangrove standard (Ward et al., 2016). Similar to this, mangroves were diminished by extreme drought and excessive salinity, although this may have been somewhat countered by land displacement brought on by rising sea levels figure 2 (Warrick & Ahmad, 2012). However, some climate change effects may be beneficial, such as increased breakdown of related chemical organic carbon under warmer conditions (Whitfield & Fisheries, 2017). Only a few of these functions have been described in mangroves and limited evidence is available from monitoring (Sierra-Correa & Kintz, 2015).

The fall in mangroves and salt flat areas happened as a result of sea-level rise, as soil-level elevation neighboring areas could not keep up with sea-level rise (J. C. Ellison, 2000). This is more likely to occur in coastal locations with little rainfall, where precipitation is insufficient to sustain surface elevation (Rain et al., 2011). There is a significant gap that will allow us to estimate the influence of climate change on mangrove ecosystem services, related wetlands, sea level rise effects on intertidal wetlands, and climate change implications on mangrove forests in other geographic regions.

CONCLUSION

There are mangrove forests along the coasts of Bangladesh, Sri Lanka, India, and Pakistan, which make about 6 to 7% of the total mangrove forests in the world. These woods provide vital environmental goods and services for biological ecosystems as well as the functioning of coastal areas with a high population density. Forests are under threat from both natural and man-made factors. Reduced freshwater runoff and alluvium flow result from deforestation. Decreased freshwater supply raises salinity levels, which harms mangrove growth and survival. Additional main drivers of Indus deforestation and degradation. Over-harvesting for fuel wood and erosion are two threats to delta mangroves. In addition, high temperatures can diminish productivity and promote erosion. Yet, the greatest threat to mangrove existence is deforestation, which must be considered alongside the consequences of climate change.

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