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NDVI VARIATION AND ITS RESPONSES TO METEOROLOGICAL FACTORS IN THE HAKALUKI HAOR AREA DISTRICT

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Abstract

The study was carried out in Hakaluki haor to examine the effects of meteorological factors on Normalized Difference Vegetation Index (NDVI) dynamics. Remote sensing and GIS technique was used to detect the spatiotemporal changes of NDVI in Hakaluki *haor* using multi-temporal satellite images from Landsat 7 ETM+ and Landsat 8-OLI images from 2000 through 2019. The results from the spatiotemporal analysis at every five year interval showed that the value of NDVI decreased rapidly, so the density of vegetation coverage was declining, and the water body was shrinking imperfectly. The resulting datasets from NDVI were compared with the meteorological parameter such as rainfall, maximum temperature, minimum temperature, and humidity to assess the impact of meteorological changes on it. Linear regression analysis model was done to identify the relationship of averaged meteorological factors as independent variables that could affect the averaged NDVI as the dependent variable at the study site. From the analysis of the linear regression model, it was found that there was a significant decrease in rainfall, with an increase in temperatures in conjunction with the decline of NDVI value. The results revealed that the NDVI value decreased with rainfall and humidity and had a negative correlation with rainfall and humidity, indicating that the vegetation growth was decreasing. The correlation between NDVI and maximum and minimum temperature was significantly positive, but there was a negative correlation between rainfall and humidity. Overall this study illustrated the effectiveness of the NDVI approach for the change detection of area under the major changes of meteorological factors in Hakaluki *haor.*

Keywords: Hakaluki *haor*, NDVI, GIS, Remote Sensing, Change detection, Landsat data, Meteorological factors.

Introduction

Normalized Difference Vegetation Index (NDVI) is a widely used index for distinguishing the spatio-temporal change of vegetation coverage on the earth's surface of vegetation through remote sensing and geographic information system (GIS) technology (Vikram and Bhamare, 2012). NDVI was first proposed by Rouse *et al.* (1973), which is often used to characterize vegetation cover, growth, yield, and health status. NDVI is developed for estimating vegetation coverage from the reflective bands of satellite data (Sahebjalal and Dashtekian, 2013). The analysis of spatiotemporal change in vegetation cover and its density has a greater significance in taxonomy and understanding the overall nature of biodiversity in response to recent meteorological change.

Application of remotely sensed data made it possible to study the changes in NDVI value in less time, at a low cost, and with better accuracy in association with GIS provides a suitable platform for data analysis, update, and retrieval (Rawat and Kumar, 2015). Satellite images are required to prepare NDVI by the GIS software. It is also a powerful tool for collecting data about vegetation from satellite images (Bid, 2016). The NDVI is one of the most successful and useful indexes to detect live green plant canopies in multispectral remote sensing data and quickly identify vegetated areas and their condition. The NDVI values always range between -1 to +1 because of high reflectance in Near Infrared Red (NIR). The NDVI value below zero indicates the presence of water bodies and the 0-1 value indicates the wide variation of vegetation from bare surface to dense forest canopy (Agone and Bhamare, 2012). Hakaluki *haor* is the largest inland freshwater wetland ecosystem in Bangladesh and one of the largest *haor* in south Asia (CNRS, 2002). It is composed of 6,000 beels (small freshwater lakes) and covers up to 18,000 ha of area during the rainy season from mid-May to mid-July (DoE, 1999). This *haor* ecosystem supports at least 73 wetland vegetation species, nearly half

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the national total of 158 species (Choudhury and Faisal, 2005). However, the quick growth of the population is a common and most serious factor which extremely influences the rapid degradation of wetland resources and species in Hakaluki *haor*. More and more settlement is built around the haor area to cope with this population pressure. Due to the excess pressure from overpopulation, the wetlands are also under serious threat, with most of them being encroached upon by the local people (Rana *et al.,* 2009). Siltation and over-exploitation of vegetation for food and fodder are major problems in Hakaluki *haor,* which causes changes in vegetation coverage and water bodies (Uddin *et al.*, 2013).

Therefore, this study aims to monitor and map the spatio-temporal dynamics of NDVI value in Hakaluki*haor* from 2000 to 2019 using multi-temporal satellite imageries from Landsat 7 and Landsat 8 data by using ArcGIS and remote sensing. The remotely sensed NDVI data set indicates the vegetation coverage and water body, and its temporal trend with meteorological factors is detected by correlation analysis. In addition, GIS techniques were applied to detect the associated driving forces for changing NDVI. Meanwhile, NDVI change detection is very essential for better understanding of vegetation coverage changes, water body changes and sustainable resource management. The specific objectives of this study were (i) to study the dynamics of NDVI in Hakaluki *haor* using remote sensing and GIS and (ii) to assess the long-term changes of the meteorological parameter concerning NDVI. The results of this study are expected to provide valuable information on changing pattern of NDVI for vegetation coverage and water body and the future planning for any development in this area.

Materials and Methods

Study area

The study area selected for this research was Hakaluki *haor*. Hakaluki *haor* is a marsh wetland ecological system in the eastern Bangladesh. It is one of Bangladesh's largest and one of Asia's larger marsh wetland resources. Hakaluki *haor* falls under the jurisdiction of two districts, Moulvibazar and Sylhet, which was declared an Ecologically Critical Area (ECA). It is also a protected Ramsar site of international importance for wetland conservation and sustainable utilization (Roy et al., 2009).

Data set and methods

For this study, Multispectral satellite imageries were used to identify the changes in NDVI in Hakaluki haor from 2000 through 2019 at every five years interval. Satellite data that comprised five years multi- temporal satellite imageries (LANDSAT 7 imageries of 2000, 2005 and 2010) and (LANDSAT 8 imageries of 2015 and 2019) for February at path (136) and row (43) were acquired from the USGS GLOVIS website. Data were prepared, managed, and analyzed by using ArcGIS10.5. Detailed information on the Landsat images are presented in Table 1.

Table 1: Sources of satellite images data

Data Type	Data Acquisition	Special Resolution	Sources
LANDSAT 7	12.02.2000	30m x 30m	USGS GLOVIS
LANDSAT 7	02.02.2005	30m x 30m	USGS GLOVIS
LANDSAT 7	16.02.2010	30m x 30m	USGS GLOVIS
LANDSAT 8	10.02.2015	30m x 30m	USGS GLOVIS
LANDSAT 8	02.02.2019	30m x 30m	USGS GLOVIS

Image pre-processing

Pre-processing of satellite images is essential and has the unique goal of establishing change detection. Various image preprocessing operations, such as image enhancement and interpretation, were considered for this study. The shape file of Hakaluki *haor* was created by geo-referencing of Hakaluki *haor* Map using ArcGIS 10.5.

Image processing for extracting NDVI features

Visual interpretability is one of the image enhancement methods which aims to increase the apparent distinction between the features (Ibrahim and Al-Mashagbah, 2016). Image processing for the change detection of NDVI is essential for establishing a more direct linkage between the data and biophysical phenomena (Rahman, 2013). From the extracted images, the base map of Hakaluki *haor* according to the administrative district was collected. The NDVI was used to extract features from the Landsat imagery and to detect the changes over the time period of 2000 to 2019 at five years' time intervals. Mainly radiometric correction of Landsat 7 and Landsat 8 images were taken into consideration for image processing of multispectral satellite imageries of satellite (Sofiullah, 2017).

Calculation of NDVI for Landsat 7

Radiometric correction for landsat 7 imageries was used to calculate NDVI value for the year of 2000, 2005 and 2010. Enhanced Thematic Mapper Plus (ETM+) spectral radiance data can also be converted reflectance using reflectance rescaling coefficients provided in the landsat 7 ETM+ metadata file (Ganie and Nusrath, 2016). The equation (1) is used to convert DN values to radiance data:

$$L\lambda = \frac{\text{LMAX}\lambda - \text{LMIN}\lambda}{Q\text{calmax} - Q\text{calmin}} \left(Q\text{cal} - Q\text{calmin}\right) + \text{LMIN}\lambda (1)$$

Where, L_{λ}= Spectralradianceatthesensor'saperture[W/ (m^2srμm)],Q_{cal}= Quantized calibrated pixel value[DN], Q_{calmin}= Minimum quantized calibrated pixel value corresponding toLMIN$_{\lambda}$[DN], Q_{calmax}= Maximum quantized calibrated pixel value corresponding to LMAX$_{\lambda}$ [DN], LMIN$_{\lambda}$= Spectral at-sensor radiance that is scaled to Q_{calmin}[W/ (m^2srμm)], LMAX$_{\lambda}$= Spectral at-sensor radiance that is scaled to Q_{calmax}[W/ (m^2srμm)]. While radiance is the quantity measured by the Landsat sensors, a conversion to reflectance facilitates better comparison among different scenes (Chanderet al., 2009). It can be calculated using the following equation (2):

$$\rho\lambda = \frac{\pi \cdot L\lambda \cdot d^2}{\text{ESUN}\lambda \cdot \sin \theta se} (2)$$

Where, ρ_{λ}=Planetary TOA reflectance[unitless], π =Mathematical constant equal to ~ 3.14159[unitless], L_{λ}=Spectralradianceatthesensor'saperture[W/ (m^2srμm)], d =Earth–Sun distance [astronomicalunits], ESUN$_{\lambda}$=band-specific radiance emitted by the sun [W/ (m^2μm)], θ_s=Solar zenith angle[degrees]. The NDVI calculation was done after doing all the radiometric correction. The Normalized Differential Vegetation Index (NDVI) is expressed in equation (3):

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \quad (3)$$

NDVI = (band 4 – band 3) / (band 4 + band 3)

For Landsat 7, Near Infrared (NIR) was represented by Band 4, and RED reflectance was represented by Band 3.

Calculation of NDVI for Landsat 8

Radiometric correction for Landsat 8 imageries was used to calculate NDVI value for the year of 2015 and 2019. OLI spectral radiance data can also be converted to TOA planetary reflectance using reflectance rescaling coefficients provided in the Landsat 8 OLI metadata file (Ganie and Nusrath, 2016). The equation (4) is used to convert DN values to TOA reflectance for OLI image:

$$\rho\lambda' = M\, \rho Q\text{cal} + A\, \rho \quad (4)$$

Where, ρλ' =TOA planetary reflectance, without correction for solar angle, Mρ =Band-specific multiplicative rescaling factor from the metadata, Aρ =Band-specific additive rescaling factor from the metadata, Q cal =Quantized and calibrated standard product pixel values (DN). Metadata means the .txt file which is along with the data. Correction of the Reflectance value with the sun angle can also be done. Reflectance with a correction for the sun angle is given in equation (5):

$$\rho\lambda = \rho\lambda\,'/\cos\theta SZ = \rho\lambda\,'/\sin\theta SE \quad (5)$$

Where, ρλ =TOA planetary reflectance. θSE =Local sun elevation angle, The scene center sun elevation angle in degrees is provided in the metadata (Sun Elevation), θSZ =Local solar zenith angle; θSZ = 90° – θSE. The NDVI calculation was done after doing all the radiometric correction. The Normalized Differential Vegetation Index (NDVI) is expressed in equation (6):

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (6)$$

NDVI = (Band 5 –Band 4)/ (Band 5 + Band 4)

For Landsat 8, Near Infrared (NIR) was represented by Band 5, and RED reflectance was represented by Band 4.

Change detection of NDVI

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. In this study, the changes in NDVI value in the periods of 2000, 2005, 2010, 2015, and 2019 and changes in area between the years of 2000-2005, 2005-2010, 2010-2015, and 2015-2019 were detected. This method was adopted due to its simplicity and capability to compare two images from different times. In addition, it is the most common approach that has been widely used to detect the changes of NDVI. The changes in area in the periods of 2000-2005, 2005-2010, 2010-2015, 2015-2019, and 2000-2019 were calculated by NDVI calculation.

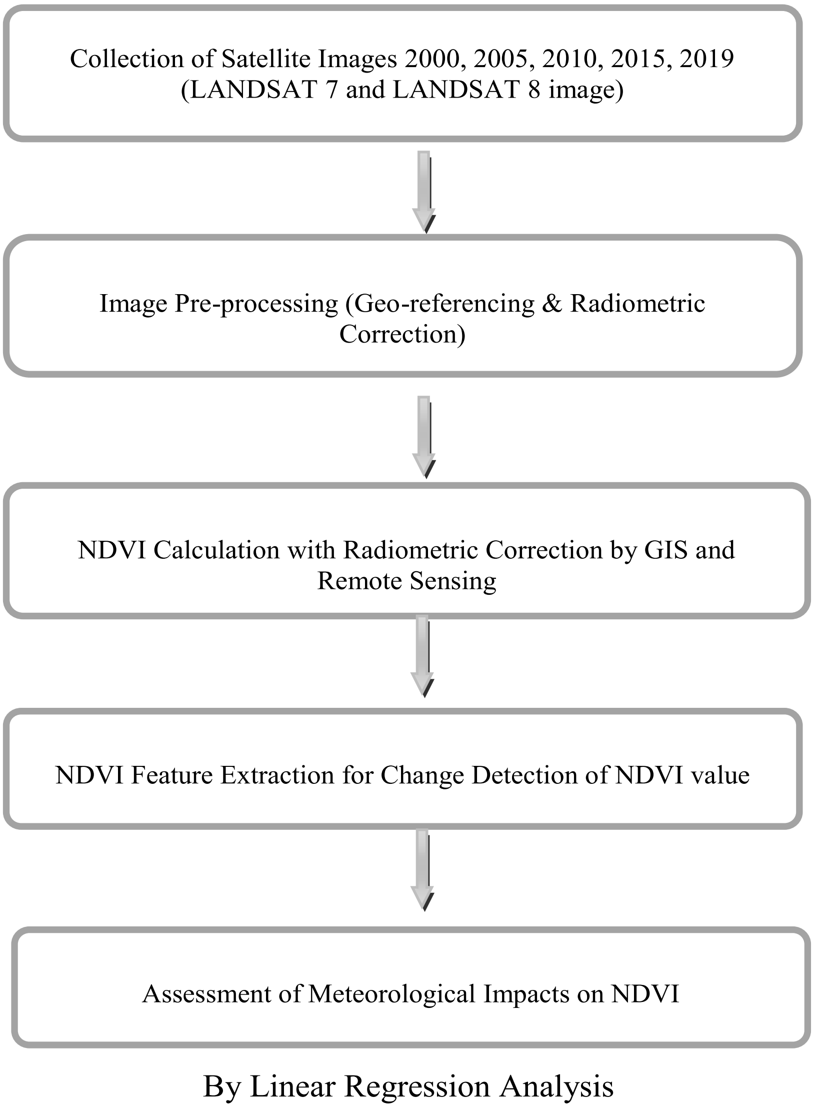
Correlation between meteorological factors and NDVI

Correlation between the meteorological factors, such as rainfall, maximum temperature, minimum temperature and humidity variation with time and the variation of NDVI value had been represented by using linear regression analysis, in order to highlight the relation between two of them. The trend of NDVI value over the period of years 2000, 2005, 2010, 2015, and 2019 with meteorological data were done by using a linear regression analysis procedure to detect the trend on an annual basis. This linear regression method was used to estimate the slope. Positive slope value indicates an increasing trend, while a negative value indicates a decreasing trend. The linear regression equation is shown in equation (7):

$$Y = a + bx \ldots\ldots\ldots (7)$$

Here, Y indicates a dependent variable, X indicates an independent variable and a, b indicates a constant value. In this study independent variable Y was the NDVI value, and the explanatory variable X was the meteorological factor such as rainfall, temperature, and humidity. The value of R-square (R^2), or the square of the correlation coefficient from the regression analysis was used to show how strong the correlation and relationship between the variables X and Y (Adedeji *et al.,* 2018).

The overall flow chart of Methodology is given below:



Results & Discussion

Changes of NDVI results for the year of 2000, 2005, 2010, 2015, and 2019

Images were collected and analyzed every five years to investigate vegetation coverage changes and shrinkage of water bodies in the central part of the study area. Area variation for vegetation coverage, water body, and fallow land/buildup/rocks in 2000, 2005, 2010, 2015, and 2019 was illustrated in the map using different colors to represent each category (Figure 1). In 2000, the NDVI value for water bodies was-0.5, for fallow land/buildup/rocks was 0.18, and for vegetation was 0.62.The lower NDVI value of-0.5 represents no vegetation that indicates the presence of water bodies. The NDVI value $0 < NDVI < 0.2$ indicated the areas of fallow land, human settlement, and barren land. The maximum NDVI value of 0.62 shows comparative dense vegetation coverage in Hakaluki haor. NDVI value in 2005 for water bodies was-0.4, for fallow land/buildup/rocks 0.115, and for vegetation coverage 0.49. The NDVI value of 0.49 for vegetation coverage in 2005 was also less than the NDVI value in 2000, which means the density of vegetation coverage was moderate in 2005. From the map of 2000 and 2005 it can be seen that the water bodies was shrunk in 2005. In 2010, the NDVI values for water bodies, fallow land/buildup/rocks, and vegetation coverage were -0.4, 0.089 and 0.46, respectively. Maximum NDVI value of 0.46 showed the area with dense vegetation as the NDVI value >0.2, and the minimum negative value of -0.4 indicated the presence of water bodies in Hakaluki haor. Because of siltation, the condition of water bodies is on a negative track.

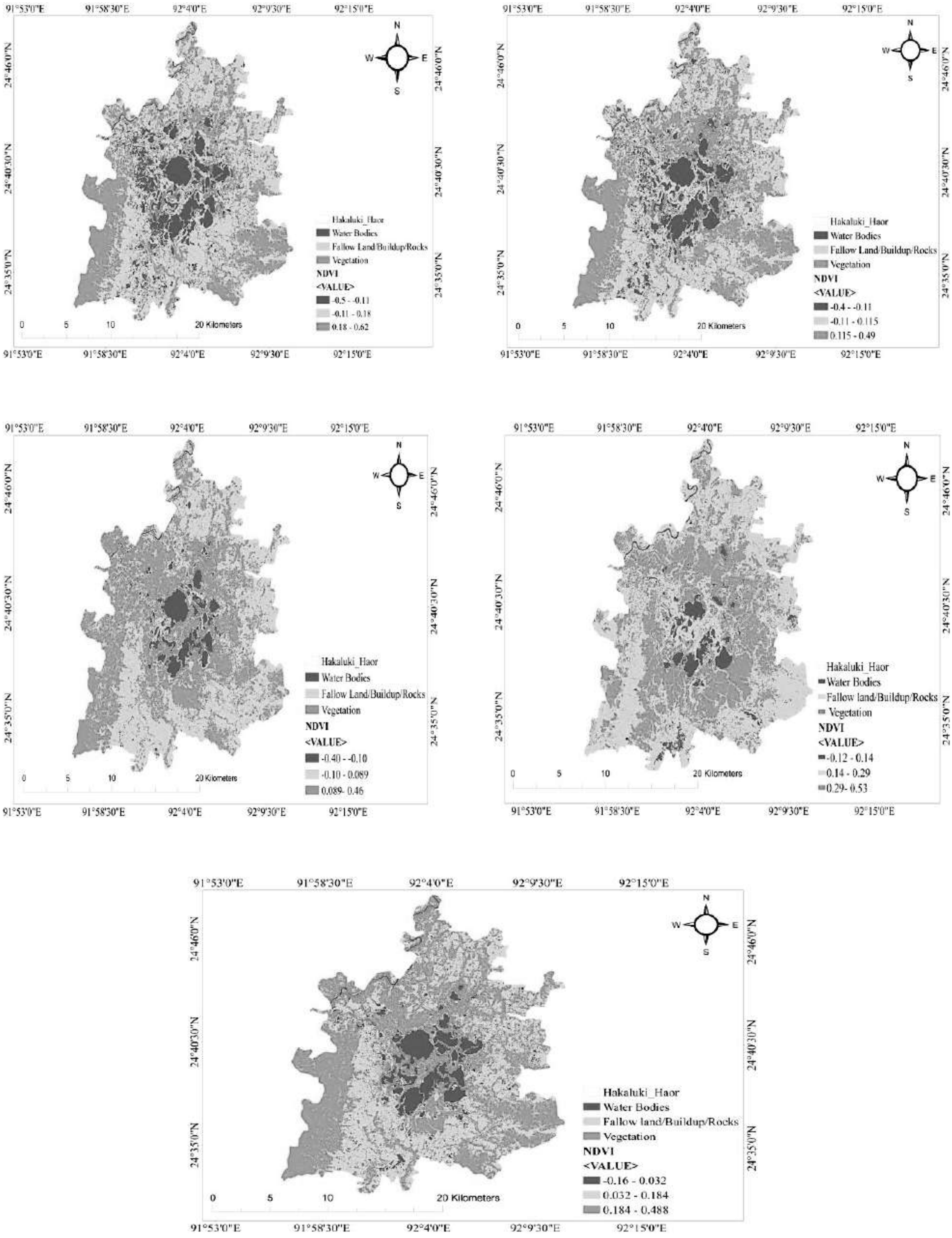


Figure 1: Spatial Distribution of NDVI in the Hakaluki *haor* area (2000 to 2019).

The siltation caused the consumption of land for settlement and cultivable lands caused a reduction in natural biological production of many wetland floras (Uddin et al., 2013). The lowest value of 0.089 represents the mixed area, including barren land, fallow land, and habitation. In 2005, the NDVI value for vegetation coverage was 0.49, which decreased to 0.46 in 2010. That means the density of vegetation coverage was not to a large extent in 2010. The NDVI value in 2015 for water bodies, fallow land/buildup/rocks, and vegetation coverage were -0.12, 0.29, and 0.53, respectively. The highest value (0.53) indicates that in 2015 the area was occupied with dense vegetation, and the lowest value (-0.12) represents the water body because NDVI negative values indicate the presence of water bodies in the study area. The NDVI value for fallow land/buildup/rocks were increased from 0.089 to 0.29 and also the area was increased. Finally in 2019, the NDVI value for water bodies, fallow land/buildup/rocks, and vegetation coverage were found -0.16, 0.184, and 0.488, respectively. The area covered with NDVI value 0.488>0.2 means that the vegetation coverage in Hakaluki haor was not that healthy and there was moderate vegetation density. Along with this, the value 0.184 represents other areas except water bodies and vegetation. Considering Figure 1, it can be observed that the condition of water bodies is on a negative track because of siltation. The siltation causes the consumption of land for settlement and cultivable lands cause a reduction of natural biological production of many wetland floras (Uddin et al., 2013). That means the shrinkage of water bodies and over-exploitation of vegetation increased the human settlement or buildup and fallow land. Choudhury and Faisal (2005) reported that an increase in the area of buildup, fallow land etc. caused grea t destruction for water bodies and vegetation coverage in Hakaluki haor. The sedimentation process was speeded with upstream water flow from the surrounding hilly areas (Ranaet al., 2010). Due to deforestation and rapid urbanization, the growth of vegetation coverage was at a slowing rate. The enhancement did not fulfill the satisfaction level because of superior urbanization and industrialization, the density of vegetation coverage was not improved and the NDVI value also noticeably decreased (Sahana et al., 2016).

Changes of area between the years of 2000-2005, 2005-2010, 2010-2015, 2015-2019

Changes in areas for water bodies, fallow land/buildup/rocks, and vegetation coverage in Hakaluki haor between the years 2000- 2005, 2005-2010, 2010-2015, and 2015-2019 were depicted in Figure 2. Between the years 2000 to 2005 the area of the water body was decreased from 66.33 km² to 57.56 km², and the area of fallow land/buildup/rocks had gone down from 217.4 to 205.49 km². The area under vegetation coverage had increased from 136.91 km² to 157.63 km² between the years 2000 to 2005. From the years 2005 through 2010 the most conspicuous changes were noticed in water bodies which had gone down from 57.56 km² to 29.07 km². The area with fallow land/buildup/rocks had slightly gone down from 205.49 km² to 200.64 km². The area under vegetation coverage had increased from 157.63 km² to 190.97 km² from 2005 to 2010. Between the years 2010 and 2015 the area under water bodies decreased from 29.07 km² to 27.37 km². The area for water bodies were persistently falling down over the period of years. That means that the area of water bodies is continuously converted to bare land, fallow land, and open field. Fallow land/buildup/rocks area increased significantly from 200.64 km² to 233.81 km². This indicated that the decrease of water bodies and density of vegetation coverage was hastily rehabilitated to fallow land/buildup/rocks areas. The result showed that vegetation coverage significantly decreased by 190.97 km² to 159.5 km², respectively, between the years 2010 and 2015. From the year 2015 to 2019, the area of water bodies enlarged from 27.37 km² to 47.11 km². The area for water bodies increased in the year 2019 compared with other years. The area changes for fallow land/buildup/rocks surprisingly decreased from 233.81 km² to 173.76 km². On the other hand, the vegetation coverage increased by 159.9 km² to 199.81km², respectively, from the year 2015 to 2019.

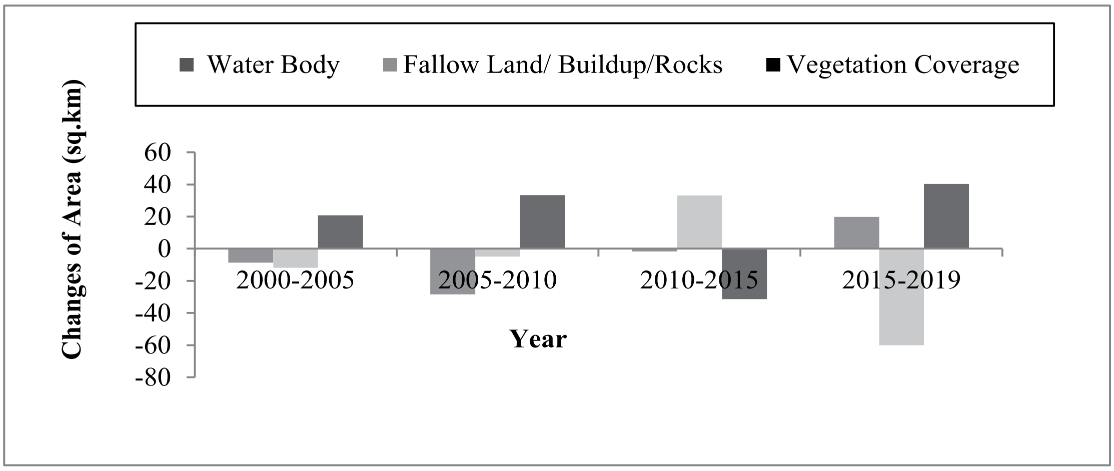


Figure 2: Changes in Area between the years 2000 to 2019

In the table 2, it can be shown that the overall changes in area for water bodies from the year 2000 to 2019 decreased from 66.33 km2 to 47.11 km2 at the rate of -4.57 %. From 2000 through 2019, fallow land/buildup/rocks area decreased significantly by -10.39 % from 217.44 km2 to 173.76 km2. The percentage of vegetation coverage area had slightly increased from 136.91 km2 to 199.81 km2 by 32.59 % to 47.5 %, registering a change of 14.69 %. A crucial findings of this study was that dense vegetation had been converted into open forest, mixed land use, and other categories. Expansion of settlements, human intervention along roads, and development of urbanization were the significant causes of slowly increasing vegetation coverage, and decreased water bodies. The study area experienced considerable spatial and temporal changes in vegetation coverage and water bodies. The vegetation coverage increased by 14.69 %, and the water body decreased by - 4.57 % respectively from 2000 through 2019.

Table 2: Change of area analysis between 2000 and 2019.

Categories	**2000**		**2019**		Change in area(2000 – 2019)	
	Area (km2)	% Area	Area (km2)	% Area	Area (km2)	% Area
Water Bodies	66.33	15.77 %	47.11	11.2 %	-19.22	- 4.57 %
Fallow Land/Buildup/Rocks	217.44	51.69 %	173.76	41.3 %	- 43.68	-10.39 %
Vegetation Coverage	136.91	32.54 %	199.81	47.5 %	62.9	14.69 %

Correlation between NDVI and meteorological parameters

NDVI statistics data, such as mean NDVI value, standard deviation, maximum NDVI value, and minimum NDVI values, were determined from ArcGIS and remote sensing to compare the effects of various meteorological changes on NDVI value. To determine the correlation between NDVI mean value and meteorological factors, the long-term trend of meteorological data normally rainfall, maximum temperature, minimum temperature, relative humidity were analyzed. After analyzing the long-term trend of meteorological data, the quantitative correlations between NDVI and meteorological parameters were determined using the linear regression analysis method over the period of 2000, 2005, 2010, 2015, 2019. The average value for NDVI and meteorological data was plotted for linear regression analysis to determine the correlations between NDVI and meteorological parameters and the NDVI variation with meteorological changes. The correlations between NDVI and meteorological parameters were shown graphically in Figures 3, 4, 5 and 6, respectively.

Rainfall had great influence on NDVI, because NDVI decreased with reduced rainfall and increased with increased rainfall (Zhang et al., 2018). It can be said that, in years of heavy rainfall, the vegetation grows lush, and in years with low rainfall, the growth slows down, and the vegetation becomes sparse (Zhang et al., 2018). During the years 2000, 2005, 2010, 2015, and 2019, the annual averaged NDVI of Hakaluki haor showed a slightly decreasing trend with rainfall. There was no significant correlation between annual rainfall and NDVI value (Figure 3) between the years 2000, 2005, 2010, 2015 and 2019.

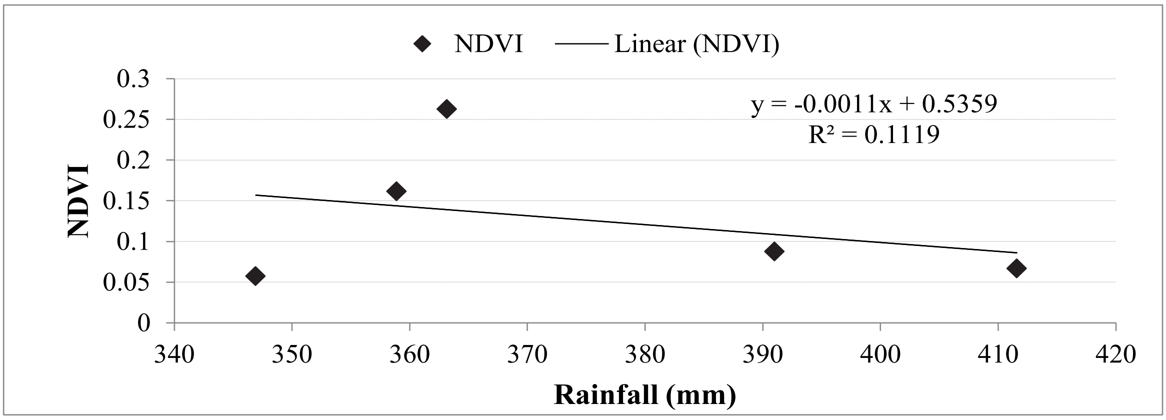


Figure 3: Linear regression analysis between rainfall and NDVI

Increasing the overall temperature will affect plant productivity and the growing season length, and these effects should be indicated in the measured NDVI records (Nasrawiet et al., 2018). The excessive temperature could limit vegetation growth because the increase in temperature will promote vegetation transpiration, leading to the lack of available water for vegetation growth. Rising temperature would increase the energy available for soil water evaporation and thus reducing the soil water content available for vegetation growth. From Figure 4, during the years 2000, 2005, 2010, 2015 and 2019, the annual averaged NDVI of Hakaluki haor showed a slightly increasing trend with maximum temperature. The relationship between the NDVI and maximum temperature (Figure 4) indicates that maximum temperature weakly correlated with NDVI.

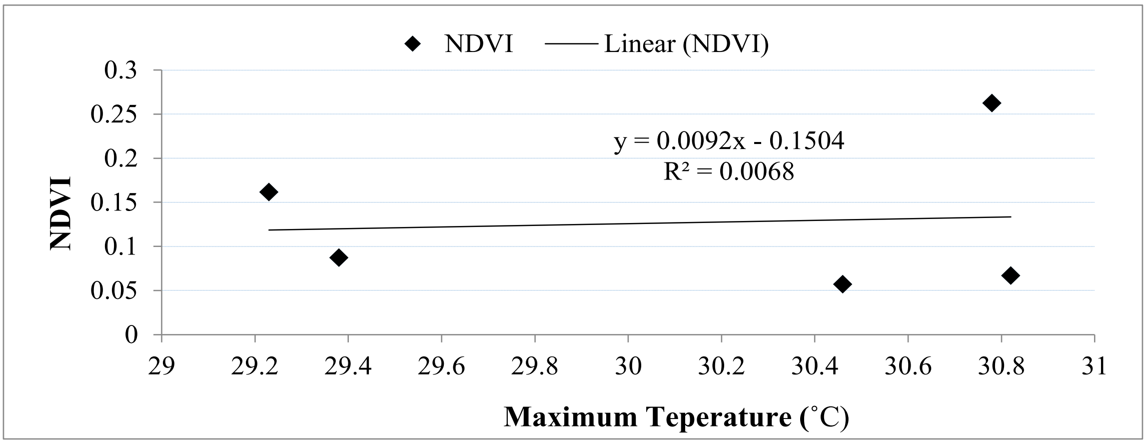


Figure 4: Linear regression between maximum temperature and NDVI.

In the years 2000, 2005, 2010, 2015 and 2019 the annual average NDVI of Hakaluki haor showed a slightly increasing trend with minimum temperature. There was no strong correlation between the minimum temperature and NDVI. High minimum temperatures during the early and late growing seasons are probably associated with lower levels of frost damage and better vegetation growth conditions. From Figure 5, it showed that the NDVI value increased at a rate of 0.0312 per year, with R^2 value 0.0277. However, the trend of NDVI value against the minimum temperature was not that much augmented because the seasonal duration of minimum temperature was not that much elongated, and for this reason, the minimum temperature had less influence on the growth of vegetation coverage (agricultural crop, shrubs, grasses, forest trees etc.), wetland resources and the deterioration of water resources.

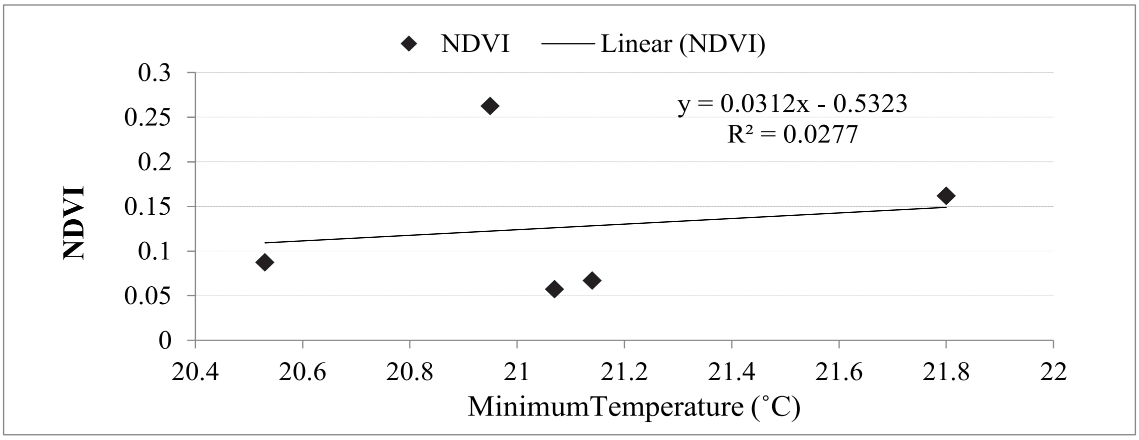


Figure 5: Linear regression between minimum temperature and NDVI.

In the year 2000, 2005, 2010, 2015 and 2019, the annual averaged NDVI of Hakaluki haor showed a decreasing trend with relative humidity. In this study, there was a severe increase in average temperature whereas the average relative humidity decreased. This increase in temperature and relative humidity decrease, resulted in increased evapotranspiration rates of water from the plants and the water body. The effect of rapid evapotranspiration from the plants and water bodies decreased the value of NDVI significantly (Shehhi et al., 2011). The linear correlations of NDVI value with relative humidity were displayed in Figure 6. The relationship between the NDVI and relative humidity (Figure 6) was insignificant.

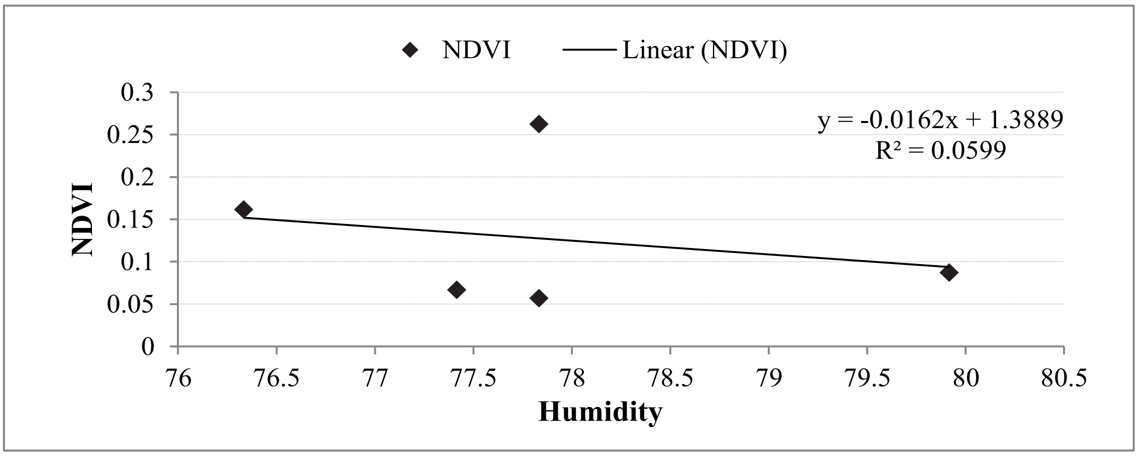


Figure 6: Linear regression between humidity and NDVI.

The correlation between the meteorological parameter and NDVI value acknowledged that the meteorological parameter had no influence on the changes of NDVI and had less influence on the growth of vegetation coverage and the water body. Hence, as a rule of thumb for interpreting the strength of a relationship based on its R-squared value. The values of R^2 ranged between 0.3 and 0.5. R^2 values clearly illustrated that the influence of meteorological parameters on NDVI changes was insignificant.

NDVI is a common and important vegetation index, widely applied in research on global environmental and meteorological changes. Information on NDVI change over a period is vital to effectively managing an area. This study showed how the differences between the visible red and near-infrared (NIR) bands of satellite images could be used to identify the areas containing significant vegetation coverage, water body and other different features. This study was conducted in Hakaluki haor because it has reached a critical state due to over-extraction of resources, natural sedimentation, and human pressure.

The study area was classified into water bodies, dense vegetation, and fallow land/buildup/rocky areas. The extent and percentage of each category with NDVI value in Hakaluki haor over the study period were determined. In the table (2), it can be showed that the area for water bodies from the year of 2000 to 2019 at every five years interval was decreased from 66.33 km^2 to 47.11 km^2 at the rate of - 4.57 %, the fallow land/buildup/rocky area was decreased significantly by -10.39 % from 217.44 km^2 to 173.76 km^2 and the percentage of vegetation coverage area had slightly increased from 136.91 km^2 to199.81 km^2 by 32.59 % to 47.5 % registering a change of 14.69 % from the year of 2000 to 2019.

NDVI changes detection during the periods of 2000-2005, 2005-2010, 2010-2015 and 2015-2019 were also detected to understand the changes in each category over the years. From the change detection process, it was found that there was a considerable change in the vegetation coverage, water bodies and bare land/fallow land/rocky areas with their NDVI value in Hakaluki haor. Linear regression analysis was used to determine the correlation between these meteorological factors and the NDVI value. The correlation between NDVI, maximum and minimum temperature, rainfall, and relative humidity was insignificant. This correlation identified that the meteorological parameter did not influence the changes in NDVI. Finally, the findings of this study showed that NDVI value changed rapidly in Hakaluki haor and helped to gain a quantitative and visual understanding of the magnitude of NDVI change. The result of this study provides a vital monitoring basis for continuous investigations of changes in the natural vegetation and will help decision makers to develop land use plans in Hakaluki hoar area.

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