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Assessment of the Role of the Sundarbans as a Natural Buffer in Diminishing the Intensity of Cyclone: A Comparative Study on Cyclone Bulbul and Sitrang

C. D. Nath[1], Z. Sultana[2], T. B. Alam[3], I. Jahan[4], D. R. Raja[5]

[1]Department of Urban and Regional Planning, CUET, Bangladesh (chayondabnath1@gmail.com)
[2]Department of Urban and Regional Planning, CUET, Bangladesh (zerin.sultana931@gmail.com)
[3]Department of Urban and Regional Planning, CUET, Bangladesh (tabassum8266442@gmail.com)
[4]Department of Urban and Regional Planning, CUET, Bangladesh (israt_jahan@cuet.ac.bd)
[3]Department of Urban and Regional Planning, CUET, Bangladesh (debasishroy@cuet.ac.bd)

Abstract

Tropical cyclones are one of the major climatic disasters plaguing the world. Every three years, Bangladesh is struck by a major cyclone. In the previous 50 years, around 718000 deaths have occurred, and along with this, cyclones have also caused significant socio-economic damage. Historical evidence shows that Patuakhali is one of the most vulnerable districts to cyclones and suffers much damage. On the other hand, the cyclones that have passed through the Sundarbans seem to cause much less damage in the inland areas. Research has emphasized the Sundarbans' impact on reducing storm surge heights. The aim of the study is to evaluate the effectiveness of the Sundarbans mangrove forest as a natural defense against the ever-changing cyclonic impacts and frequency induced by climate change. To fulfill this goal, two cyclones, Bulbul and Sitrang, have been selected for examination, of which the major tract of Bulbul passed through the Sundarbans mangrove forest, while the major tract of Sitrang did not. Wind speed and storm surge have been chosen as parameters to indicate the cyclone intensity. The results indicate that the Sundarbans plays a vital role in reducing cyclone wind speeds, as evidenced by a strong negative relationship between NDVI and wind speed. Also, the Sundarbans were found to have a vital role in reducing the extent and impact of the storm surge caused by the cyclones. Hence, the concerned authorities should take the necessary steps to preserve and enrich Bangladesh's mangrove forests.

Keywords: *Tropical Cyclones; Sea Surface Temperature; Normalized Difference Vegetation Index; Wind Speed; Storm Surge.*

1 Introduction

Tropical cyclones are low-pressure systems that develop over warm tropical regions, e.g., the ocean. (Australian Bureau of Meteorology, 2022). They can last for several weeks with unpredictable courses. It often causes devastating damage due to the intensity of wind, heavy rainfall that leads to flooding, and destructive storm surges (Walsh et al., 2019). Annually, over 45 tropical cyclones form in various parts of the world. These storms produce strong winds up to 119 km/h, torrential rainfall, large waves, and, in some cases, significant destructive storm surges and coastal floods (Ortiz et al., 2023). Approximately 726 million people worldwide were affected by tropical cyclones between 1998 and 2017, resulting in 233,000 deaths (World Health Organization [WHO], 2019). According to the WHO (2019), rising temperatures and altered precipitation patterns are two effects of climate change. Several studies (Knutson et al., 2019; Chand et al., 2022) find that the devastating effects of cyclones are worsening due to increased intensity and precipitation. Given its distinctive geographic location, Bangladesh is frequently hit by destructive tropical cyclones. From 1965 until 2020, at least 12 significant tropical cyclones made landfall in Bangladesh, resulting in 479,490 fatalities (Hossain & Mullick, 2020). Mangrove forests play a critical role in mitigating the devastating impacts of tropical cyclones, among the most destructive natural hazards in Bangladesh and India (Kairo et al., 2001). Sundarbans, an important mangrove forest extending up to 80 kilometers into the Bay of Bengal, also has an important role in reducing cyclone impacts (Unnikrishnan et al., 2012). As the frequency and intensity of cyclones increase due to climate change, it is imperative to understand natural defense systems, such as mangroves, to develop effective adaptation strategies (Dasgupta et al., 2013). There has also been research assessing the role of the Sundarbans in reducing storm surge inundation (Sakib et al., 2015). But scientific research has not been conducted to assess the role of the Sundarbans in abating the cyclone intensity, which limits the ability of the concerned authority to understand

the significance of conserving the Sundarbans. This study aims to evaluate the effectiveness of the Sundarbans mangrove forest as a natural defense against the ever-changing cyclonic impacts and frequency induced by climate change. The authors have defined distinct objectives to fulfil the aim: 1) To determine the correlation between a climate change indicator (SST) and cyclone frequency, 2) To determine the correlation between NDVI and wind speed during the cyclone for both regions (Sundarbans and Patuakhali), and 3) To illustrate the Storm surge over both regions during the cyclone. Historical data indicate that the Sundarbans took over 25 years to recover from severe cyclone damage, with significant vegetation loss observed (Islam, 2014). Hence, this study emphasizes the need to conserve the Sundarbans.

2 Methodology

2.1 Study Area

We have selected two regions for this analysis. One is Sundarbans (a) with dense vegetation & another is Patuakhali district with low vegetation. The Bangladesh Sundarbans cover approximately 6017 km2, making up 60% of the entire Sundarbans region. Geographically, it is situated in the world's second-largest watershed system, the lower Ganges–Brahmaputra delta. About 30% of the Sundarbans is interwoven with a complex network of rivers and streams of varying widths and depths. The forest's elevation ranges from 0.5 m to 3.0 m above sea level, with 70% of the area lying below 1 m. During regular tidal floods, much of the vegetation is submerged twice daily. In 1999, the Department of Environment of Bangladesh declared a 10-km buffer zone surrounding the forest as 'Ecological Critical Area'. On the other hand, the other area of study for cyclone hazard assessment is the district of Patuakhali (b), located in the south-central part of Bangladesh and under the Barisal Division. The lands here are composed of alluvial soil deposits of the Meghna Basin and a few char lands (Riverine Island) located in the southeast. The average height above the sea surface ranges between 3 and 3.5 meters. Being a coastal district, it has been frequently affected by cyclones and associated storm surges (Sazeed & Rabby Hossain, 2018).

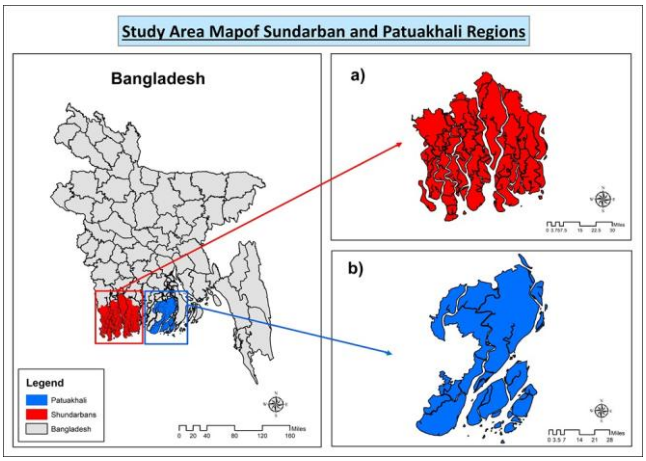

Figure 1. Study Area Map.

2.2 Data & Methodology

To establish the theoretical foundation, the study begins with an extensive literature review, followed by the formulation of the aim and objectives. In the data collection phase, the data is categorized into two main types: environmental data and climate data. Environmental data include wind speed and intensity, cyclone paths, and flood data in the surrounding area, while climate data include sea surface temperature (SST) and cyclone frequency. The wind speed was determined using the Inverse Distance Weighted (IDW) interpolation method, and NDVI was assessed using multiple band imagery. For the identification of inundated areas, the temporal VV backscatter difference between bands was used. In the data analysis phase, two key correlations were examined: NDVI and wind speed across different distance zones, and SST and cyclone frequency to assess the impact. The results are compared between two regions to determine the significance of the Sundarbans in mitigating cyclone and flood impacts.

Table 1. Data types and sources.

Data	Description	Sources	Spatial Scale
Wind Speed and Pressure	Global wind speed and atmospheric pressure observations	NOAA	Interpolated from point data

Track	Path and trajectory of cyclones	International Best Track Archive for Climate Stewardship (IBTrACS)	Global (all ocean basins, point tracks)
Cyclone Frequency	Number of cyclones per year	Indian Meteorological Department (IMD)	Bay of Bengal basin
Sea Surface Temperature (SST)	Annual SST data for the Bay of Bengal	NOAA ERSST dataset	-
NDVI	Normalized Difference Vegetation Index for analysis	Sentinel-1	10 m spatial resolution

3 Result & Discussion

3.1 Climatic impact on cyclone

Rising sea surface temperatures (SSTs) are among the primary factors of climate change. According to several recent studies (Sun et al., 2024), there is a correlation between increasing SST and TC intensity. Stronger cyclones, such as Yaas in 2021, which intensified rapidly due to favorable pre-cyclonic conditions, have been correlated with SSTs above 31°C in the Bay of Bengal (Ray et al., 2024).

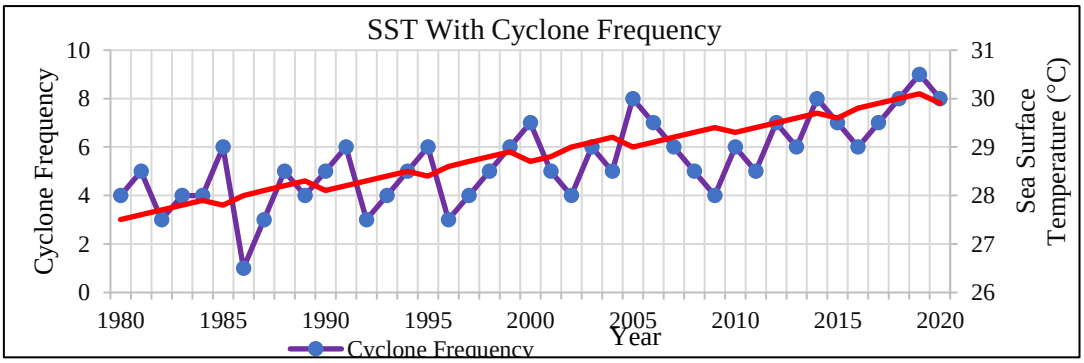

Figure 2. SST with cyclone frequency within four decades.

According to Figure 3, the SST increases over time from 1980 to 2020. The SST has increased 4 °C over the last four decades. Although the relationship is nonlinear, the data suggest that even modest changes in SST may eventually be associated with a higher frequency of cyclones. Figure 4 shows the positive correlation between SST & cyclone frequency. Sea Surface Temperature is on the Y axis & Cyclone frequency is on the X axis. It highlights that higher SSTs lead to higher cyclone frequency.

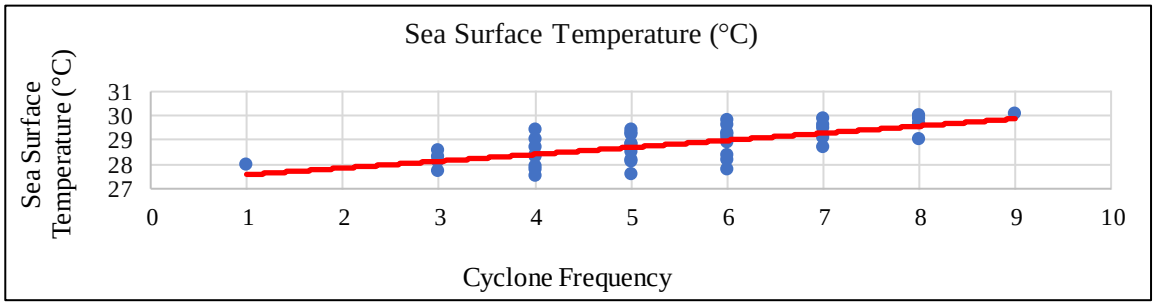

Figure 3. Correlation of SST vs Cyclone frequency.

3.2 Wind Speed

Figure 5(a) shows the interpolation map of wind speed of the Bulbul cyclone, which shows the variation of wind speed in the Sundarbans area. The variation is categorized into 5 classes: very low, low, moderate, high & very high. Figure 5(a) shows how the wind speed of the bulbul cyclone decreased noticeably from 60 knots before entering the Sundarbans to 40 knots after passing through the area. This map indicates extremely high wind speeds before crossing the Sundarbans vegetation. However, wind speed drops significantly as it passes through vegetation. According to the map, the wind speed is very high to high (45 to 50 knots) in the Shatkhira district,

moderate to low (40 to 45 knots) in the Khulna district, and low to very low (35 to 40 knots) in the Bagerhat and Pirojpur districts. Figure 5(b) shows the interpolation map of the wind speed of the Sitrang cyclone. There is a slight variation in wind speed across the Patuakhali district, as shown in the interpolation map of the Sitrang cyclone that affected the district in 2022. One fourth of the area in the northern part of Patuakhali has moderate to low wind speeds of 43 to 44 knots.

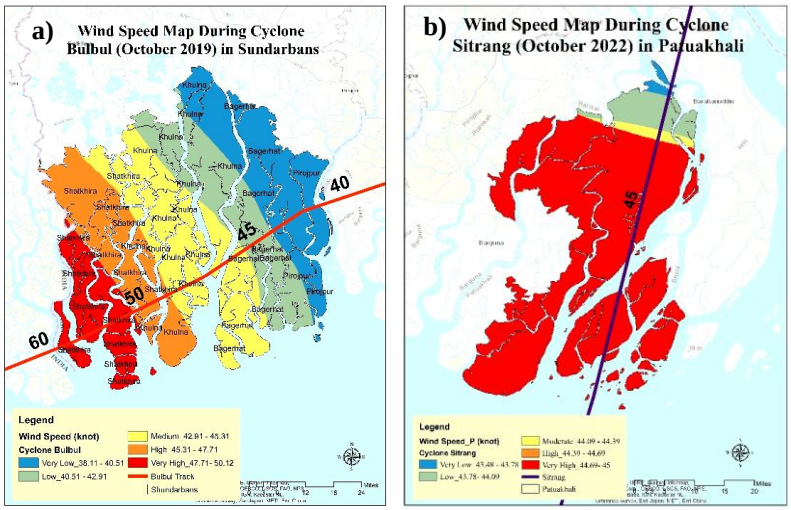

Figure 4. a) Wind speed map of cyclone Bulbul, b) Wind speed map of cyclone Sitrang.

3.2.1 Variation of wind speed with Vegetation density

The NDVI map of the Sundarbans area in 2019 is depicted in Figure 6(a). The NDVI Map of the Sundarbans (2019) illustrates the condition and abundance of vegetation within the Sundarbans. The NDVI ranges from 0.60 to -0.31. In 2022, the NDVI map of the Patuakhali area is depicted in Figure 6(b). The NDVI ranges from 0.09 to -0.08.

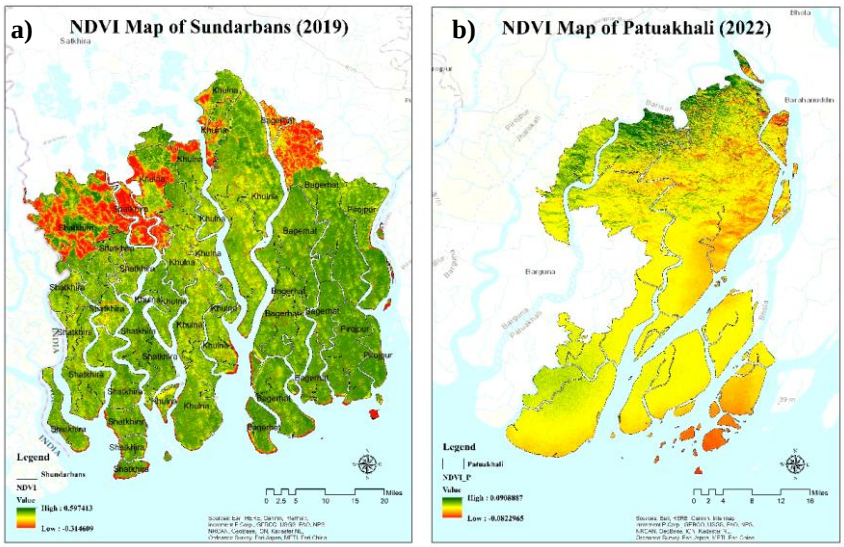

Figure 5. a) NDVI map of Sundarbans, b) NDVI map of Patuakhali.

3.2.2 Distance wise correlation between NDVI & Cyclone wind speed

Figure 7 illustrates how vegetation density (NDVI) may influence reductions in wind speed along the path of the Bulbul cyclone. Wind speed decreases steadily from around 50 knots in the first 15 km to about 40 knots between 85 and 95 km. Meanwhile, the NDVI values increase with distance, starting at 0.36 and peaking at 0.46 between 75 and 85 km. This trend suggests that as the cyclone moves through areas with denser vegetation, indicated by higher NDVI values, the wind speed gradually decreases. The increasing vegetation density likely

acts as a natural barrier, absorbing the cyclone's energy and contributing to the reduction in wind speed as the cyclone progresses. This emphasizes the potential role of vegetation in mitigating cyclone intensity.

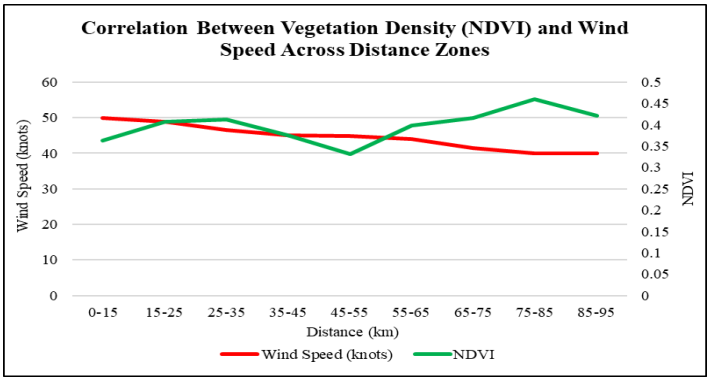

Figure 6. Correlation Between Vegetation Density (NDVI) and Wind Speed Across Distance Zones.

3.3 Storm Surge

Vegetation serves as a natural flood barrier, slowing and minimizing the impact of flooding. Trees, grasses, and other plants stabilize the soil, minimizing erosion and limiting the quantity of silt carried away by floodwaters. Vegetation also enhances water absorption, reducing the amount of water that flows into streams and rivers and lowering the risk of flooding (Toosi, 2023). Figure 10(a) clearly shows the significant role of vegetation in protecting the Sundarbans from storm surges.

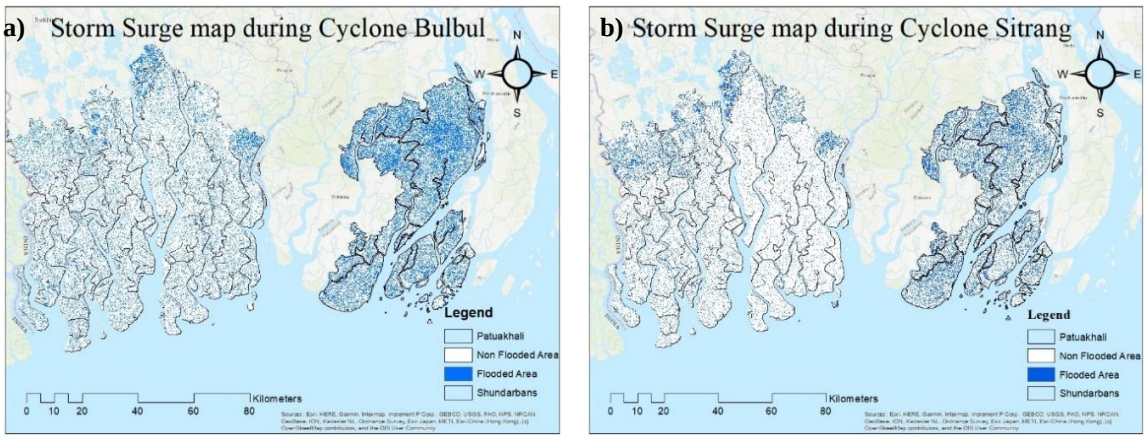

Figure 7. Storm surge map during cyclone bulbul in Sundarbans & Patuakhali.

Figure 8(a) shows that during Cyclone Bulbul, Patuakhali was more affected by storm surge than the Sundarbans, highlighting the protective role of forests. Figure 8(b) shows the same turn during Cyclone Sitrang. From both figures 8 (a, b), it is highlighted that Sundarbans' dense vegetation can decrease the effect of storm surge by slowing its speed.

Table 2. Undisturbed sample properties.

Region	Cyclone	Flooded Area (%)	Non-Flooded Area (%)
Sundarbans	Bulbul	14.37	85.63
	Sitrang	9.89	90.11
Patuakhali	Bulbul	37.58	62.42
	Sitrang	25.96	74.04

The table compares the percentage of flooded and non-flooded areas in the Sundarbans and Patuakhali regions after Cyclones Bulbul and Sitrang. In the Sundarbans, Bulbul caused 14.37% flooding, while Sitrang caused less at 9.89%. Non-flooded areas were higher in both cases, with 85.63% for Bulbul and 90.11% for Sitrang. In Patuakhali, the impact was more significant, with Bulbul flooding 37.58% of the area and Sitrang flooding 25.96%, while non-flooded areas accounted for 62.42% and 74.04%, respectively.

4 Conclusion

This study has shown that, despite cyclone frequency rising due to climate change, the Sundarbans mangrove forest remains essential for reducing cyclone intensity. The significance of effective natural defense mechanisms is further highlighted by the finding that rising sea surface temperatures (SSTs) coincide with a considerable increase in cyclone frequency, as analyzed using SST as a climate change indicator. This study has shown that, despite cyclone frequency rising due to climate change, the Sundarbans mangrove forest remains essential for reducing cyclone intensity. It has been demonstrated that the Sundarbans, compared with areas lacking this type of mangrove protection, such as Patuakhali, effectively act as a natural barrier against the destructive forces of tropical storms by reducing wind speeds and storm surge during cyclones. While a finer-scale analysis could further strengthen the causal interpretation, the reliance on freely available global datasets limited the ability to draw more precise causal interpretations. Nevertheless, the observed spatial trends clearly demonstrate the gradual changes and protective influence of the Sundarbans. These results indicate a worrying vulnerability and confirm the Sundarbans' protective significance.

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