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Original Article

Forest degradation assessment of Ratargul Special Biodiversity Protection Area for conservation implications

Ratargul Özel Biyoçeşitlilik Koruma Alanındaki koruma önerileri kapsamında ormandaki bozulmanın değerlendirilmesi

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ABSTRACT

Forest degradation is threatening the biodiversity of moist tropical forests since the beginning of their development. Bangladesh is losing its forests and associated biodiversity continuously due to forest-dependent livelihoods. The only freshwater swamp forest of the Ratargul Special Biodiversity Protection Area in Bangladesh is also very prone to degradation due to anthropogenic disturbance. This distinct swamp forest has unique biological diversity compared to other forest types. To assess its degradation and to propose implications for conservation, sentinel images with 10×10 m resolution were used. Also, field data were collected and analyzed. This research produced a map of forest cover change and outlined an area that can be used in restoration planning. Branch cutting, dry season overgrazing, illegal tree felling, fuelwood collection, trampling by tourists, and insect and disease epidemics were identified as causes of degradation. Functional conservation effort ensured by strong political will and area-specific forest protection regulation is essential for the conservation of last swamp forest and its remnant biodiversity. Community-based conservation approaches need to be applied for mass awareness regarding this ecosystem's value and its sustainability.

Keywords: Conservation implications, environmental degradation, freshwater swamp forest, remote sensing, sustainable ecosystems

ÖZ

Ormanların bozulması, var oldukları günden bugüne nemli tropik ormanların biyolojik çeşitliliğini tehdit etmektedir. Bangladeş, ormana dayalı geçim kaynakları nedeniyle ormanlarını ve ilişkili biyolojik çeşitliliğini sürekli olarak kaybetmektedir. Bangladeş'teki Ratargul Özel Biyoçeşitlilik Koruma Bölgesi'nin tek su basar ormanı da antropojenik etkilerden dolayı bozulmaya çok eğilimlidir. Bu farklı su basar ormanı, diğer orman türlerine kıyasla benzersiz biyolojik çeşitliliğe sahiptir. Bu alandaki bozunmanın değerlendirilmesi ve korumaya yönelik önerilerde bulunabilmek için 10 × 10 m çözünürlüklü sentinel görüntüleri kullanılmış olup, ayrıca alandan toplanan veriler de analiz edilmiştir. Bu araştırma, orman örtüsü değişiminin bir haritasını çıkarmış ve restorasyon planlamasında kullanılabilecek bir alanı ortaya koymuştur. Ağaç dallarının kesilmesi, kurak mevsimde aşırı otlatmaların yapılması, yasadışı ağaç kesimi, yakacak odun toplama, turistlerin dolaşması ile toprağın sıkıştırılması, böcek ve hastalık salgınları ormandaki bozulmanın nedenleri olarak belirlenmiştir. Güçlü siyasi irade ve bölgeye özgü orman koruma düzenlemesi ile sağlanan işlevsel koruma çabası, son su basar ormanının ve kalan biyolojik çeşitliliğinin korunması için gerekli görülmektedir. Bu ekosistemin değeri ve sürdürülebilirliği konusunda kitlesel farkındalık için topluluk temelli koruma yaklaşımlarının uygulanması gerekmektedir.

Anahtar Kelimeler: Koruma önerileri, çevresel bozulma, su basar ormanı, uzaktan algılama, sürdürülebilir ekosistemler

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INTRODUCTION

Biodiversity is the foundation of ecosystem services upon which all individuals rely (Sala et al., 2000). However, it is currently recognized that the worldwide diversity scenario is vulnerable and much beyond any time of its history (FAO, 2015). The magnitude of biodiversity change is massive, thus it is currently thought that it has caused a crucial global amendment (Sala et al., 2000). The concept of protected areas (for example, National Parks) is the foundation of all regional biodiversity conservation approaches (Masum et al., 2016). But the establishment of a protected area is not followed by effective management and enforcement regulations (UNEP, 2007). Thus, drivers of global change, such as changes in land cover and land use, remain active in these important conservation areas and, consequently, affect their biodiversity (Akber and Shrestha, 2013; Masum et al., 2017a).

Ratargul Special Biodiversity Protection Area is the last freshwater swamp forest in Bangladesh. It contains unique biological diversity compared to other forest types of the country. Unfortunately, it is highly prone to degradation due to anthropogenic disturbance. The freshwater swamp forest, also known as a flooded forest, is inundated by freshwater either permanently or seasonally. These forest types can be located in riparian areas, which have an essential function in hydrological, ecological, and geomorphic processes. Freshwater swamp forests are natural phenomena for Southeast Asia, South America, and Africa. There is also only one swamp forest in Bangladesh that has a distinct ecosystem function compared to other forest types designated as Ratargul Special Biodiversity Protection Area (RSBPA). The special features of these forest types are their tendency to maintain the hydrographic micro-watershed, as well as the aquatic ecosystem healthy and resilient (Agnew et al., 2006; Allan et al., 2008; Attanasio et al., 2012; Burkhard et al., 2010; Naiman and Décamps, 1997). These forests have great potential in achieving sustainable development through the protection and maintenance of their water resources and biodiversity. Unfortunately, people living near the area are completely dependent on this forest for fuelwood and livelihoods. Consequently, degradation due to biodiversity impoverishment and forest cover reduction has become a regular phenomenon (Islam et al., 2016), thus special attention is needed for its conservation. Moreover, a partial restoration of the degraded area is required, especially in the context of ongoing global discussions on the importance of environmental protection for human beings' life quality (Collins et al., 2013). Several previous studies have assessed ecotourism carrying capacity and plant community conditions; however, this study is the first attempt to assess forest degradation in RSBPA (Islam et al., 2016; Jahan and Akhter, 2018). According to UNDP, the freshwater swamp forest needs to be mapped with remote sensing techniques to identify potential restoration sites (UNDP, 2008).

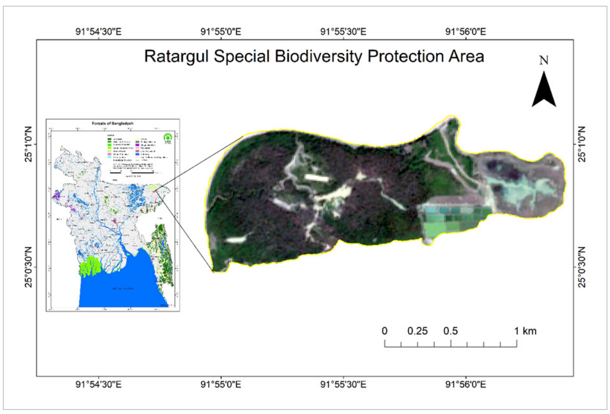

Figure 1. Location of the study area (Band 4, 3, and 2 combinations of Sentinel-2A image)

The use of remote sensing technique has been well established worldwide. It has also been employed in tropical countries in the field of forestry and can be used in various forestry applications (Çakır et al., 2019; Langner et al., 2007; Phua et al., 2007; Yoshino et al., 2010). Remote sensing can provide accuracy in selecting degraded and restoration sites and ensure cost-effective measures. Ratargul Special Biodiversity Protection Area (RSBPA) has two major biodiversity sources, i.e. the swamp forest and diverse fishery. Recently, it has become a tourist attraction site. Bangladesh Forest Department (BFD) is working on a plan to draw more tourists to the place while keeping its biodiversity intact. Furthermore, BFD is also planning to plant more trees and close the patches with thinned canopy, thus enlarging the breeding habitat of some species. To be successful, this plan needs to outline the most appropriate sites where the restoration project can take place. The restoration of degraded forests is generally known as ecological restoration. According to the Society for Ecological Restoration International (SER) and the International Union for the Conservation of Nature (IUCN), ecological restoration is the process of assisting the recovery of an ecosystem that was and is now being degraded, damaged or destroyed. Ecological restoration is a way of sustaining the Earth's diversity of life and reestablishing an ecologically healthy relationship between nature and culture. Ecological restoration can and should be a fundamental component in conservation and sustainable development programs throughout the world by virtue of its inherent capacity to provide people with the opportunity to not only repair ecological damage, but also improve the human condition (Gann et al., 2019).

This is where the usefulness and flexibility of remote sensing comes. First, the remote sensing technique is cost-effective. Second, it can be used to obtain temporary data on RSBPA and to outline the most suitable restoration sites, thus to monitor the progress of these sites over time. To select the restoration sites within this area with remote sensing techniques, it is better to use Sentinel-2A imagery as it is an open-source, rather than the most successful free satellite imagery Landsat TM. Landsat has a resolution of 30 × 30 m, which is not sufficient for this small wetland area. Sentinel-2A imagery provides a higher resolution (10 × 10 m) satellite images compared to Landsat TM.

MATERIALS AND METHODS

Study Area

The study territory covers an area of 181.5 ha. It is located in Gowainghat Upazilla, Sylhet, Bangladesh, better known as the RSBPA. The administrative office is situated in RSBPA. The protected area has a latitude of 25°00.025'N and longitude of 91°58.180'E. In 1932, an area of 118.41 ha (292.60 acres) was declared Reserved Forest under the Assam Forest Act (Choudhury et al., 2004). In 2015, an area of 204.25 ha was declared Special Biodiversity Area There are two major biodiversity sources in RSBPA, i.e. the swamp forest and diverse fishery. RSBPA is widely known as the Ratargul swamp forest. Figure 1 shows the extent of the study area.

Rainfall and Climate

Rainfall intensity and distribution across the RSBPA are important because the main water sources are the rainfall and the Gowain river. The study area has a tropical monsoon climate due to its location. The average annual rainfall is about 4162 mm. The maximum rainfall occurs in July with an average of 1250 mm, but there is another less-pronounced rainfall month – December. May and October are the hottest months reaching a maximum temperature of about 32°C, while January is the coldest month with a minimum temperature of 12°C. The relative humidity is about 74% during December and over 90% during the period from July to August (Choudhury et al., 2004).

Vegetation

About 73 plant species can be found in RSBPA (Choudhury et al., 2004). There are two vegetation strata - upper and lower stratum. The upper stratum encompasses trees of all sizes and is dominated by *Pongamia pinnata*. The lower stratum includes shrubs, herbs, climbers, and grasses. It is dominated by *Schumannianthus dichotomus*. In both lower and upper strata, the taxonomic diversity is moderate. The floristic quality index is moderate (Saha et al., 2018).

Table 1. Characteristics of the imagery used in this study

Date (MM/DD/YYYY)	Satellite	Instrument	Resolution
12/19/2015	Sentinel-2A	Multi-Spectral Instrument	10×10
01/12/2019	Sentinel-2A	Multi-Spectral Instrument	10×10

Table 2. The spectral bands and resolutions of Sentinel-2 MSI sensor(Source: Sentinel-2A SatelliteSensor | Satellite Imaging Corp)

Sentinel-2 Bands	Central Wavelength (μm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation red edge	0.705	20
Band 6 – Vegetation red edge	0.740	20
Band 7 – Vegetation red edge	0.783	20
Band 8 – Near-infrared	0.842	10
Band 8A – Vegetation red edge	0.865	20
Band 9 – Water vapor	0.945	60
Band 10 – Short wave infrared	1.375	60
Band 11 – Short wave infrared	1.610	20
Band 12 – Short wave infrared	2.190	20

Data Analysis of Satellite Images

To select and calculate the forested area's restoration sites, there was a need to determine the previous condition of the area and what it will become afterward. Thus, a map of the land cover change rate was required. The satellite image provides temporal information and allows outlining the restoration sites from forest cover change data. Thus, the goal of this study was to produce a map of change rate to direct conservation measures.

The satellite image analysis was performed with software ArcGIS v10.6. Statistical data analysis was done in Microsoft Excel 2016. Garmin GPS was used to save coordinates in the field-based data verification.

Satellite data of Sentinel-2A from December 19 (2015) and January 12 (2019) was used. Other supplementary data included a topographic map and geospatial-based data. Satellite image data was collected from ESA Copernicus Open Access Hub. The image characteristics and Sentinel-2A properties are listed in Tables 1 and 2, respectively.

The image processing procedure and research approach are shown in Figure 2. The processing tasks, like geometric and radiometric corrections, were done before any classification process. The geometric correction aimed to correct map coordinates. The radiometric correction aimed to divide the pixel values by the sine of sun distance using the raster calculator in ArcGIS. The subject area was subsetted from the procured images using a clip tool in ArcGIS. All subsetting processes were done in both 2019 and 2015 Sentinel-2A images. Then, a normalized

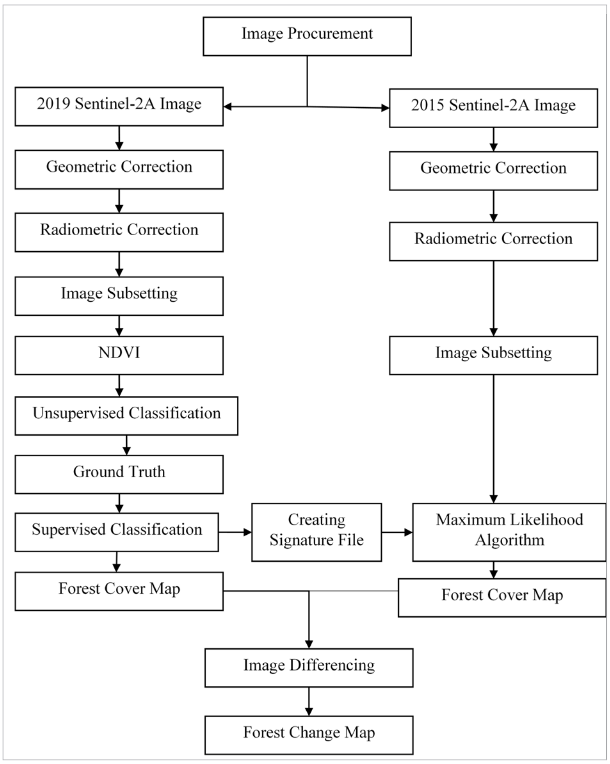

Figure 2. Schematic diagram of the research approach

difference vegetation index (NDVI) of 2019 Sentinel-2A was calculated. From that NDVI value, unsupervised classification for the study area was performed.

The NDVI is a non-linear transformation of the visible (Red) and near-infrared (NIR) bands of satellite images. NDVI is defined as the difference between Red and NIR bands divided by their sum. The NDVI is an alternative measure of vegetation cover and health. It regards vegetation characteristics such as biomass, leaf area index, and vegetation cover percentage. In this study, the NDVI algorithm was used to create an unsupervised classification map to understand the overall vegetation condition before performing a field survey in the study area. NDVI is calculated by the following formula (Weier and Herring, 2000):

$$\text{NDVI}= \frac{[Near\ infrared\ (NIR) - Red]}{[Near\ infrared\ (NIR) + Red]}$$

For Sentinel-2A image:

$$\text{NDVI}= \frac{[Band\ 8 - Band\ 4]}{[Band\ 8 + Band\ 4]}$$

Unsupervised Classification

The unsupervised method used the ISODATA approach to classify and recalculate statistics of image signature. This method

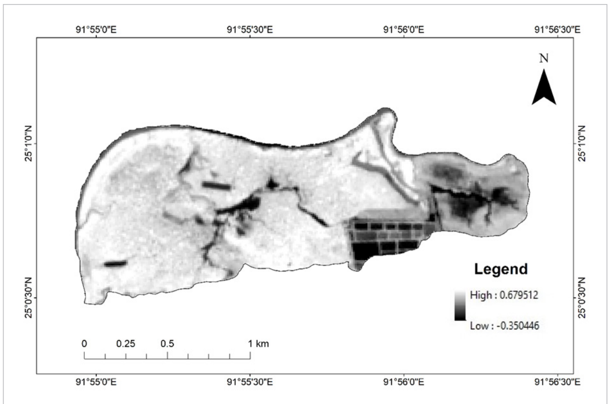

Figure 3. Sentinel-2A NDVI image of the RSBPA in 2019

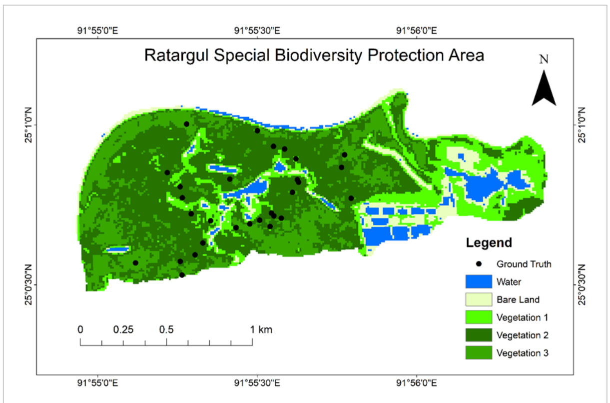

Figure 4. Unsupervised classification of the study area with field verification points (2019 Sentinel-2A image)

uses minimum spectral distance to assign a cluster for each representative pixel. The process begins with a specified number of arbitrary clusters or the means of existing signatures, and then it processes repetitively so that those means will shift to the means of clusters in the data (Hamzah et al., 2013). After performing the unsupervised classification, a field survey was conducted.

Field-Based Data Verification

The field survey is an important and necessary approach to verify the vegetation classes derived from the unsupervised classification. It adjusts the actual field conditions and improves the accuracy of the overall image classification. A total of 31 randomly distributed sampling points (Appendix 1) were visited during the field survey.

Supervised Classification

The supervised classification is a process where the image interpreter has the experience and first-hand knowledge of the field data combined with other resources, such as aerial photos, topographic maps, or other classified satellite images. The supervised classification of the 2019 image was implemented to the satellite image taking into account the unsupervised classification, as well as the information from the field survey. From this supervised classification of 2019 image, a signature file was created. It was applied to the 2015 image using a maximum likelihood algorithm to create a forest cover map of the 2015 image in ArcGIS.

Creating a Forest Change Map

Image differencing is likely the most widely applicable method in the change detection algorithm (Singh, 1989). Image differencing seems to perform significantly better than other methods of change detection (Deng et al., 2008; Fraser et al., 2005). Image differencing of 2019 and 2015 images was performed with an image analysis tool in ArcGIS, thus the forest change map was produced.

RESULTS AND DISCUSSION

NDVI

The NDVI was calculated from the 2019 Sentinel-2A image using band 4 (Red) and band 8 (NIR). The NDVI values range from −1 to +1. Healthy vegetation has a high NDVI value, close to +1. Bare soil and rock show similar levels of near-infrared and red and produce near-zero NDVI values. Clouds and water bodies are completely different from the vegetation. They reflect more visible light and near-infrared light resulting in negative NDVI values. The NDVI image results range from a low value of −0.350446 to a high value of +0.679512. The NDVI map of the 2019 image is shown in Figure 3. The NDVI image is a meaningful indicator of vegetation patterns in the swamp forest. The high-density vegetation with high NDVI value can be separated from the more open vegetation and shrublands. The NDVI values are similar for the open-canopy forests, shrublands, and bare lands.

Unsupervised Classification

The unsupervised classification of the study area was set to five classes named water, bare land, vegetation 1, vegetation 2, and vegetation 3. Different colors were assigned to each class to make easily comprehensible while performing field verification. The unsupervised vegetation classes are shown in Figure 4.

Table 3. Final vegetation classes of RSBPA

Cover classes	Vegetation description
Water	Canal, submerged agricultural land, fishery pond
Bare land	Grassland, agricultural land, margin line of fishery pond and canal
Shrubland	*Schumannianthus dichotomus, Calamus guruba, Vetiveria zizanioides*, and with other lower stratum shrub species with a height of 2–2.5m.
Forest	*Pongamia pinnata, Barringtonia acutangulata, Syzygium formosanum, Crataeva nurvala*, and *Trewia nudiflora* with other upper stratum tree species

RSBPA: Ratargul Special Biodiversity Protection Area

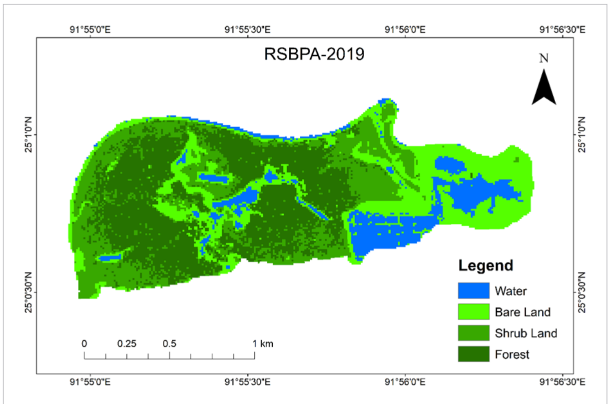

Figure 5. Forest cover map of the study area after supervised classification of 2019 Sentinel-2A image

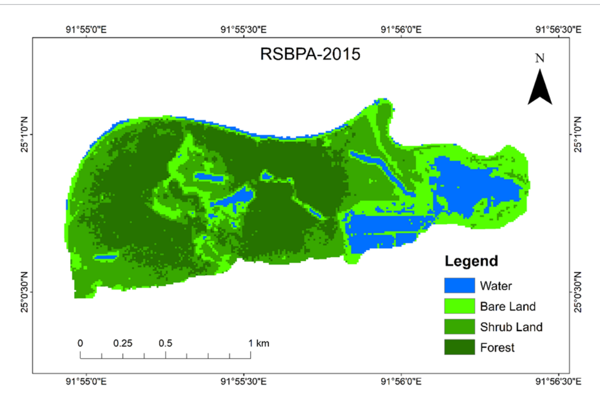

Figure 6. Forest cover map of 2015 Sentinel-2A image

Field-Based Data Verification

The field survey shows that some areas expected to be forested were shrublands. Shrublands look like a forest canopy in satellite imagery. Most of vegetation 3 areas were shrublands dominated by *Schumannianthus dichotomus*, *Calamus guruba*, *Vetiveria zizanioides*, and some other shrub species. Vegetation 3 represents mostly the lower stratum of the Ratargul swamp forest. In some areas, these shrubs form a bush-like stand, which confounds forested areas with shrublands in unsupervised classification. Again, some forested areas were also included in vegetation 3. Vegetation 2 represents the forest canopy area dominated by *Pongamia pinnata*, *Barringtonia acutangulata*, *Syzygium formosanum*, *Crataeva nurvala,* and *Trewia nudiflora*. During the field survey of vegetation 2, shrublands were also found. Vegetation 1 on the east side of the study area was comprised of low-dense shrubs, grasslands, and agricultural lands. Bare lands and water bodies were correctly classified. During the field survey, it was anticipated that with proper forest management this forest area could recover back to its former condition.

Supervised Classification

Field verification data was analyzed and a final classification map of the study area was produced. After the integration of field verification data, the unsupervised three vegetation classes of the 2019 image were reclassified into two vegetation classes as summarized in Table 3. Vegetation 1 was distributed

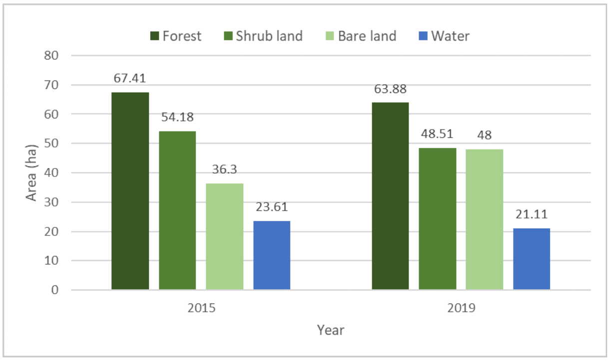

Figure 7. Areas of forest cover classes derived from supervised classification (area against year diagram)

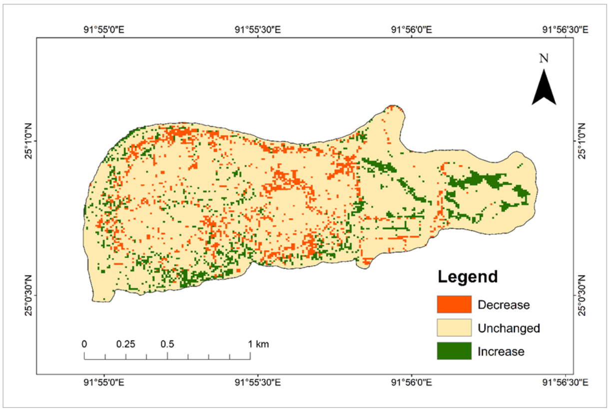

Figure 8. Forest change map of the study area

between bare land and shrubland classes. Low-density shrubland was included in the shrubland and grassland classes. The agricultural land on the east side of the study area was included in the bare land class. Vegetation 2 was classified as a forested area. The dense shrublands in this class were included in the vegetation 3 class, which was renamed as shrubland. The forested area within vegetation 3 was also removed and included in vegetation 2. The final forest cover map of the 2019 image is shown in Figure 5.

After classifying the 2019 image, the 2015 image was also classified with the maximum likelihood algorithm. The resultant forest cover map of the 2015 image is shown in Figure 6.

Forest Change Statistics

Summary statistics of forest cover classes of RSBPA derived from the supervised classification of 2015 and 2019 maps are listed in Table 4. A diagrammatic representation is shown in Figure 7. In the 2015 map, the areas of canopy forest and shrubland are 67.41 ha and 54.18 ha, respectively. In the 2019 map, forest and shrubland cover 63.88 ha and 48.51 ha, respectively.

Forest change map was created by differencing of supervised classification maps of 2015 and 2019 images. In Figure 8, red areas represent a decrease whereas green areas correspond to an increase in forest cover. The rest represents a lack of change.

Map Accuracy Assessment

Map accuracy assessment is a method of comparing the classification results to geographical data or field survey data. To assess the accuracy of forest cover maps, an error matrix (confusion matrix) was generated. From error matrices, producer's accuracy, user's accuracy, and overall accuracy are calculated. The producer's accuracy refers to the probability that a certain land cover of an area on the field is classified as such. On the other hand, the user's accuracy refers to the probability that a pixel labeled as a certain land cover class in the map is true (Hamzah et al., 2013).

Error matrices of 2015 and 2019 are shown in Appendix 2 and Appendix 3, respectively. The overall map accuracy produced from the supervised classification of the 2015 image is 87.5% and the overall accuracy of the 2019 map is 88% (Appendix 2 and Appendix 3).

Forest Change Analysis

The resultant map of 2015 shows that 67.41 ha or 37.1% of the total study area is forested and 54.18 ha or 29.9% consists of shrubland (Table 4). On the contrary, in the 2019 map, the upper stratum (forested area) is 63.88 ha or 35.2% of the total study area and the lower stratum (shrubland) is 48.51 ha or 26.7% of the total study area (Table 4). That makes a total of 112.39 ha, which is the total vegetation cover of the swamp forest by 2019. In the Ratargul swamp forest, both the upper stratum forested area and the lower stratum forested area are significantly important. Thus, these two types of forest cover need to be analyzed in forest change analysis. In this study, it was found that by January 2019, after declaring Ratargul Swamp Forest as Special Biodiversity Area in 2015, the degradation of the upper stratum (forested area) is 3.53 ha or 1.9% and the degradation of lower stratum (shrubland) is 5.67 ha or 3.2% of the study area (Table 5). The total decreased area is 9.2 ha or 5.1%. The amount of decrease does not seem significant but compared to the total area of 181.5 ha, a 9.2 ha decrease in 3 years is concerning. The degradation rate (1.69% per year) of swamp forest as shown in Table 5 is alarming. It is higher than the current loss of forest cover for Bangladesh (0.2%) (FAO, 2015). It is also much higher than the degradation rate (1% per year) in the tropical forest (Mayaux et al., 2005; Miettinen et al., 2011). This rate is only lesser than the current forest loss of nearby Peninsular Malaysia's tropical forests due to increased economic development (Masum, et al., 2017b).

Table 4. Area (in hectares) and percentage of forest cover classes resulted from supervised classification

Year	Forest	Shrubland	Bare land	Water	Total
2015	67.41 (37.1%)	54.18 (29.9%)	36.3 (20%)	23.61 (13%)	181.5
2019	63.88 (35.2%)	48.51 (26.7%)	48 (26.5%)	21.11 (11.6%)	181.5
Change	−3.53 (1.9%)	−5.67 (3.2%) (-)	+11.7(6.5%)	−2.5 (1.4%)	

(–) represents a decrease and (+) represents an increase.

Table 5. Annual rate of forest cover change of the study area

	Change from December 2015 to January 2019		Annual rate of change	
Classes	Area (ha)	% of the study area	Area (ha)	% of the study area
Forest	-3.53	-1.9%	-1.18	-0.63%
Shrubland	-5.67	-3.2%	-1.89	-1.06%
Total	-9.2	-5.1%	-3.07	-1.69

(–) represents a decrease and (+) represents an increase.

Identification and Selection of Restoration Sites

The study area of 181.5 ha is a small wetland regarded as a swamp forest. Studying small wetlands needs the use of airborne or high-resolution satellite systems (Jensen, 2007). But high-resolution satellite image data is costly. Thus, open-source satellite imagery Sentinel-2A with high resolution (10 × 10 m) was used.

Vegetation cover can be detected by satellite images, which can provide quantitative estimates of wetlands (Klemas, 2013). It was estimated a total area decrease of 9.2 ha or 5.1%. This 9.2 ha area has to be included in the restoration planning. Red areas in the forest cover change map (Figure 8) show the distribution of degraded habitats. The dependency of local people on the swamp forest seems to be the most probable cause for the degradation of the studied area. Among different types of disturbances, branch cutting in the wet season and livestock grazing in the dry season are most significant (Saha et al., 2018). The field survey revealed that illegal tree felling, fuelwood collection, trampling from tourists, and insect and disease epidemics also contribute to the degradation of this swamp forest.

Image data of winter season was considered to identify the restoration sites because, during the rainy season, RSBPA becomes flooded to an average depth of 4 m. Thus, the lower stratum becomes submerged (its height is 2–2.5 m) and it is impossible to be identified.

CONCLUSION

Remote sensing techniques represent a good tool to identify restoration sites of RSBPA. Approximately 9.2 ha of RSBPA was found to be degraded. Also, the forest cover change map displayed the restoration sites. In an attempt to improve vegetation growth in the degraded swamp forest area, the supervised classification map of the 2019 image and the forest cover change map can further be used to plan the restoration project. The swamp forest plays an important role in economic development and maintains proper environmental conditions. Therefore, it is important to manage the swamp forest on a sustainable basis. This research produced a forest cover change map and a 2019 map of the study area, which can assist forest managers to have a better comprehension of the area and formulate appropriate restoration or reforestation strategies. Since the swamp forest is inundated during the rainy season, restoration activities there are expensive compared to other forest types. Thus, restoration projects should be applied during the dry season. Restoration methods for degraded swamp forests such as conventional tillage, small mound tillage, acclimated seedling tillage, and dry season tillage can be applied since the implication of these four methods for degraded swamp forest was proved successful (Marconato et al., 2015). Finally, after the restoration of degraded habitats, monitoring can be done through remote sensing.

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Appendix 1. Field verification points of the study area

Latitude	Longitude	Land Cover
25.01315	91.92684	Forest
25.01368	91.92716	Forest
25.01381	91.9271	Forest
25.01051	91.92216	Forest
25.00989	91.92175	Forest
25.00884	91.92107	Forest
25.01511	91.92957	Shrubland
25.01445	91.92941	Forest
25.01344	91.92097	Shrubland
25.01284	91.92991	Forest
25.01167	91.92256	Bare Land
25.01203	91.92155	Forest
25.01287	91.92109	Bare Land
25.01418	91.9203	Forest
25.0118	91.92626	Forest
25.01192	91.92587	Forest
25.0117	91.92513	Forest
25.0115	91.92461	Shrubland
25.01131	91.9239	Forest
25.01081	92.92292	Forest
25.00955	91.92098	Forest
25.01207	91.92574	Forest
25.01137	91.92567	Forest
25.01671	91.92131	Shrubland
25.0149	91.92702	Bare Land
25.01541	91.92643	Forest
25.00947	91.91864	Shrubland
25.01555	91.92585	Forest
25.01637	91.92501	Shrubland
35.0146	91.92412	Forest
25.01384	91.92357	Shrubland

Appendix 2. Error matrix of forest cover map produced by supervised classification of 2015 Sentinel-2A image

	Reference data					
Classified Data	Water	Bare land	Shrubland	Forest	Row total	User's Accuracy (%)
Water	50	0	0	0	50	100
Bare land	10	40	0	0	50	80
Shrubland	0	10	50	0	60	83.3
Forest	0	0	10	70	80	87.5
Column total	60	50	60	70	240	
Producer's Accuracy (%)	83.3	80	83.3	100		
Overall accuracy is 87.5%						

Appendix 3. Error matrix of forest cover map produced by supervised classification of 2019 Sentinel-2A image

	Reference data					
Classified Data	Water	Bare land	Shrubland	Forest	Row total	User's Accuracy (%)
Water	60	0	0	0	60	100
Bare land	10	40	0	0	50	80
Shrubland	0	0	50	10	60	83.3
Forest	0	0	10	70	80	87.5
Column total	70	40	60	80	250	
Producer's Accuracy (%)	85.7	100	83.3	87.5		
Overall accuracy is 88%						