SPATIO-TEMPORAL ANALYSIS OF ENVO-CLIMATIC PARAMETERS AT THE SOUTH-WESTERN REGION OF BANGLADESH

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ABSTRACT

Climate change impacts on regional weather patterns have become increasingly evident across South Asia, with Bangladesh being particularly vulnerable due to its geographic location and monsoon-dependent climate system. This study investigates long-term seasonal climate trends in the southwest region of Bangladesh, examining temperature, rainfall, and vegetation changes over a 48-year period to understand regional climate variability and environmental degradation patterns. Seasonal climate analysis was conducted using meteorological data from five strategic stations (Jessore, Satkhira, Khulna, Chuadanga, and Mongla) spanning 1973-2020. The study period was divided into two comparative phases: 1973-1996 and 1997-2020, with data classified into four hydrological seasons (Pre-monsoon, Monsoon, Post-monsoon, and Winter). Percent bias methodology was employed to quantify climate trends, while NDVI analysis (1996-2024) assessed vegetation dynamics across different land cover categories. Significant warming trends were observed across all seasons, with monsoon season exhibiting the highest temperature increase of +1.05°C (3.24%), followed by post-monsoon (+0.69°C, 2.23%) and winter (+0.16°C, 0.60%). Minimum temperatures showed more pronounced increases than maximum temperatures, ranging from 0.08% to 7.08% across stations and seasons. Rainfall patterns revealed a notable seasonal redistribution, with post-monsoon precipitation increasing substantially (6.50% to 30.22%) while winter rainfall decreased dramatically (-6.47% to -26.90%). Monsoon rainfall patterns varied spatially, with coastal stations experiencing different trends than inland locations. Vegetation analysis revealed significant environmental degradation, with dense vegetation cover declining from 23% to 17% and stressed/low vegetation increasing from 22% to 34% over the 28-year period. The study identified a critical seasonal shift in precipitation patterns from traditional monsoon-dominant to post-monsoon-enhanced rainfall regimes. Coastal stations (Mongla, Satkhira) demonstrated different climate responses compared to inland locations (Jessore, Chuadanga) due to maritime influences and varying topographic characteristics. The most concerning finding was the widespread vegetation degradation concurrent with temperature increases, indicating ecosystem stress and potential agricultural implications. The observed shift from monsoon to post-monsoon rainfall, combined with winter precipitation decline, suggests fundamental changes in regional hydro-climatic cycles. These findings have critical implications for agricultural planning, water resource management, and climate adaptation strategies in one of Bangladesh's most economically important regions.

Keywords: *Spatio-Temporal Analysis, Innovative Trend Analysis(ITA), NDVI, Climatic Parameters*

1. INTRODUCTION

The southwest region of Bangladesh (Figure 1) also primarily known as the Ganges dependent part in Bangladesh consists of districts like Satkhira, Khulna, Chuadanga, Mongla, Jessore and so on. The Ganges provides water for domestic, industrial and agricultural uses and originates in the Himalayas and travels from the Himalayas to the Bay of Bengal. In Bangladesh, the south-western region depends largely on the Ganges for irrigation and fresh water, particularly for rice farming which is important for the food security of the country. The seasonal flow of water in the river is necessary to sustain agriculture production, fisheries and drinking water. The installation of the Farakka Barrage in 1975 by India, nonetheless, has profoundly affected the region with drastic changes in the natural hydrological system.

The Farakka Barrage across the Ganges River was constructed for the diversion of water to enhance the navigability of the Calcutta Port. But this diversion has caused an extreme water shortage in the lower regions primarily Bangladesh. A study explains that the diversion has diminished the flow of the Ganges, particularly at the season its water is most required for agriculture. The Farakka Barrage has led to severe depletion of groundwater recharge, which has led to water stress in the sub-region of south-western Bangladesh. This has been exacerbated by the increasing salinization in the surface and ground water, making it increasingly difficult for them to practice agriculture and posing a threat to food security in the region(Mirza, 1997). In addition, the diminished sediment flow of the Ganges has resulted in loss of wetland habitats in the area. Wetlands, critical for biodiversity and natural water filtration, have been destroyed by the lack of freshwater input. It has messed local aquatic ecological systems, depending freshwater biology who do not have enough water flow and suffering with the high salinity. Another study also discusses how the Farakka Barrage, among other human intervention and climate change exerted pressure on the region's ecosystems(Masood et al., 2015).

Besides the agricultural effects, the aquatic ecosystems of the area have undergone severe degradation. Ecologically, wetlands are 'hotspots' of biodiversity and are nature's filters, needing steady inflows of fresh water to function properly. The habitat loss and alteration due to reduced river flow and increased salinity has driven declines in species diversity and abundance. Some authors argue that the above-mentioned climatic variations exacerbate the hydrological variability in the Ganges Basin, aggravating the management of water systems and agricultural systems at risk of failure. Farmers, for example, find it increasingly difficult to predict the time to plant and harvest crops, which, in turn, can cause both crop failure and economic distress(Hossain et al., 2016). Other than anthropogenic causes, overall climate of GDA has been changing diversely since past few decades. Southwest region is most vulnerable in terms of rise in temperature and dynamic rainfall pattern changes(Haider et al., 2024a). Both natural and man-made forces have had a significant impact on the climate in Bangladesh's southwest, especially in the Sundarbans and coastal areas. The Farakka Barrage in India has caused the Ganges River's freshwater flow to decrease, which has raised soil and waterway salinity, harmed mangrove habitats, and decreased agricultural output(Shibly & Takewaka, n.d.).

Results from the current trend analysis and MK tests revealed mostly identical decreasing precipitation trends across stations and timescales, indicating reliable analysis. The study also found significant changes in rainfall patterns at most stations from 1981 to 2021. The current trend analysis revealed decreasing trends at 25 out of 29 meteorological stations, with negative trend slopes. Eleven stations exhibited non-monotonic trends, while eight had non-monotonic decreasing trends and eight displayed monotonic decreasing patterns(Roy et al., 2024).

Another different study investigated detailed characteristics of rainfall of Bangladesh from 1966 to 2019. Rainfall features like the precipitation concentration index (PCI) and seasonality index (SI) were estimated to characterize spatial patterns of rainfall regimes, and innovative trend analysis (ITA) and percent bias (PBIAS) were used to detect the trend, and its reliability was tested by using the Mann–Kendall (MK) or modified Mann–Kendall (mMK) test. The magnitude of changes was computed by using Sen's slope estimator (Q), and discrete wavelet transform (DWT) was employed to find out the dominant periodicity of the trend of annual series. SI and PCI revealed that rainfall is mainly seasonal and markedly with the long dry season, and the distribution of rainfall is irregular for the major portion of Bangladesh. The result of ITA and PBIAS showed a similar trend for all the stations and time scales. ITA showed that 23 stations experienced significant (α = < 0.05) increasing (39.13%) and decreasing (39.13%) trends in annual rainfall. For the seasonal scale, post-monsoon rainfall is dominated by significant increasing trend (60.87%), whereas winter rainfall is dominated by significant decreasing trend (65.28%)(Das et al., 2021). The rainfall and maximum temperature are inversely related during the monsoon and dry seasons as the rainfall and temperature show decreasing (0.65 mm/yr) and increasing (0.017 ◦ C/yr) trends, respectively. The pre- and post-monsoonal rainfall values also reflect the decreasing trends, indicating prevailing drought conditions, especially in the northern and central parts of the country. In the past 20 years, the country's western region experienced more drought years, whereas the coastal region experienced more wet years. The majority of the stations experienced cold years from 1975 to 1995; subsequently, warm years prevailed(Haider et al., 2024b).

The annual maximum rainfall and the number of days with high intensity rainfall have remained almost static. The annual maximum tidal high-water level is increasing and the annual minimum low water level is decreasing at a rate of 7 - 18 mm and 4 - 8 mm per year, respectively. There is a negative correlation between the Gorai flow and the river water salinity around Khulna. Dredging of the Gorai during 1998-2001 resulted in an improvement of the salinity situation in the Khulna region. The variation in water salinity, tidal water level and sweet water flows in different time periods in dictates that the human interventions through upstream diversion and coastal polders have contributed more in hydro-morphological changes in the southwest than the climate change(Mehzabin & Mondal, 2021). Another research delves into the specific context of the western coastal zone of Bangladesh, examining the relationship between morphological changes (shoreline erosion and accretion) and vegetation index variations, while also considering the influence of river discharge and salinity. The study reveals that decreasing NDVI trends are observed in periods of increased salinity, which is linked to reduced Ganges River flow due to the construction of the Farakka Barrage. The increased salinity leads to soil dispersion, hindering forest growth and ultimately impacting vegetation health. The research also highlights that higher erosion rates and decreasing trends of vegetation index were observed during periods of high salinity. This finding directly connects human intervention (the Farakka Barrage), environmental changes (increased salinity), and vegetation dynamics (decreased NDVI) in a coastal zone highly dependent on the Ganges River. This case study is particularly relevant to this study because it directly addresses the impact of alterations in Ganges River flow on vegetation health in a sensitive coastal ecosystem(Shibly & Takewaka, n.d.).

This study seeks to systematically examine how climate change has altered spatio temporal conditions in southwestern Bangladesh. This comprises an analysis of the long-term trends in rainfall including changes in annual cumulative, the seasonality, and inter-annual variability of rainfall as these are essential drivers of river discharge, groundwater recharge. The study will explore increasing temperature trends and variability, studying how higher temperatures also lead to higher evapotranspiration rates, which results in higher demands for water by crops and enhances challenges on water availability. In addition, this study will investigate the climate change combining long term variation of different spatial and temporal parameters. Acknowledging that climate change is causing more frequent and severe extreme weather events such as floods and droughts, this target will consider to what extent climatic extremes compound water shortages, affect agricultural seasons and compromise food security. An important aspect of this study is to make trend analysis of relevant hydrological and meteorological data in order to distinguish time influential changes associated to both human impact and to climatic variability. Based on the datasets obtained from both BMD and USGS, the study will investigate temperature, precipitation, relative humidity and soil moisture focusing on the comparing the two critical pre- 1996 and post-1996 periods to represent two baseline conditions and understand the pre- and post- environmental status from the barrage diversion works. This temporal comparison will allow to determine statistically significant trends and anomalies in hydrological parameters and shifts in the hydrological regime.

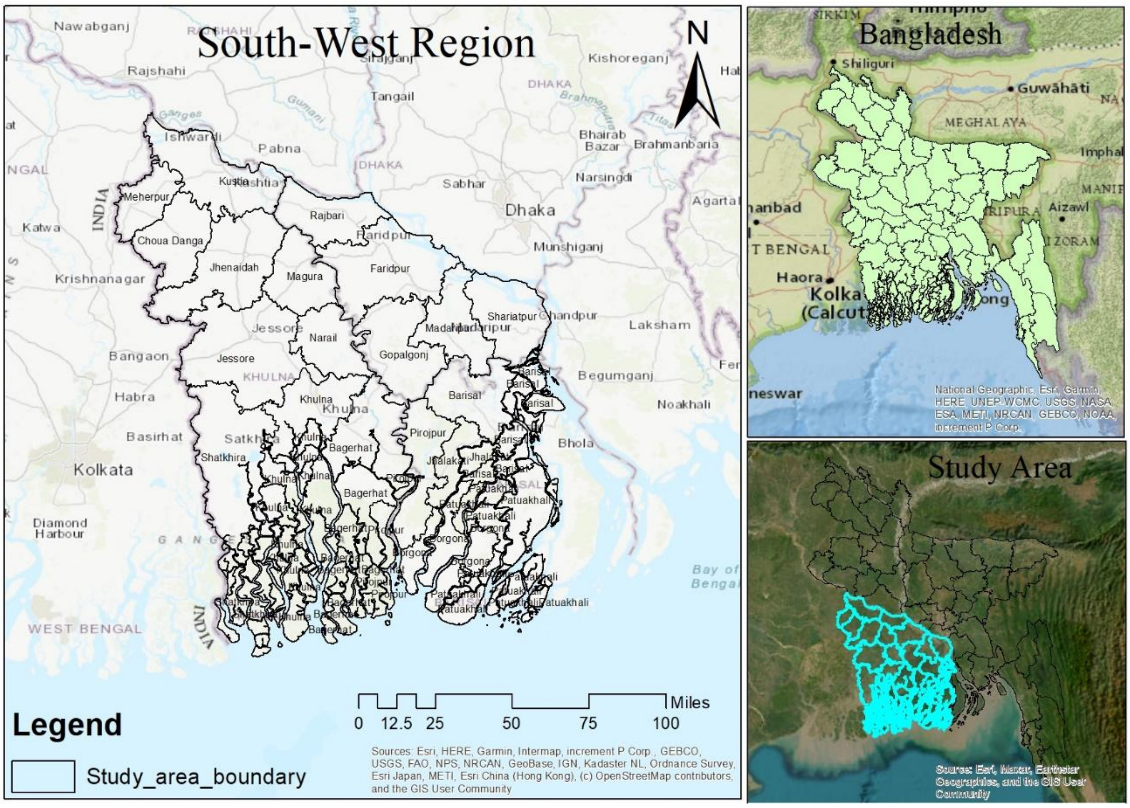


Figure 1: Study Area (South-West Region of Bangladesh)

2. METHODOLOGY

2.1 Data Collection and Pre Processing

Monthly hydrological data of maximum and minimum temperature and total rainfall was collected from the Bangladesh Meteorological Department (BMD) from the year [1973 to 2020]. The quality of data was controlled using outlier rejection and interpolation (e.g., linear interpolation). NDVI imagery was obtained from (Landsat 5 and Landsat 8) and preprocessed by removing the influence of clouds and the presence of atmosphere with standard remote sensing practices. Hydrological data quality control, being the first step in climate trend analysis, is of importance. A multistage pre-processing routine was applied for maximum temperature, minimum temperature, and total rainfall data downloaded from the Bangladesh Meteorological Department. Outliers were identified using both statistical and visual approaches. Using find and replace tool of Microsoft excel was particularly useful for the detection of temperature record outliers, as all the sites of even the final down sampled subset appeared to reside in between the range. Gaps and star marked symbols were considered as outliers and therefore required verification. In case of rainfall data, which is usually skewed, generalized extreme studentized deviate test showed better performance in identifying statistically significant outliers. The methodology is shown in Figure 2.

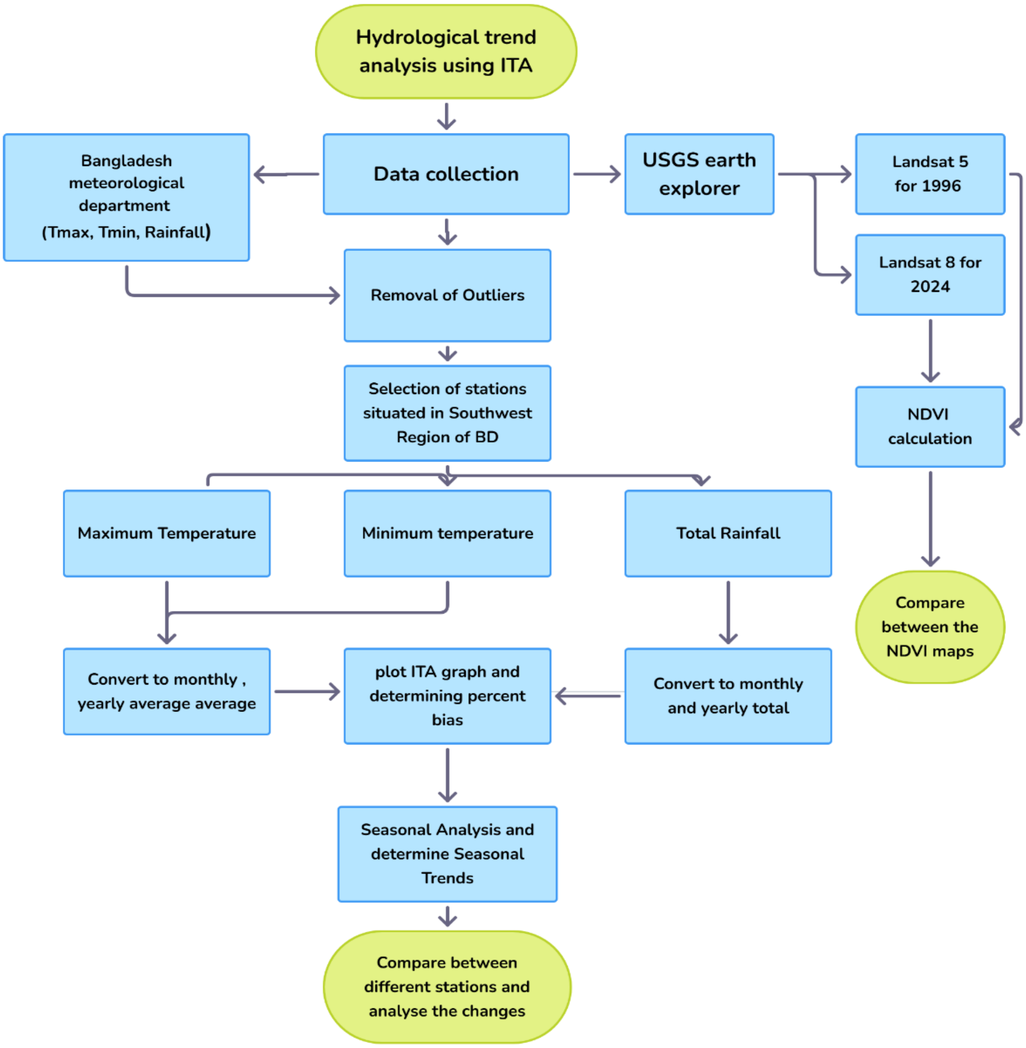


Figure 2: Flowchart of the Methodology

2.2 Innovative Trend Analysis and Percent Bias Method

There are strong climatic and hydrological variations in the south-west region of Bangladesh the factor to receive maximum attention adversely impacting both agriculture and water and overall ecosystem sustainability. The current research aims at fully describing the spatio-temporal hydrological characteristic of Innovative Trend Analysis (ITA) on selected key climate parameters: T_{max} (maximum temperature), T_{min} (minimum temperature), and total rainfall over the long-term period in the five stations located in the southwestern part of Bangladesh: namely Mongla, Chuadanga, Satkhira, Jessore, and Khulna. The analysis is for the period 1973–2020 and is based on data from the Bangladesh Meteorological Department (BMD). Excel has a built-in Excel makes it easy to use and understand data and trends.

The analysis is based on monthly time series data of T_{max}, T_{min} and rainfall from 1973 to 2020. Split samples to avoid any structural breaks as well as overlapping periods, the data was divided into two equal sub-samples:

First Half (1973–1996)

Second Half (1997–2020)

Monthly means were calculated for T_{max} and $T_{min,}$ whereas rainfall was summed across months. Mean annual values (temperature) and total annual values (rainfall) were then generated to explore decadal variations. (Şen, 2017)

For the detection of monotonic trend, the ITA method was used; this method does not assume normality and independence in the series, which increase the robustness applied to hydro-meteorological studies. The steps include:

Division of Data: For each parameter, its chronology was split into two equal parts.

Scatter Plotting: The two halves (1973–1996, 1997–2020) were plotted on Excel, with the first half being the X axis and the second half being the Y axis.

Trend Interpretation:

- The points above the 1:1 line (45° line) represent an increase trend.
- Points down indicate a downtrend.
- No trend indicated by the points along this line.

Seasonal Trend Assessment

For the purpose of capturing intra-annual variation, the year was divided into four hydrological seasons

- Pre-Monsoon Season (March – May)
- Monsoon (June - September) 91–95%
- After-Monsoon (October –November)
- Winter (December to February)

2.3 Equations

Means (for temperature) and sums (for rainfall) were calculated for the season as a whole and the two sub-periods. % bias approach was used to quantify trends:

$$\textbf{\% bias} = \left(\frac{(x_1 - x_2)}{x_1}\right) \times 100\% \qquad \textbf{(1)}$$

Where, X_1= Mean of the first half (1973–1996)
X_2= Mean of the second half (1997–2020)

A positive value indicates an increasing trend, while a negative value signifies a decreasing trend.

3. RESULT AND DISCUSSION

3.1 Seasonal Analysis and Trends

3.1.1 Maximum Temperature

Table 1: Percent Bias of Maximum Temperature

Station	Pre Monsoon	Monsoon	Post Monsoon	Winter
Jessore	0.10%	3.23%	2.22%	0.60%
Satkhira	0.23%	1.14%	0.05%	0.20%
Khulna	0.05%	2.36%	1.30%	0.10%
Chuadanga	0.92%	2.28%	1.11%	0.16%
Mongla	1.60%	2.79%	2.01%	1.16%

For pre monsoon Mongla had the highest atmospheric maximum temperatures reaching 36.13°C, and the values were relatively lower in Khulna, reaching 35.34°C; That's why the percent bias also reflects that the maximum increase is observed in Mongla and Minimum increase in Khulna. But out of all stations, Monsoon Jessore had the maximum increase(3.23%) and post monsoon Satkhira had Minimum increase (0.05%) pre-monsoon is generally hot and dry in Bangladesh, the differences can be explained by less maritime domination, as insinuated by their spatial orientation to the bay, and the bridging infrastructure such as landmass and vegetation between them and the bay. In monsoon, Mongla displayed the highest maxima (maximum 33.20°C). In post monsoon, Maximum temperature was reported from Jessore (31.86°C). Temperatures were lower (30.87°C) in Khulna. During the after monsoon, inland cools slower than the coast. In winter, The highest maxima were recorded at Jessore (27.86°C). (26.73°C) in Khulna had the lowest. Winters are generally warmer inland than on the coast as showed in (Table 1).

3.1.2 Minimum Temperature

Table 2: Percent Bias of Minimum Temperature

Station	Pre Monsoon	Monsoon	Post Monsoon	Winter
Jessore	1.55%	1.62%	7.08%	0.08%
Satkhira	0.23%	1.29%	1.53%	0.19%
Khulna	2.76%	1.43%	1.36%	4.89%
Chuadanga	1.72%	1.65%	1.15%	2.95%
Mongla	1.33%	2.04%	1.47%	3.62%

In pre monsoon, higher minimum temperatures (up to 24.35°C) were recorded in Jessore. Khulna recorded the maximum increase in temperature (2.76%) Land areas (Jessore) are slow to cool in the night where as water bodies have a moderating influence in coastal areas (Khulna). The minimum temperature was slightly less at Khulna (32.08°C) in monsoon but Mongla had the maximum increase in temperature(2.04%). Coastal stations, such as Mongla, have higher humidity, with the potential to increase apparent temperatures. For post monsoon, Jessore and Satkhira were the highest minimum temperatures (maximum 26.57°C) as well as highest increase (7.08% and 1.53%), whereas chuadanga had the lowest increase. Inland sites store heat and the old city-center may be cooled sometimes due to the sea breezes. In winter, Jessore experienced the lowest increase in temperature. Khulna is experiencing lesser cool days in winter as it had the most imcrease in minimum temperature. Water has more heat capacity than air, it cools faster because we have a lot of moisture in the air and wind. In winter, lowest minimum temperatures were reported from Jessore (up to 15.92°C). The lowest was in Khulna (12.64°C). Coastal regions are cooler at night due to coastal influences. The most noticeable fact is that, across all stations and for all seasons, minimum temperature has increased significantly as shown in (Table 2).

3.1.3 Total Rainfall

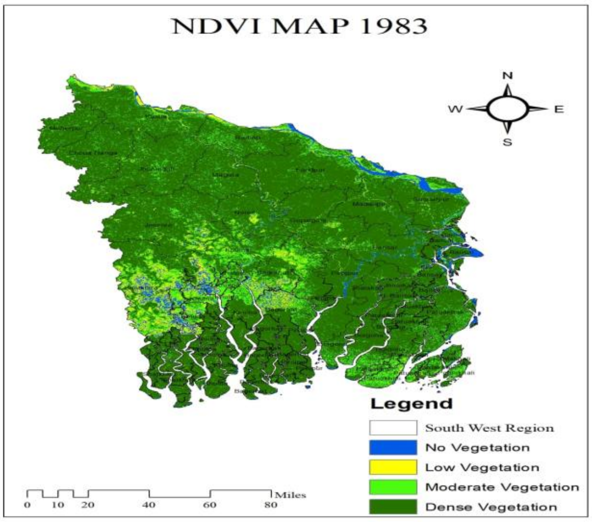
Table 3: Percent Bias of Total Rainfall

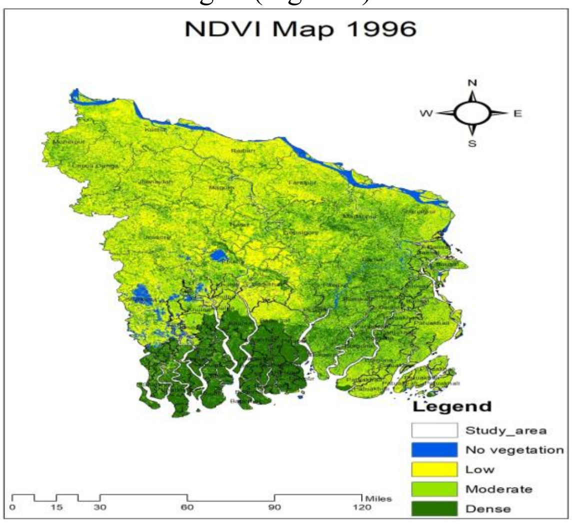
Station	Pre Monsoon	Monsoon	Post Monsoon	Winter
Jessore	0.33%	4.16%	6.50%	-16.70%
Satkhira	11.10%	0.25%	12.56%	-13.83%
Khulna	-11.30%	8.70%	12.60%	-6.47%
Chuadanga	-17.98%	-22.05%	20.75%	-26.90%
Mongla	-11.66%	-2.38%	30.22%	-14.42%

Interior stations (Jessore, Chuadanga) are generally warmer than coast stations (Khulna, Mongla), since maritime moderation is less. Along the coast, the temperatures are more constant, with less diurnal variation. Coastal localities (Mongla and Satkhira) experience relatively heavier monsoon precipitation such as lies close to the moisture sources. Inner stations (Jessore, Chuadanga) are more variable in nature, having higher pre-monsoon and winter rainfall. From the seasonal analysis we observed that , Tmax and Tmin has increased throughout the seasons. It can be seen, Monsoon rainfall has decreased most in Chuadanga and increased most in Khulna. Post monsoon rainfall has increased majorly in all areas. This indicates that monsoon behaviour is shifting. Pre monsoon rainfall has increased in a few areas while most of the locations has a significant decrease as shown in (Table 3).

3.2 Normalised Difference Vegetation Index (NDVI)

In 14 years of interval, four different maps are shown with visible changes. (Figure 3).





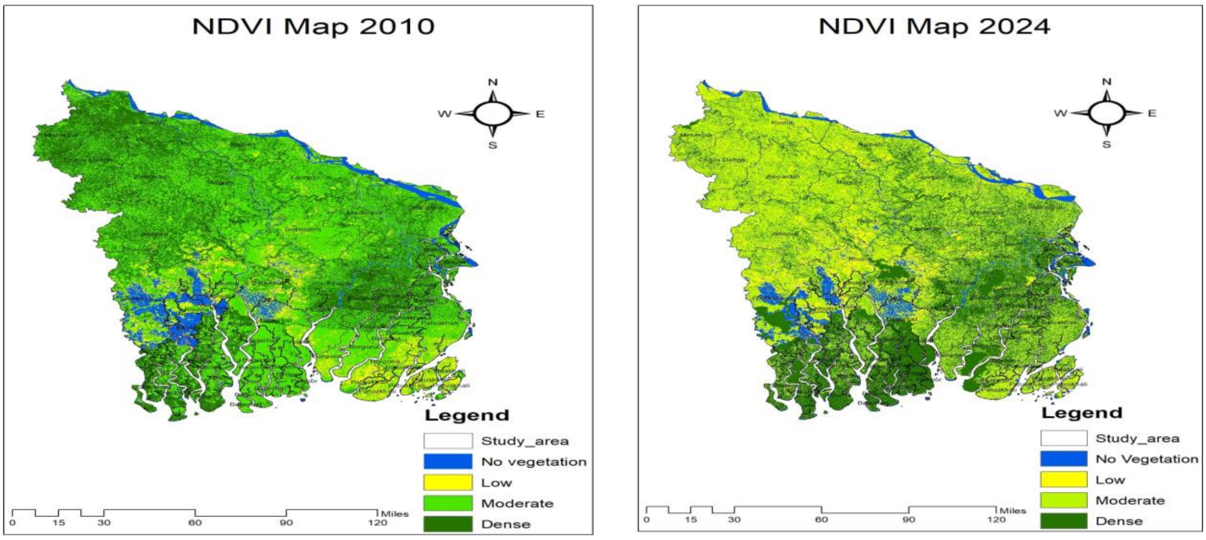


Figure 3: Vegetation in different years at 14 years interval

3.2.1 NDVI Summary Table

Table 4: Percent Changes in Vegetation

Vegetation Type	NDVI value	In 1983	In 1996	In 2010	In 2024
No vegetation	NDVI< 0.1	4%	8%	9%	11%
Low vegetation	0.1≤ NDVI < 0.3	2%	22%	16%	34%
Moderate vegetation	0.3≤ NDVI < 0.6	29%	46%	48%	38%
Dense vegetation	NDVI≥ 0.6	65%	23%	27%	17%

As shown in (Table 4) The 1983 landscape was the most vegetated, characterized by prominent thick bushes in the southwest and minimal barren land. By 1996, a strong north-south gradient was visible, with dense forests concentrated in the south and more moderate and low vegetation elsewhere. A slight recovery was noted in 2010, with both dense and moderate vegetation classes expanding slightly. However, the 2024 data reveal a severe degradation, where the once-dense southwestern forests have diminished, low vegetation has spread significantly, and non-vegetated areas have substantially increased, pointing to greater anthropogenic pressure on the environment.

4. CONCLUSION

This research used an integrated methodological framework involving Innovative Trend Analysis (ITA) and geospatial tools to evaluate spatio temporal variation in hydrological components and vegetation trend in the Ganges Dependent Area (GDA) of Bangladesh. The approach used long-term climate (maximum temperature, minimum temperature, and cumulative rainfall) and NDVI (Normalized Difference Vegetation Index) estimates obtained from satellite imagery to infer the changes in environmental conditions during a period of decades. Use of software facilities such as ArcGIS guaranteed vigorous data treatment and statistical validation that was carried out by employing ITA provided confidence to the trend analysis. Findings indicated that there were noticeable changes in climate, such as increasing temperatures and unpredictable rainfall patterns that were associated with evident vegetation degradation. NDVI analysis led to show reducing in dense vegetation cover, especially in the southwestern, and increasing in low and un-vegetated areas. These modifications were associated with human activities (agricultural development, urbanization, resource exploitation), as well as climate-induced stressors, that had a profound anthropogenic impact including long-term drought and rainfall regime changes. This talk highlighted the ecological fragility of the GDA, tackling the effect of loss of vegetation on soil erosion and biodiveristy as well as reduction in ecosystem services, all of which are very important for local communities. Combining hydrological and vegetation information allowed for a more comprehensive picture of land–atmosphere interaction and revealed that climate variability and human influences have a combined effect in forcing landscape change. This study had its limitations though, including restrictions concerning the data resolution and the difficulties associated with disentangling climate-driven variations from the effect of human disturbances. Future studies may utilize higher resolution satellite images and survey of dwelling communities in order to validate remote sensing observations.

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