

Forest Co-Management and Restoration Programs Enhanced the Vegetation Coverage: Evidence from the Baraiyadhala-Hazarikhil Forest Landscape in Bangladesh

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Abstract

The detection process of the land use and land cover change can denote a change in the continuous characteristics of land features. The study identified the land use and land cover (LULC) change in the Baraiyadhala-Hazarikhil forest landscape consisting of Baraiyadhala National Park and Hazarikhil Wildlife Sanctuary (HWS) from 1990 to 2020. The LULC changes were identified through analyzing the Landsat satellite imageries of 1990 and 2020. The study also investigated the drivers of LULC through key informant interviews. Finally, the potential strategies and techniques to continue gaining forest cover and combat the drivers of deforestation and degradation were recommended and discussed. The study identified five major land uses, i.e., dense vegetation, light vegetation, agriculture, barren land, and settlement. The remaining land covers that fall outside these land uses were grouped as “other land uses”. The finding of the satellite imageries indicated an increase of dense vegetation (75%) and light vegetation (17%) from 1990 to 2020. Moreover, the barren land, agricultural land, and other land use areas were also reduced by 92%, 93%, and 38%, respectively. All these can be deemed as a positive change of forest cover. However, there are also some negative changes, including the increase of settlement (142%). The vegetation increase is attributed to the plantation projects, forest conservation initiatives, and forest co-management programs conducted under the leadership of the Forest Department. The increase in landscape settlement can be explained by the incursion of landless people from the nearby island in the Bay of Bengal due to the frequent occurrence of natural disasters. The study recommends eviction or relocation of illegal settlements, strict enforcement of forest laws, control of road network expansion inside the landscapes, awareness-raising among local people, covering barren land with environmentally sound restoration initiatives, and motivation of the political leaders for further improvement of the forest cover and overall forest health in the landscape.

Keywords: *Dense vegetation, Ecotourism, Remote sensing, Restoration, Satellite imageries.*

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সারমর্ম: ভূমি ব্যবহার এবং ভূমি আচ্ছাদনের পরিবর্তনের সনাক্তকরণ প্রক্রিয়া ভূমির ক্রমাগত বৈশিষ্ট্যের পরিবর্তন নির্দেশ করে। এই গবেষণাটি বারইয়াঢালা-হাজারিখিল বন ল্যান্ডস্কেপ এর (বারইয়াঢালা জাতীয় উদ্যান এবং হাজারিখিল বন্যপ্রাণী অভয়ারণ্য) ১৯৯০ থেকে ২০২০ সালের মধ্যে ভূমি ব্যবহার এবং ভূমি আচ্ছাদন পরিবর্তন সনাক্ত করে। এই পরিবর্তনগুলি ১৯৯০ এবং ২০২০ এর ল্যান্ডস্যাট উপগ্রহের ছবি ব্যবহার করে নির্ধারণ করা হয়েছে। প্রধান তথ্যদাতাদের তথ্য বিশ্লেষণ করে এই পরিবর্তনের কারণগুলো খুঁজে বের করার জন্য তথ্যানুসন্ধান করা হয়। সবশেষে, কিভাবে বনাচ্ছাদন বাড়ানো যায় এবং বনধ্বংস ও বনের ক্ষয় এর কারণগুলোকে দূর করা যায়, তার কৌশল ও কারিগরি দিক নিয়ে আলোচনা করা হয়। গবেষণাটি পাঁচটি প্রধান ভূমি ব্যবহার সনাক্ত করে, যেমন, ঘন বনভূমি, অবক্ষয়িত বনভূমি, কৃষি, বিরানভূমি এবং বাসভূমি। এই ভূমি ব্যবহারের বাইরের কিছু জমি “অন্যান্য ভূমি ব্যবহার” হিসাবে শ্রেণীভুক্ত করা হয়েছে। উপগ্রহের ছবিগুলি বিশ্লেষণ করে পাওয়া তথ্য সূচিত করে যে, ১৯৯০ থেকে ২০২০ সালের মধ্যে ঘন বনভূমি (৭৫%) এবং অবক্ষয়িত বনভূমি (১৭%) বৃদ্ধি পেয়েছে। তাছাড়া, বিরানভূমি, কৃষিভূমি এবং অন্যান্য ভূমি ব্যবহারের এলাকা যথাক্রমে ৯২%, ৯৩%, এবং ৩৮% কমেছে। এটা বন আচ্ছাদনের একটি ধনাত্মক পরিবর্তন হিসাবে বিবেচিত হতে পারে। তবে, কিছু বিপরীতমুখী পরিবর্তনও হয়েছে, যেমন বাসস্থানের বৃদ্ধি (১৪২%)। বন আচ্ছাদন বৃদ্ধির কারণগুলো হলো বন বিভাগের নেতৃত্বে বৃক্ষরোপণ, বন সংরক্ষণের জন্য গৃহীত প্রচেষ্টা এবং বন সহব্যবস্থাপনা উন্নয়ন। বাসস্থানের সংখ্যা বৃদ্ধির জন্য বঙ্গোপসাগরের দ্বীপ থেকে নানান প্রাকৃতিক দুর্যোগের ফলে উদ্ভাস্ত হওয়া মানুষের অস্থায়ী বসবাস কাজ করেছে। গবেষণাটি অবৈধ বাসস্থানের উচ্ছেদ বা স্থানান্তর, বন আইনের শক্তিশালী প্রয়োগ, সড়ক নেটওয়ার্ক প্রসারণ নিয়ন্ত্রণ, স্থানীয় মানুষের সচেতনতার উন্নয়ন, পরিবেশগতভাবে উচ্চমানের বন-পুনর্বাসন প্রকল্প গ্রহণ এবং রাজনীতিবিদদের অনুপ্রেরণার মাধ্যমে বন আচ্ছাদন বাড়ানো এবং সামগ্রিক বন-স্বাস্থ্যের আরও উন্নতির জন্য পরামর্শ দেয়।

1. Introduction

Global climate change is becoming more intense due to the ever-increasing concentration of greenhouse gases (GHG) in the atmosphere [1]. Deforestation and forest degradation are significant causes of GHG emissions [2]. Sustainably managed forests can conserve the forest ecosystem and restore the deforested and degraded areas. In the face of the substantial anthropogenic causes of deforestation and forest degradation in Bangladesh, there was a strategy to declare at least 10% of forest areas into Protected Areas (PA). Baraiyadhala National Park (BDNP) and Hazarikhil Wildlife Sanctuary (HWS) are two of 52 PAs declared in Bangladesh [3]. These two PAs combined formed a unique forest landscape in the northern part of the Chattogram district. Even after the declaration of the PAs, the forests could not save themselves from degradation except in a few cases [4]. However, both BDNP and HWS harbors many endangered species in Bangladesh. In 1990, it housed more than half of the mammals species of the country [5]. However, the habitats of these species have been drastically hampered by anthropogenic causes, especially by the local population pressure and over-extraction to meet their increasing demand. Due to this case, it has lost several faunal and floral species during the last three decades. Hence, this habitat has been regarded as critical.

Complex interactions of environmental and socioeconomic factors determine the forest cover changes. A wide range of understanding of these dynamics can reconstruct the present land cover changes [6]. In understanding the land-use changes, remote sensing techniques have already been a helpful tool [7-9]. To understand the latest forest land-use changes, repetitive and updated land-use change information is crucial for determining the various environmental influences on these changes [10]. Different researchers detected forest degradation based on socioeconomic and physical parameters [9, 11, 12]. Dontree [13] and Cropper et al. [14] investigated the land use dynamics and factors that affected the deforestation location in Thailand. Kelarestaghi et al. [15] reported 2.99% forest area decrease and 9.2% dry farming increased in four decades in Northern Iran. In Bangladesh, many researchers applied remote sensing for the identification of land use and land cover (LULC) changes in the forest landscapes, e.g., Islam et al. [16], Islam et al. [17], Redowan et al. [18].

Along with the land use and land cover change assessment, the drivers must also be explored to address forest management strategies better. There is a significant lack of information about the LULC and its drivers, especially for PAs in Bangladesh. In this circumstance, integrating remote sensing with social parameters can be an excellent approach to assessing the land use and land cover change and identifying the drivers of change.

It has been grossly estimated that the forests in Bangladesh are getting negative change by 9000 km² since the 1930s, with an annual deforestation rate in excess of 1% [19]. Chowdhury and Koike [4] described that by getting such a deforestation rate, Bangladesh would lose its all-natural forests by the next 35-40 years except for the Sundarbans. So, forest conservation in Bangladesh received sincere attention from policymakers earlier in the last two decades. From this mindset, the Government of Bangladesh undertook some substitute forest management systems. One of them was the designation of protected areas [20]. Agroforestry and other afforestation projects were intended to increase forest coverage [21]. So, within the last two decades, there has been a change in the land use and land cover in the forest areas, particularly in the protected areas in Bangladesh. However, understanding this change in the protected forest areas is very important. The study of analyzing the satellite imageries with the time series data along with the socio-economic and physical factors can give the policy makers a clear visualization of the forest land use and land cover changes [22].

Land use and land cover changes analysis in the forests applying GIS technology with temporal satellite imageries can determine the extent of deforestation, forest degradation, and restoration [23]. A social survey can derive the causes behind the positive or negative changes in land use and land cover. The purpose of this study is

to comprehend habitat deterioration or destruction in relation to physical and socioeconomic issues. This understanding will enable the policymakers to take effective and case-specific measures to combat the degradation and restore the BDNP and the HWS. This action will assist in protecting rare and threatened species and reinstall the forest ecosystem services of the BDNP and the HWS, which is interlinked with the overall social, environmental, and economic development [24]. The study hypothesizes that the socio-economic factors significantly affect the land use and land cover in the BDNP and HWS in Bangladesh. So, this study holds the research question: What are the spatial and temporal changes of the forest land use and land cover in the BDNP and the HWS between 1990 and 2020? What factors influenced the land use and land cover changes in the BDNP and the HWS between 1990 and 2020? What measures can be undertaken to combat negative changes in the BDNP and the HWS? The study can be useful to the forest conservationists in Bangladesh.

2. Methodology

Description of the study area

BDNP consists of two beats (the lowest administrative unit of forest department), namely Baraiyadhala and Borotakia. BDNP is located about 207 km south-east of Dhaka and 40 km north of Chattogram in Mirsharai and Sitakunds Upazila in Chattogram district. Geographically, the area lies between 22°39'-22°47' N latitude and 91°35'- 91°41' E longitude (Figure 1). BDNP covers 2933.61 ha of tropical semi-evergreen forests. It was established in 2010 through a gazette notification. HWS covering 2908.50 ha land area was a reserve forest under Chattogram north forest division. Bangladesh Government declared the Hazarikhil reserve forest as Hazarikhil Wildlife Sanctuary (HWS) in 2010 through a gazette notification.

Both the protected areas of Baraiyadhala and Hazarikhil landscape are under the jurisdiction of the Chattogram North Forest Division. Under the Bangladesh Wildlife (Preservation) (Amendment) Act 1974, farming activities, killing, hunting, capturing wildlife, and entering or building settlements in protected areas is strictly prohibited. Both BDNP and HWS are characterized by a sub-tropical monsoonal climate [25]. However, the southwest airflow allows for most of the annual precipitation in the landscape. The landscape receives 3000 mm annual mean rainfall ranging from 1,611 to 3,878 mm. The temperature and humidity of the area range from 12.5 °C to 37 °C and from 38.9% to 88% all year round [25]. The low ridges cover a significant portion of the HWS, while the remainder is flood plains. The hilly land consists of sand-loam to coarse sand, and the floodplain contains clayey to clay-loam soil. BDNP is featured by some unique waterfalls that attract significant number of tourists every year whereas HWS is one of the rich habitats of many animals include some threatened

animals, for example Himalayan serow, Capped Langur and Great Slaty Woodpecker, etc. Declaring BDNP as a National Park enabled the tourists to visit its pristine areas in addition to emphasizing the urgency of its natural resources conservation. On the other hand, declaring HWS as wildlife sanctuary was necessary to protect the wildlife habitats and breeding grounds from human encroachments.

A previous study identified 88 dicotyledonous plant families with 478 species in the HWS [26]. Trees, shrubs, and herbs belong to 189, 119, and 170 species. It has been reported that among the floral species, 86 are rare, and 14 are critically endangered. Birds, mammals, reptiles, and amphibians consist of 85, 27, 34, and 12 species, respectively, in the landscape [25]. The co-management Committee (CMC), established in 2014 as part of the CREL (Climate Resilient Ecosystems and Livelihoods) project activity, played a crucial role in shielding the forests [27]. The forest department conducted afforestation and enrichment plantations for increasing green coverage and restoration in these protected areas. Moreover, many people from the surrounding communities living in Fatikchari, Najirhat, Mirsharai, and Sitakunda are more or less dependent on the landscape for different types of forest resources. It is assumed that these known and unknown factors strongly influence the overall forest health of both the BDNP and the HWS.

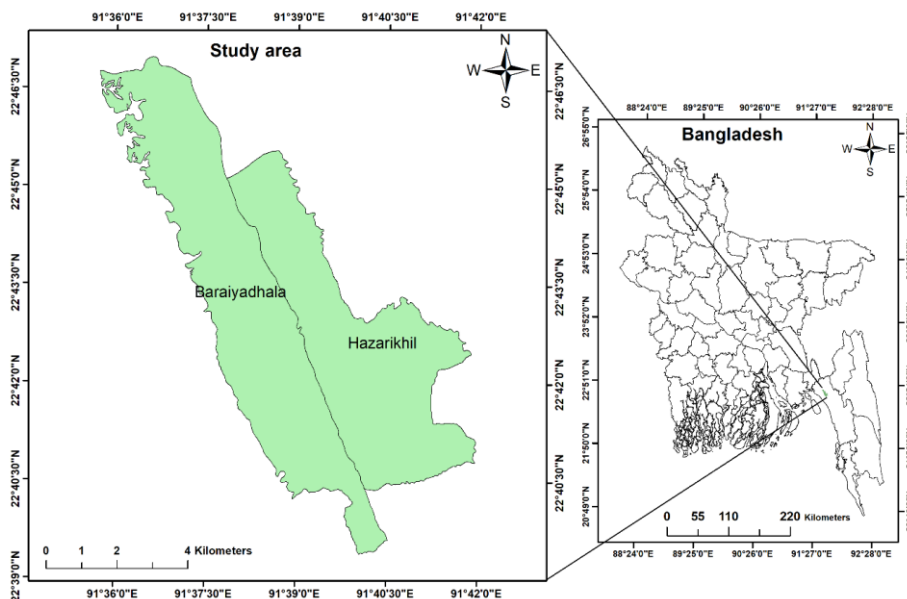


Figure 1. Baraiyadhala and Hazarikhil protected forest areas in Bangladesh.

Methods

Both the remotely sensed satellite imageries and field data were used in the current study. The satellite imageries included the Landsat archives, including Landsat 5 (TM) and Landsat 8. Some ancillary data were also collected from sources like the Forest Department and the Protected Planet. The direct observation in the field and ground-truthing provided the field data to identify the features on the images. The questionnaire survey through Key Informants Interview (KII) provided the understanding of the causes behind the temporal and spatial changes of the features.

2.1.2.1 Satellite data and its analysis

Cloud-free landsat satellite imageries were collected for 1990 and 2020 from the United States Geological Survey (USGS) web portal at <https://earthexplorer.usgs.gov/>. The imageries were downloaded from the Landsat collection 2, Level 2 platform [28]. The image acquisition date for Landsat 5 was 26 december 1990 and for Landsat 8 was 13 december 2020. The shapefile of the BDNP and HWS were collected from the web portal of the "Protected Planet," www.protectedplanet.net/. In order to convert the images into a standard projection, the images were pre-processed. The support vector machine (SVM) supervised classification technique generated the land-use change maps and NDVI (Normalized Difference Vegetation Index). SVM, as a binary classifier, provides good accuracy with least sensitivity to training data size. Sixty percent of ground-truthing points were used to identify the appropriate land use on the map, while the remaining 40% ground-truthing data was used to analyze the classification accuracy through Kappa number and the confusion matrix. This is a very commonly used approach used in accuracy assessment of LULC classification that adapted from Colditz [29], Abdi [30], and Ghayour et al. [31]. After the classification, land-use changes were detected over time and space through comparison. The study used ArcGIS Desktop 10.5 to generate a detailed map and classify the BDNP and HWS. It also detected different objects, including the human settlements inside the forests. For classification of the images, the study used the ERDAS IMAGINE 2015. The study provided the time series and land-use change maps of the BDNP and HWS. The study maintained a scale ratio of 1:80,000 for creating the maps. As cloud-free imageries were used for landuse classification and NDVI, the images were not atmospherically corrected. This is the limitation of the study.

Instruments, accessories, and data analysis

The study collected the base map of the BDNP and the HWS from the forest range offices under the Chattogram North Forest division. It also collected specific base maps from the forest beat offices under these forest ranges. It helped the study navigate the forest areas while verifying different objects and temporal and spatial

changes of the features. It used the GPS (Global Positioning System) set for ground-truthing. The GIS and image processing software, i.e., ArcGIS 10.5 and ERDAS IMAGINE 2015, processed the data with the help of MS Excel. It used the statistical package R (version 3.2.2) for statistical analysis. A desktop computer system with the necessary processor and memory helped accommodate this software.

The calculation of the overall accuracy and the Kappa coefficient used the following formula [32, 33];

Overall accuracy = (Total number of the correctly classified points/total number of reference points) $\times$ 100

Kappa coefficient = $\frac{((\text{Total sample} \times \text{Total correct sample}) - \sum (\text{Column total} \times \text{Row total}))}{(\text{Square of total sample} - \sum (\text{Column total} \times \text{Row total}))} \times 100$

The study classified the land uses into five major classes (i.e., Agricultural land, Barren lands, Dense vegetation, Light vegetation, and Settlements), and one combined class named as other land uses (i.e., streams, small water bodies, and open grasslands). Agricultural lands are the lands being used to cultivate single or multiple annual or perennial crops. These are mainly the low-lying lands. However, there are some slopping agricultures in the Baraiyadhala-Hazarikhil landscape. Barren lands are those lands devoid of any vegetation. According to visual estimation, dense vegetation is the forests (plantations or natural forests) covered by tree crowns by more than 50%. Light vegetation is those forests (plantation or natural) having canopy coverage ranging between 10-50%. Scrub forests with <10% canopy coverage are also classified as light vegetation. Settlements are mainly the forest offices and houses of the *Tripura* ethnic communities living inside the Baraiyadhala-Hazarikhil forest landscape. Other land uses are mainly streams, tourist spots, road networks, grasslands. The methodological flowchart of the study has been shown in the figure 2.

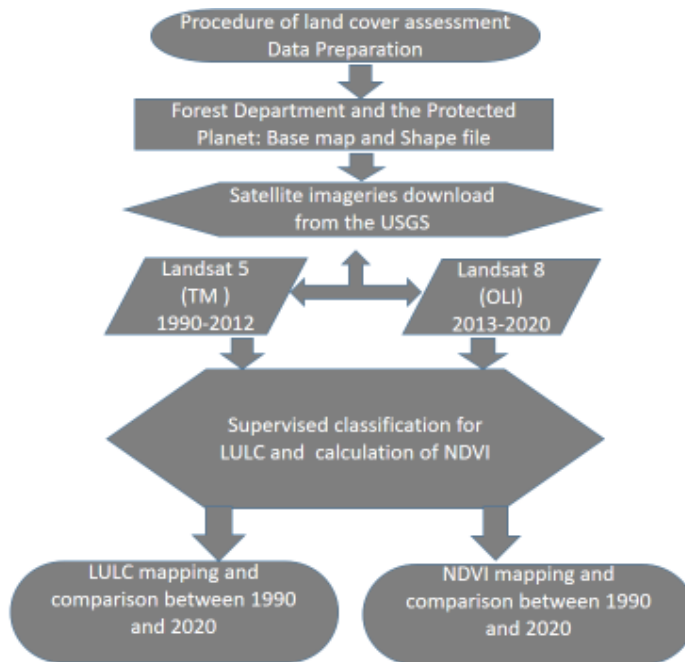


Figure 2: Methodological flowchart of the study.

The Normalized Difference Vegetation Index (NDVI) was calculated for both years, i.e., 1990 and 2020. NDVI is the vegetation index representing the greenness and presence of chlorophyll which is critical and closely related to the oxygen production in a specific area [34]. It was calculated in the ArcGIS using the following formula [35, 36].

$$NDVI = (NIR - RED) / (NIR + RED)$$

The maps of classification and NDVI were created for 1990 and 2020.

2.1.2.4. Key Informants Interview

The key informant interview was conducted to explore the drivers of changes in the LULCs. It has been conducted in three steps. Firstly, we identified the key informants based on the background, research or managerial focus, and work experience of the stakeholders concerning the Baraiyadhala-Hazarikhil landscape. A total of 52 key informants were listed who are mainly from Forest Department (FD), Bangladesh Forest Research Institute (BFRI), Universities, Non-Government Organizations (NGO), and representatives of local communities. One common characteristics with all the key informants was having some dependency for livelihoods or experience of

working for administration or natural resource management in the landscape. After the supervised classification, a semi-structured questionnaire was developed based on the findings of the supervised classification. Finally, we have interviewed the key informants at their convenient time and place by making an appointment over the phone. In cases, the key informants were not available for interview, the questionnaire was sent to the key informants through email. In the interview form, the key informants were first briefed about the changes in area of LULC classes during 1990 to 2020; then they were asked to identify the drivers of the observed changes in the extent of the identified LULC classes. As the drivers of LULC change was an open question; hence we listed the drivers and harmonized them into 52. In addition, we asked about the positive and negative consequences of the land-use changes observed in the study area. The development projects implemented so far in the study area were also asked of the key informants. The study directly interviewed the forest officials, including the Assistant Conservator of Forest (ACF) and the Deputy Conservator of Forest (DCF), by physically visiting the office of the respective Chattogram North Forest Division. A total of 50 responses were considered for the study on the drivers of changes in the LULCs.

3. Results

3.1. Land use and land cover classes

The supervised classification of the satellite imageries revealed that in 1990, Dense Vegetation was the major LULC in the study area, covering 1801 ha (34%) area which is followed by Light vegetation with 1148 ha (22%) and Agricultural land with 1144 ha (21%) (Figure 3). However, the other land uses (i.e., streams, ponds, etc.) cover 634 ha composing 12% of the study area during that time. For the same time point, Barren land and Settlements as LULC contain 475 ha and 128 ha, respectively, which together make only 11% of the total area of the Baraiyadhala-Hazarikhil landscape (Table 1).

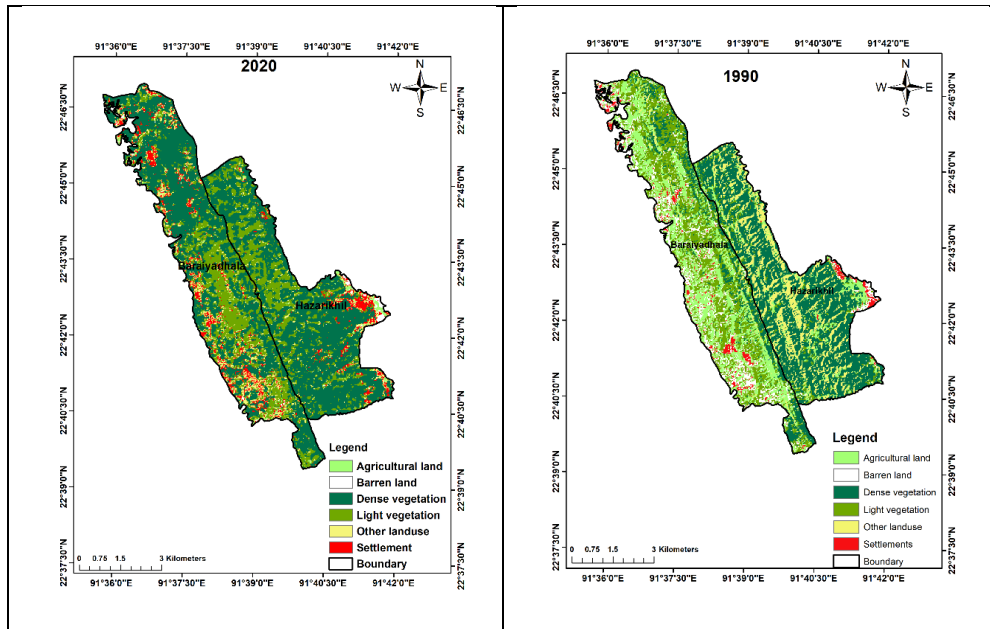


Figure 3: Land use classes of the Baraiyadhala national park and the Hazarikhil Wildlife Sanctuary in Bangladesh in 1990 and 2020. [The maps were generated using the ArcGIS Desktop 10.5 with the data]

The LULC analysis showed radical changes in some of the LULC classes in the past 30 years. In 2020, the Dense vegetation increased to 3160 ha, about 59% of the total landscape, followed by Light Vegetation with 1352 ha (25%). The Agricultural land, Barren land, Settlements, and other land uses together comprised only 15% of the total study area (Table 1).

Table 1: Distribution of the area under land use and land cover classes under Baraiyadhala-Hazarikhil landscape in 1990 and 2020.

SN	Land use and land cover class	Total area in the Baraiyadhala-Hazarikhil landscape (ha)		Baraiyadhala National Park (ha)		Hazarikhil Wildlife Sanctuary (ha)	
		1990	2020	1990	2020	1990	2020
1	Agricultural land	1143.7(21)	80.6(2)	922.2(32)*	43.2(2)	221.5(9)	37.4(2)
2	Barren land	474.9(9)	37.0(1)	432.9(15)	11.5(00)	42.0(2)	25.5(1)
3	Dense vegetation	1800.9(34)	3159.5(59)	369.7(13)	1577.3(54)	1431.2(59)	1582.1(65)
4	Light vegetation	1148.3(22)	1351.8(25)	1008.9(35)	776.2(27)	139.4(6)	575.6(24)
5	Other land uses	633.6(12)	390.9(7)	68.5(2)	282.2(10)	565.1(23)	108.6(4)
6	Settlements	127.5(2)	309.3(6)	97.5(3)	209.3(7)	30.1(1)	100.1(4)
All LULCs		5329	5329	2899.7	2899.7	2429.3	2429.3

*Figure in the parenthesis indicate the percentage value

LULC areas in Baraiyadhala National Park

The total area of Baraiyadhala National Park (BDNP) in the Baraiyadhala-Hazarikhil landscape was 2899.7 ha. This total area little deviates from the gazetted area of this PA (2933.61 ha). It is, though negligible, due to the difference in the spatial features, i.e., shapefile delineating the boundary of the PA. In 1990, light vegetation was the major LULC of BDNP, covering 1009 ha (35% area), followed by agricultural land (922 ha) and barren land (433 ha). In 2020, dense vegetation became the major land use with 1577 ha (54% area), followed by light vegetation (776 ha) (Table 1).

LULC areas in Hazarikhil Wildlife Sanctuary

The total area of HWS is 2429.3 ha in the Baraiyadhala-Hazarikhil landscape. Unlike BDNP, the major LULC in HWS was dense vegetation covering 1431 ha (59% of HWS) in 1990. Dense vegetation was followed by agricultural land (222 ha, 9% area) and light vegetation (139 ha, 6% area) (Table 1). Barren land and settlement together composed of only 72.1 ha. However, the unclassified land uses under the other land uses are substantial in this PA, covering about 565 ha. In 2020, dense vegetation

increased slightly to 1582 ha (65% area), followed by light vegetation (576 ha). In the BDNP-HWS landscape, Dense Vegetation and Light Vegetation were the two dominant LULC classes, intogether covering 56% area in 1990, which surprisingly increased to 84% in 2020. Increase of dense vegetation from 34% in 1990 (1801 ha) to 59% of the total area (3159 ha) indicates a significant positive change in the forest ecosystem by improving forest coverage.

3.2. Normalized Difference Vegetation Index

In 1990, the mean NDVI value in HWS was 0.310 ± 0.035 ranging from 0.096 to 0.399, which is slightly higher than BDNP. In 1990, the mean value of NDVI in BDNP was 0.298 ± 0.031 , which ranged from 0.124 to 0.412. The NDVI for the Baraiyadhala-Hazarikhil landscape is represented in the following Figure 4.

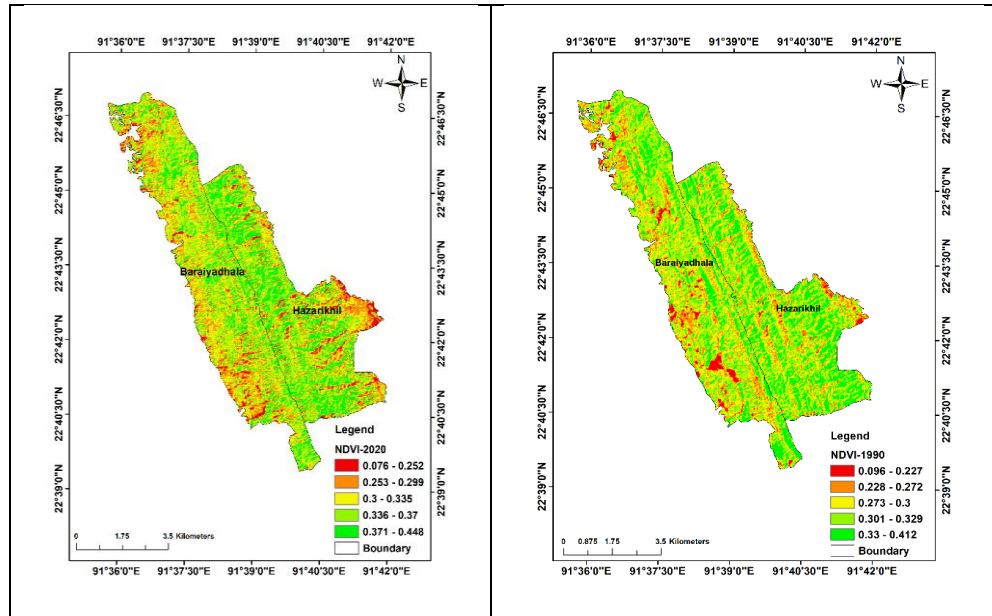


Figure 4: NDVI of the Baraiyadhala National Park and the Hazarikhil Wildlife Sanctuary in 1990 and 2020 in Bangladesh. [The maps were generated using the ArcGIS Desktop 10.5 with the data]

In 2020, the study found some improvement in both the PAs in terms of the value of NDVI. During this time, the mean value of BDNP is 0.328 ± 0.04 , which is little (0.03) higher than the mean NDVI in 1990. However, the NDVI ranged from 0.076 to 0.439. On the other side, the mean NDVI value of HWS in 2020 is 0.336 ± 0.047 , which ranges from 0.138 to 0.448. Like BDNP, the HWS also experienced a positive change that increased NDVI value. The findings of NDVI values for the two-time

points match the results of the supervised classification of the Baraiyadhala-Hazarikhil landscape into the LULCs.

3.3. Land Use and Land Cover changes

The area of LULC classes changed between 1990 and 2020. The rate of change varied with the LULC and PAs of the appraised landscapes. The findings indicated that agricultural land and barren land have decreased from 1990 to 2020. The decreasing trend of agricultural land is almost similar in both BDNP and HWS. The decrease rate is 95% (from 922 to 43 ha) in BDNP and 83% (from 221 to 43 ha) in HWS. Barren lands have experienced a 97% decline (from 433 ha to 12 ha) in BDNP. In comparison, the rate of decline in HWS is low (39% decline; from 42 ha to 25 ha) due to low area coverage (Figure 5).

The dense vegetation class significantly increased (327%) in BDNP (from 370 ha to 1577 ha). In comparison, HWS showed only an 11% increase (from 1431 ha to 1582 ha) in this LULC. Light vegetation has decreased 23% (from 1009 ha to 776 ha) in BDNP, which may be a positive sign based on the assumption that the light vegetation has been turned into dense vegetation. On the other hand, HWS experienced a sharp increase (313% increase; from 139 ha to 576 ha) of light vegetation (Figure 5).

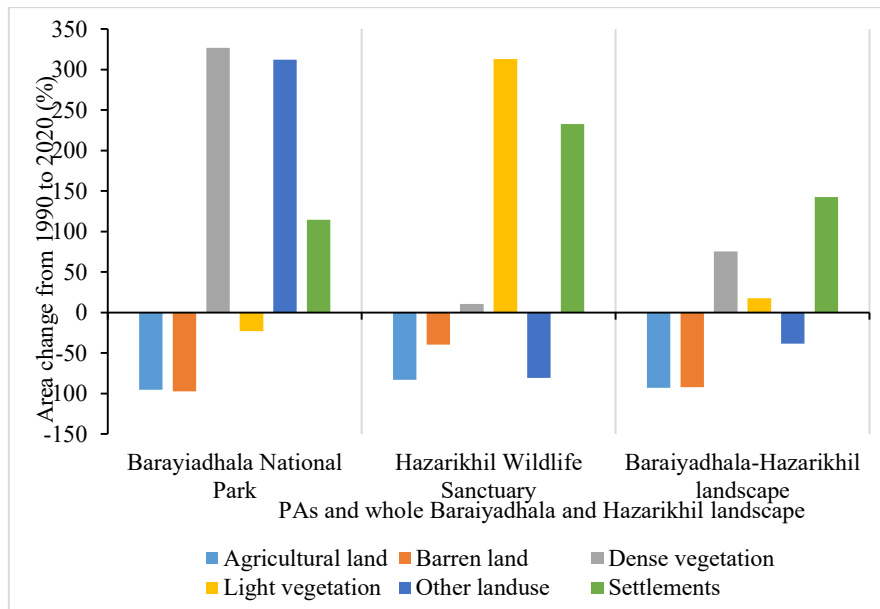


Figure 5: Relative percentage area changes in LULCs of Baraiyadhala National Park, Hazarikhil Wildlife Sanctuary, and whole Baraiyadhala-Hazarikhil landscape in Bangladesh.

Although illegal, settlement within the landscape increased in both PAs over the period 1990-2020. The increase is 115% (from 97 to 209 ha) in the BDNP, with 233% (from 30 to 100 ha) in the HWS. The probable reasons for the increasing settlement are discussed in the following section. According to Bangladesh Forest Department (FD) officials, settlement in the western part of the landscape increased from 1990 to 2005 due to the migration of landless people who lost homes during severe natural disasters during that period. However, after 2005, there was very little chance of increasing settlement inside the landscape. Because, from 2005 to 2020, many eviction drives were conducted by FD to displace the settlements from the forest.

The total change of the LULCs in the whole landscape indicated gains in the dense vegetation, light vegetation, and settlements and reduced agricultural land, barren land, and other land uses (i.e., stream, water bodies, grassland). However, in terms of the area of the LULCs, the overall impression is a positive change that means the increase of forest canopy cover and, indirectly, improvement of forest health.

3.4. Drivers of land use and land cover change

The drivers of LULC changes are responded differently by the different key informants. Change in one LULC leads to change in another LULC. Some drivers were responsible for changing several LULC classes. Moreover, opposite changes of a particular LULC class were possible in different parts of the Baraiyadhala-Hazarikhil landscape. Furthermore, differences of some LULC types were explained by the key informants both positively and negatively. For example, an increase of light vegetation is explained by some key informants as a result of the degradation of dense vegetation due to forest fire, forest resource extraction, illegal felling, settlements. On the other hand, some key informants opined that the light vegetation increase was attributed to restoring the agricultural lands and barren lands through eviction of the encroachers followed by plantations, PA declaration, and raising awareness among the Forest User Groups (FUGs).

The agricultural land decreased because people became more interested in agri-farming (poultry, fishery, plantation forestry) than traditional agriculture. It seems like they were getting more economic return from Agri-farming than conventional crop production.

Overall, plantation activities, PA declaration, forest co-management, mass awareness, enhanced protection of forests were some of the major drivers responsible for positive change that means an increase of dense and light vegetation. The FD implemented substantial interventions in collaboration with different other partners through plantations under Thana Banayan and Nursery Development Project (1990-1994), Extended Social Forestry Project (1994-1996), Forest Resource Management Project (FRMP) (1996-2000), Forestry Sector Project (FSP) (1997-2000), Ramgarh-

Sitakunda Nogna Pahar Banayan Prokalpa (2000-2005), Climate Resilient Participatory Afforestation and Reforestation Project (CRPARP) (2013-2016), Climate Resilient Ecosystem and Livelihoods (CREL) project (2012-2018). On the other side, development of road networks, forest resource extraction, population pressure, migration of landless people to the forest from the nearby islands, promotion of uncontrolled ecotourism were some of the major drivers causing negative changes that mean an increase in settlement, light vegetation, and other land uses. Table 2 explains the differences, specifically with percentages of key informants opined in favor of different drivers.

Table 2: Drivers of changes in the land use and land cover classes in the Baraiyadhala National Park and the Hazarikhil Wildlife Sanctuary in Bangladesh [Here, the percentage change of the LULC classes from 1990 to 2020 is provided in parenthesis beside the LULC classes. The negative sign indicates a decrease of an area, and a positive sign indicates an increase of an area.].

SN	Drivers of LULC change	Percentage of KI responded in favor of the LULC change from 1990 to 2020*				
		Agricultural land (-93%)	Barren land (-92%)	Dense vegetation (+75%)	Light vegetation (+18%)	Other land uses (-38%)
1	Agricultural practices		27			
2	Awareness raised among FUGs			27	18	
3	Controlling encroachment by FD			27		
4	Damage of crops by wildlife (i.e., Wild boar)	9				
5	Development of road networks	18				36
6	Diversification of livelihoods	9		27		
7	Enhance protection by FD	18	18	36	45	
8	Environmentally sound forest management			9		
9	Expansion of industries in BDNP boundary					27
10	Expansion of tea garden in HWS					18
11	Expensive and unavailability of labor	9				
12	Fish farming in HWS					27
13	Forest co-management		27	64	45	
14	Forest dependency					9
15	Forest fire in HWS				18	

SN	Drivers of LULC change	Percentage of KI responded in favor of the LULC change from 1990 to 2020*				
		Agricultural land (-93%)	Barren land (- 92%)	Dense vegetation (+75%)	Light vegetation (+18%)	Other land uses (- 38%)
16	Forest resource (i.e., fuelwood, bamboo, etc.) extraction				36	
17	Illegal felling of dense vegetation				45	
18	Increase of land value					9
19	Influence of local elites					
20	Infrastructure (i.e., bazar, road, industry, etc.) development	27	9			18
21	Meeting demands from homestead forest				9	
22	Migration into forests (i.e., landless, climate refugee, etc.)					73
23	Over grazing				9	
24	PA declaration		18	36	36	
25	Plantation (i.e., participatory, short rotation spp., rare and endangered spp., etc.)	9	36	73	45	
26	Plantation in the barren hills		55	73		
27	Population pressure in the adjacent area					73
28	Promotion of eco-tourism				18	36
29	Recovery of land from grabbers				36	
30	Reduction of forest fire			27		
31	Regulation of ecotourism			27		
32	Reluctance to traditional agriculture	27				
33	Restrictions of forest resource extraction		18	36		
34	Settlement by local people	36	18		18	

*Since the key informants responded to the multi-response questions regarding the driver of land use and land cover changes, the sum of the percentages will not be 100.

3.5. Discussion

The study revealed a significant change in the land use and land cover in the Baraiyadhala-Hazarikhil PAs from 1990 to 2020, which answered the first research question. The findings of widespread land use and land cover change provided a positive impression that the cover of vegetation area has increased over the period between 1990 to 2020. The settlement increase can be clarified by the frequent occurrence of devastating cyclones and natural disasters from 1990 to 2020, forcing many people to migrate towards government forest lands. However, the reasons behind the changes have been well explained in the previous section based on the key informant's response.

The study results conform to the report of land use and land cover change in similar areas of Bangladesh reported by other studies. The settlement and built-up area are increasing all over the country [37]. The present findings match with the report of Redowan et al. [38], mentioning an increase of medium dense forest (155 ha to 317 ha) in Khadimnagar National Park from 1988 to 2010. The NDVI based classification of Khadimnagar National Park also indicated an increase of medium dense forest, which also conforms with the present study [38]. Dewan and Yamaguchi [37] reported substantial growth of built-up areas and decreased vegetation areas in greater Dhaka from 1975 to 2003. Masum and Hasan [39] studied the land use and land cover of Satchari National Park. The study reported a decrease in dense vegetation and increased degraded and barren lands from 1993 to 2019. However, the present study showed a partly opposite trend of the forest cover change. It is because of the special forest restoration efforts throughout the BDNP and HWS within the designated timeframe (1990-2020).

The present study explored the social factors of land use and land cover change in the Baraiyadhala-Hazarikhil PAs through key informant interviews, which is the second research question of the present study. The drivers of the LULC changes are almost similar for the forests across Bangladesh [40, 41]. Xu et al. [42] reported on the conversion of agricultural land to other land uses (i.e., water bodies) from 2000 to 2010 in Bangladesh, driven by household dynamics, population growth, road network proliferation. Redowan et al. [38] reported illegal felling, encroachment, and settlements as the reason for forest cover loss while plantation of different forms as the gain of forest cover, which is similar to the reasons indicated by the key informants for change LULC in Baraiyadhala-Hazarikhil landscape. UN-REDD Bangladesh National Program (2016) denoted encroachment, illegal settlement, industrialization, and urbanization as the leading causes of deforestation and degradation in Chattogram, Bangladesh.

Supervised and NDVI-based classifications are straightforward and easy to apply in land-use change analysis [38]. Hence these are popular classification techniques for satellite imageries. Classification accuracy was high for supervised classification. Landsat 5 imageries classification in 1990, the overall accuracy was 96.75%, and the Kappa coefficient was 95.36%. For the Landsat 8 imageries classification in 2020, the overall accuracy and the Kappa coefficient were 97.88% and 91.58%, respectively.

Both supervised and NDVI methods showed a similar trend in land use and land cover change over the 30 years: increased dense and light vegetation cover. The phenomena of increasing vegetation coverage can be attributed to the plantation activities by the FD under different projects, including Thana Banayan and Nursery Development Project, Forest Resource Management Project, Forestry Sector Project, Climate Resilient Participatory Afforestation and Reforestation Project, and Climate-Resilient Ecosystems and Livelihoods Project, and conservation initiatives through forest co-management after the declaration of PA (*pers.comm.*, 2021). The current trend follows the expectation that dense vegetation will increase, increasing ecosystem services. Co-management and restoration interventions were proven helpful for conserving and enhancing forest cover in the protected areas of Bangladesh [17, 43].

The increased dense vegetation will give rise to ecosystem services, i.e., provisioning services, ecotourism, biodiversity, and carbon sequestration. Officials from the FD and local people indicated an increase of some wildlife (i.e., monkeys, porcupines, snakes, deer, jungle fowl) sighting in the forests. Though there is no study to support the claim, FD officials expect an increase in the streamflow level due to the expansion of vegetation cover in the landscape.

Though there is no clear statistics about the human population size living inside the landscape, however, based on the discussion with the key informants, the study approximated that 600 people, mainly from *Tripura* ethnic communities, belonging to about 150 families are settled inside the boundary of the HWS-BDNP landscape; they are grouped into three villages with one in HWS and two in BDNP. The increase of settlements inside the forest is a severe threat to the continuous improvement of the forest cover and the flow of ecosystem services. The settlements inside the forests may also promote illegal practices and agricultural expansions to the forest, which will ultimately cause degradation of forest health through clearing forests, and initiating soil erosion. In BDNP, the increase of the area under other land use categories can be attributed to the spread of road and communication networks inside the national parks. If not controlled, the road networks inside the forest will augment illegal practices like tree cutting, encroachment, and grabbing forest lands. In order to overcome the negative consequences of the increase in settlements and other land

uses in the PAs, ecotourism should be controlled and regulated in a more environmentally friendly way. Understanding and cooperation between the FD, local politicians, and other government entities are fundamental to ensure political will and coordinated efforts for sustainable protected area management.

Participatory plantations with short rotation and exotic species may have attained substantial coverage, particularly in the BDNP. However, these are not suitable for the natural restoration of the forests in the long run. The overall improvement of the vegetation coverage may enhance the natural regeneration of the available tree species. If well protected, this may increase the natural restoration capacity of the forest.

Increased agro-farming is the sign of faster rural development but the loss of natural forests. With the increase of agro-farming, BDNP will somehow overlook the traditional crop production, and at the same time, it will be a considerable threat to the natural forest species habitat loss (e.g., Cycas) [40]. Changing watershed direction and streamflow can cause flash flooding shortly.

The FD implements collaborative forest management and habitat restoration through plantations under the Sustainable Forest and Livelihoods (SUFAL) project. Protibesh, a USAID-funded project, is also planning to intervene in the landscape to promote sustainable forest management in PAs. In addition, there is an eco-park titled "Mohamaya Eco-Park" in the adjacent areas of BDNP, which may positively impact the Bariyadhala-Hazarikhil landscape.

Finally, it can be expected that the evidence of improvement will undoubtedly encourage the forest managers and members of the co-management committees to continue their efforts of conservation, protection, and restoration of the remnant forests of the Bariyadhala-Hazarikhil landscape

3.6. Measures to combat the negative changes

The study's findings indicated that undertaking several additional measures and precautions in the forest management schemes may help sustain the health of the PAs. Given that context attributed to the satellite imageries analysis and KII, the following recommendations are outlined for combating the negative land use and land cover change and for the enhanced biodiversity conservation, higher flow of environmental services, and sustainable management of the protected landscape:

-The FD should undertake an initiative to evict the illegal settlers inside the PAs and strongly patrol to prevent further settlement in the forest, and these will help stop the further increase of the settlement in the forest landscape [44]. The movements and trespass through existing roads inside the forests should be strictly monitored and controlled.

-Briefing local people about the forest laws regarding the expansion of road and communication networks inside the PAs will help control the further development of the road networks inside the landscapes [45].

-The barren lands should be brought under plantation programs with local native species, and the environmentally sound restoration programs, i.e., Assisted Natural Regeneration (ANR), can be practiced in the light vegetation areas [46, 47].

-Alternative Income Generation Activities (AIGA) should be promoted through appropriate training and incentives among the forest-dependent local people and agriculture practitioners inside the PAs.

-Agricultural practices in the hill slopes are detrimental to the environment as it causes soil erosion to increase the chance of landslide [48]. Practitioners should be made aware of it and discouraged from agricultural practices inside the forests.

-Community-based organizations (CBOs) like the co-management Committee (CMC) community-patrolling group (CPG) should be made aware and motivated adequately about their role in the protection of forests from encroachers and strategies of environmentally sound forest management. Political commitment is vital for the conservation of nature and the ecosystem.

-To prevent and mitigate the risk of forest fires, raising local communities' awareness, equipping FD with necessary fire fighting logistics, increased patrolling, and creating fire control lines are crucial.

-Coordination and harmonization of all the related works of government departments will play a critical role in protecting and sustainable management of the landscape.

-The study suggests several ways to continue gaining forest cover and combat the possible deforestation and degradation in the landscape. Some of the recommended ways were proved helpful in the existing literature [49-52], while other techniques were deemed potential based on the existing condition of the landscape. It is worth mentioning here that the Forest Act 1927 has provisions to punishment for any illegal activities involving the forests which can be strictly implemented for protecting and conserving the forests through updating in line with the forest policy to fit the current social and environmental context.

3 Conclusion

The study discussed the extent and changes of the LULCs in BDNP-HWS landscape in two-time points, 1990 and 2020. Dense vegetation and light vegetation were the two major LULC classes in the landscape, as deemed in the imageries analysis. A significant increase in the forest cover and forest health through an increase of the dense vegetation from 1990 to 2020 was observed in the imageries analysis. Plantation in the barren hills, enhancement of protection by the FD, and co-

management practices were the primary drivers of the positive changes. The FD was regulating ecotourism by initiating a ticketing system for entrance to the PA, which helped reduce local peoples' trespass, consequently reducing the collection of forest resources. On the other hand, settlements inside the landscape, forest fires, unsustainable promotion of tourism, grazing, illegal and over-extraction of the resources, forest dependency of the local people for fuelwood, timber, bamboo, etc. are the major reasons for the negative changes (i.e., increase of settlement and light vegetation) in the Baraiyadhala-Hazarikhil landscape; presumably contributing to GHG emission through deforestation and threatening the conservation of the biodiversity protected by the national park and wildlife sanctuary. Finally, the study recommended ways to continue positive change in vegetation cover that can potentially increase carbon sequestration and help climate change mitigation, discussed repercussions of the existing threats favoring negative land use changes, and ways to mitigate these consequences on the biodiversity and environment of the landscape. The results of this research can be useful for forestry development in Bangladesh.

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