GeoPlanning
Journal of Geomatics and Planning

Geoplanning: Journal of Geomatics and Planning, Vol. 13, No. 1, 2026, 101 - 110

Received: 06 March 2025;
Revised: 26 March 2026;
Accepted: 17 June 2026
Available Online: 20 June 2026;
Published: 25 June 2026

Keywords:
Freshwater Swamp Forest, Forest Sustainability, Digital Elevation Model, Special Biodiversity Protection Area

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Original Research Open access

Appraising Land Use Dynamics and Dam Feasibility in Ratargul Swamp Forest, Bangladesh via Sentinel-2 Data

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DOI: 10.14710/geoplanning.13.1.101-110

Abstract

Ratargul Swamp Forest (RSF), the only freshwater swamp ecosystem in Bangladesh, is well-known for its rich biodiversity and unique wetland features that attract significant tourist traffic. However, dry season water scarcity restricts tourism, reducing local income and driving communities to illegally harvest resources, which accelerates forest degradation. This study aims to analyze land use and land cover (LULC) changes in the RSF from 2016 to 2024 and evaluate the feasibility of placing a dam to regulate dry-season water flow. Sentinel-2A satellite imagery was utilized to assess long-term LULC dynamics. Additionally, a Digital Elevation Model (DEM) was applied to identify optimal dam locations along the Chengir Khal to control water flow during the dry season. LULC analysis revealed that forest vegetation decreased at an annual rate of 1.23% while bare land expanded by 1.04% annually. Thus, highlight an urgent need for emergency conservation efforts in this special biodiversity area. The current dry season watershed area spans 80 hectares. DEM identified potential dam location to control water flow during the dry season. Establishing a dam at Chengir Khal is projected to increase the dry season water area to 121 hectares, without subverting or damaging existing forest plant habitats. Constructing a dam at Chengir Khal offers a sustainable solution to mitigate dry season water scarcity. By maintaining water levels, the dam will enhance the travel activity, secure local livelihoods, eliminate resource-dependence degradation, and promote long-term forest conservation.

1. Introduction

Freshwater swamp forests are vital wetland ecosystems that provide essential services including flood regulation, water quality maintenance, and habitat conservation for diverse flora and fauna (Abdullah et al., 2021; Bren et al., 2025). Characterized by unique vegetation and high-hydrological requirements (Chowdhury et al., 2025), these forests typically occupy low-lying areas along the lower reaches of rivers and adjacent to freshwater lakes. Periodic flooding deposits nutrient rich sediments into these waterlogged soils, promoting rapid tree growth, especially in areas where flood disturbances alter the forest structure (Ranganathan et al., 2022). Although freshwater swamp forests offer significant ecosystem services and benefits, but the biodiversity and species interactions within these forests remain poorly understood (Ashraf et al., 2026; Borbhuyan et al., 2026). Moreover, these distinct ecosystems are experiencing unprecedented rates of deforestation (de Almeida et al., 2025; Fahim et al., 2025). Eventually biodiversity loss became conspicuous within both the swamps and neighboring terrestrial forests (Dutta et al., 2026; Suurkuukka, 2014; Volkova et al., 2023).

In Bangladesh, the Ratargul Special Biodiversity Protection Area in Sylhet represents the country's only freshwater swamp forest and one of only 22 globally recognized freshwater swamps (Humayun-Bin-Akram & Masum, 2020). It harbors exceptional biological diversity that distinguishes it from other regional forest types (Fahim et al., 2025), leading to its official designation as a "Special Biodiversity Protection Area" in 2015 swamps (Humayun-Bin-Akram & Masum, 2020). Beyond conserving biodiversity and maintaining a healthy and resilient aquatic environment and hydrographic micro-watershed (Chowdhury et al., 2025; Khosravi et al., 2025), Ratargul supports local livelihoods by generating revenue through ecotourism (Refat et al., 2025), fuelwood extraction and non-wood forest products (Das et al., 2020; Islam et al., 2016; Krüger, 2005). However, population pressure, unplanned tourism, agricultural expansion, illegal extraction, and poor institutional coordination heavily degrade the forest and reduced its natural regeneration potential (Siddika et al., 2019).

Assessing land use classification proves to be vital for understanding forest vulnerability, as it helps identify areas more susceptible to degradation and informs targeted conservation strategies (Fagun et al., 2025; Masum et al., 2025). Prior LULC studies on Ratargul heavily relied on low-resolution Landsat images (30m) which struggle to accurately differentiate between under-canopy water networks, open water bodies, and water-logged agricultural zones. The potential of high-resolution Sentinel-2 multi-spectral (Major et al., 2025) and red-edge imagery to monitor micro-level vegetative and bathymetric responses (Rangel et al., 2025) remains under-researched in this region. Consequently, this study utilizes Sentinel 2A multispectral data to detect change variations in forest cover.

Although Ratargul plays an important role in biodiversity conservation and ecotourism, seasonal water scarcity has increasingly affected wetland hydrology and associated ecosystem services. Alterations in upstream flow regimes may contribute to reduced water availability during the dry season, resulting in the exposure of previously inundated areas and potential impacts on tourism-dependent livelihoods. These changes may also intensify pressures on forest resources and accelerate ecosystem degradation. Existing studies have primarily examined tourism-related socioeconomic aspects, conservation perceptions, forest boundary degradation, and ecosystem health (Biswas et al., 2004; Chowdhury et al., 2025; Das et al., 2020; Fahim et al., 2025; Hossain et al., 2023; Humayun-Bin-Akram & Masum, 2020; Islam et al., 2016; Jahan & Akhter, 2018; Nahian et al., 2018; Refat et al., 2024; Siddika et al., 2019). However, studies investigating watershed-scale water-retention potential and its implications for wetland sustainability remain limited.

Therefore, this study evaluates dry-season wetland degradation in Ratargul using multi-temporal geospatial analysis. The objectives are to: (1) identify and map areas undergoing persistent forest-cover degradation from 2016 to 2024, and (2) assess the watershed's capacity to enhance year-round water retention.

2. Data and Methods

2.1. Study area

Ratargul Swamp Forest (RSF) is situated 45 kilometers northwest of Sylhet City (at 25°00.025′N latitude and 91°58.180′ longitude) under Fatehpur union, Gowainghat Upazilla in the Sylhet District (Figure 1). The Gowain River originates in the mountainous region of Meghalaya (India), flows through forests area by three channels (locally known as Chengir Khal, Kaier Khal, and Shiali Chhora) and then falls into the Surma River (Chowdhury et al., 2025; Das et al., 2020). The river serves as a crucial lifeline for the swamp forest, providing essential nutrients to the Ratargul ecosystem (Islam et al., 2016). Inundated and nourished by the freshwater streams of this river. The swamp forest area declared as a "Special Biodiversity Conservation Area" by the Government of Bangladesh on thirty first May, 2015 (Jahan & Akhter, 2018).

The soil is gray, heavy, silt-clay loam with clays that predominate. Soils under the condition of vegetation cover are mostly clay loam to clay in texture. Soils are more clay in the river and depression sites (Nahian et al., 2018). Ratargul Special Biodiversity Protection Area (RSBPA) is characterized by a wide variety of vegetation including various swamp grasses, shrubs, and herbaceous species. About 73 plant species can be found until now and 80% of forest area are covered with these trees (Chowdhury et al., 2025). The Gowain River runs alongside

DOI: 10.14710/geoplanning.13.1.101-110

the site. In the monsoon season, the river gets filled with rainwater and floods its banks. This flooding typically begins around May and lasts until early October. However, from February to early April, the water level subsides, allowing people to easily walk across the river at several points. The riverbanks consist of sandy-to-sandy loam soil and support various types of annual plants. In certain areas of the riverbed where the water slows down, seasonal basins provide habitats for aquatic plants and animals (Biswas et al., 2004).

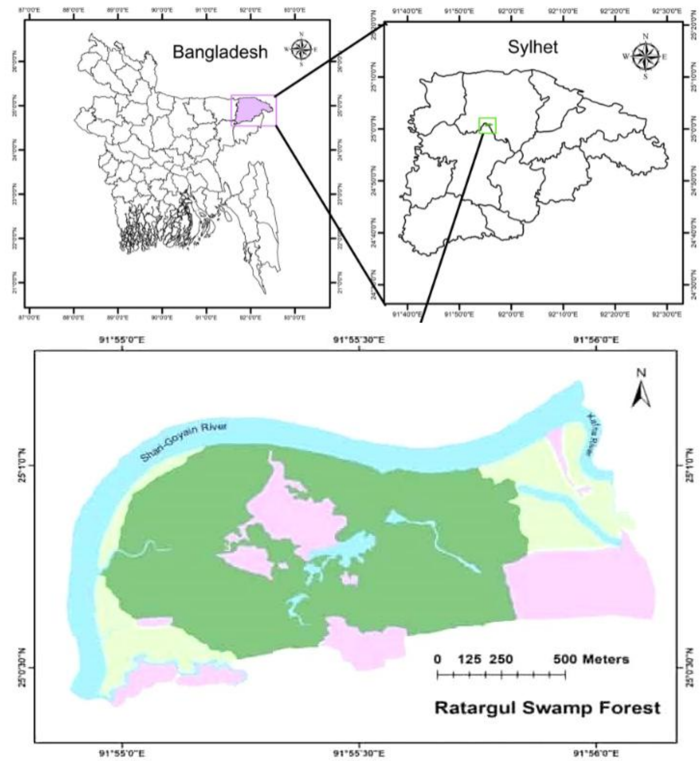

Figure 1. Map of the Study Area (Ratargul Special Biodiversity Protection Area

2.2. Data Analysis of Satellite Images

Land use and land cover (LULC) changes in the Ratargul Swamp Forest (RSF) were analyzed using remote sensing techniques. Image differencing is a widely used change detection algorithm that has been shown to be effective in a variety of settings. It works by subtracting two images of the same area taken at different times (Jiang et al., 2024). Sentinel-2A satellite imagery for 2016 (acquired March 18, 2016) and 2024 (acquired February 26, 2024) with cloud cover below 5% was obtained from the European Space Agency (ESA) Sentinel data hub. These datasets were already radiometrically corrected using the Sen2COR processor developed by the ESA (Table 1). The Sentinel-2A image's high spatial resolution of 10x10 meters offers detailed information ideal for detecting land use and land cover in this small wetland.

Table 1. Characteristic of the Collected Satellite Images

Date (DD-MM-YYYY)	Satellite	Resolution	Instrument
18-03-2016	Sentinel-2A	10×10	Multi-Spectral Instrument (MSI)
26-02-2024	Sentinel-2A	10×10	Multi-Spectral Instrument (MSI)

The area of interest (AOI) RSF is subset from the acquired Sentinel-2A satellite images for image classification in ArcGIS using the “Clip” tool from the Data Management Toolbox. The sub setting process was performed separately for the years 2016 and 2024 images. Separate signature files were created for both the years 2016 and 2024 images. These signature files contained the spectral characteristics and information which is necessary for classification of image.

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The generated signature files were individually applied to perform supervised classification of the 2016 and 2024 images using the Maximum Likelihood algorithm to generate forest cover change maps. The images were classified into four broad Land Use and Land Cover (LULC) classes, including Forest, Water, Shrubland, and Bare Land. This classification enabled land cover changes between 2016 and 2024 to be identified. Images were geometrically corrected using 46 Ground Control Points (GCPs) gathered via the Global Positioning System (GPS) and reference images from Google Earth Pro. Image processing and analysis were conducted using ArcGIS 10.8, Excel, Google Earth Pro and Google Earth Engine. To evaluate the accuracy of the classified LULC maps, a confusion matrix (error matrix) was employed. The confusion matrix was used to derive Overall Accuracy (OA), Producer's Accuracy (PA), User's Accuracy (UA), and the Kappa coefficient, which are widely used to assess classification performance. The overall classification accuracy was calculated using Equation (1):

$$OA = \frac{\text{Number of Correct Predictions}}{\text{Total Number of Samples}} \times 100 \ldots\ldots \textit{(Equation 1)}$$

where the number of correct predictions is the sum of the diagonal elements in the confusion matrix. Classification performance was further evaluated using Producer's Accuracy (PA), User's Accuracy (UA), and the Kappa coefficient.

2.3. Dam Site Feasibility Analysis

Digital Elevation Models (DEM) data with a spatial resolution of 30 meters were utilized to analyze the terrain, hydrological flow patterns and water storage capacity required for optimal dam placement. Terrain attributes, including elevation, slope, aspect, stream networks, and drainage basins, were extracted to characterize surface flow and water accumulation patterns. Based on these hydrological characteristics, potential dam sites were identified using the Hydrology toolset available in the ArcGIS Spatial Analyst extension. The methodological workflow is presented in Figure 2.

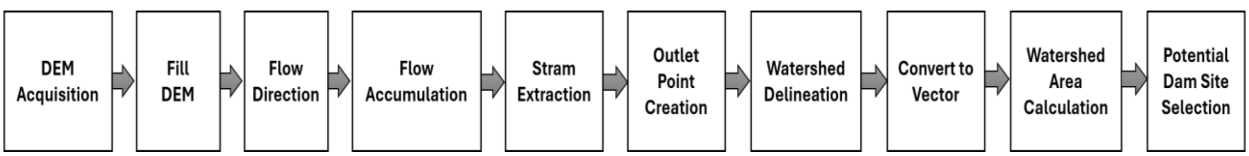

Figure 2. Workflow for Potential Dam Site Selection using DEM-based Watershed Delineation and Hydrological Analysis

3. Result and Discussion

3.1. Data Analysis of Satellite Images

The LULC classification result revealed a decline in forest cover between 2016 and 2024 (Figure 3). In 2016, the total forest cover area was 69.45 hectares, but by 2024 this figure had fallen to 56.62 hectares. Of particular concern is the annual rate of decline in total forest vegetation cover, which stands at 1.23%. Conversely, there has been a significant increase (8.39%) in the area of bare land, rising to 15.7 hectares (Table 2). These changes indicate progressive thinning of the upper and middle canopy layers, accompanied by increasing landscape fragmentation, suggesting ongoing structural degradation of the RSF ecosystem.

The observed degradation is likely associated with seasonal variations in water turbidity, fluctuations in water depth due to seasonal conditions (Badhon et al., 2026), and anthropogenic factors (overfishing, agricultural expansion, firewood collection, illegal logging, irrigation, grazing, infrastructure, human settlements, unplanned tourism activities, and poaching) arising from a vulnerable economic situation (Akter et al., 2024; Das et al., 2020; Humayun-Bin-Akram & Masum, 2020). The continued loss of forest cover may adversely affect biodiversity conservation and ecotourism potential within the RSF. These findings emphasize the need for strengthened conservation strategies and sustainable land-management practices to reduce further forest loss and enhance ecological resilience through continuous LULC monitoring (Badhon et al., 2026).

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Table 2. Land Use Change in the Study Area

Land Coverage in ha (Percentage)				
Year	**Forest**	**Water**	**Bare Land**	**Shrubland**
2016	69.45 ha (37.12%)	31.44 ha (16.80%)	29.59 ha (15.82%)	56.62 ha (30.26%)
2024	61.81 ha (33.04%)	34.09 ha (18.22%)	45.29 ha (24.21%)	45.91 ha (24.54%)
Annual Rate of Change	- 0.51%	0.18%	1.05%	- 0.72%

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

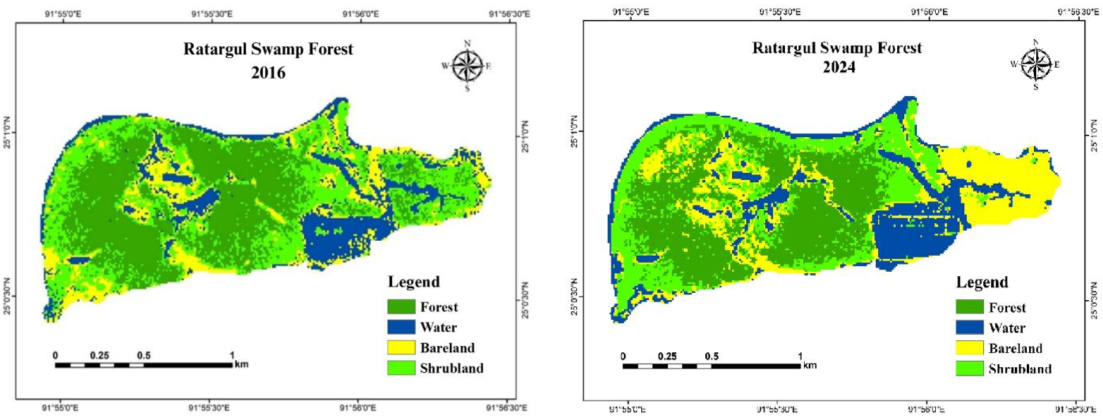

Figure 3. LULC Scenario of RSF in 2016 and in 2024

3.2. Change in between the Coverages in RSF

The land use and land cover (LULC) of the Ratargul Swamp Forest (RSF) underwent noticeable changes between 2016 and 2024, with the most significant transformations occurring in the southern, eastern, and parts of the western sections of the forest. These areas experienced relatively higher levels of disturbance because of their accessibility to local communities, who depend on the forest for fuelwood collection, fishing, harvesting medicinal plants, collecting honey, and gathering other non-timber forest products. Consequently, land cover changes were more pronounced in these accessible areas than in the forest interior.

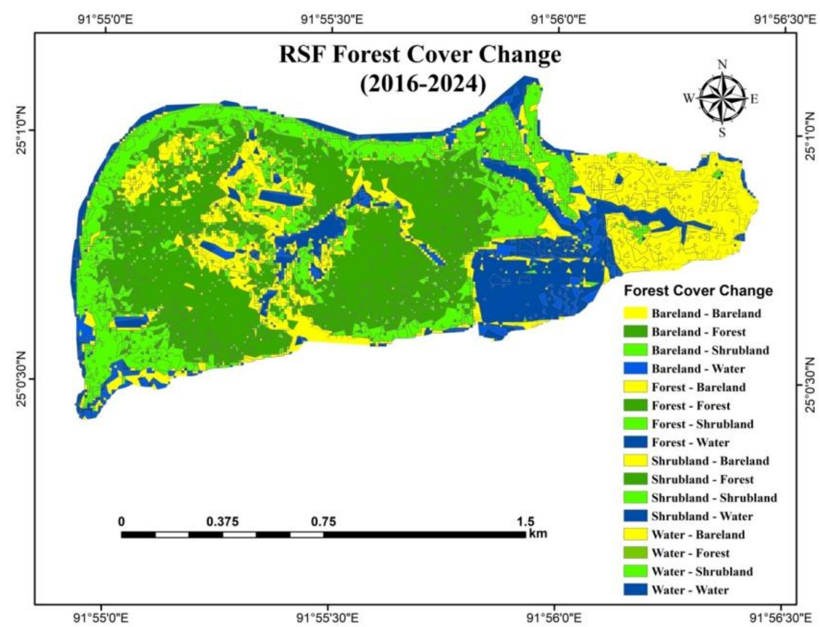

Figure 4. Change in between the Coverages in RSF from 2016 to 2024

The southern portion of the forest exhibited the greatest conversion of forested land into agricultural land during the study period. Besides local resource extraction, tourism activities have also contributed to environmental pressures within the forest. The lack of proper ecotourism planning has resulted in unregulated tourism activities and localized noise pollution (Das et al., 2020). Furthermore, inadequate tourism infrastructure restricts visitors to only a limited portion of the watershed, leading to repeated use of the same locations and intensifying disturbances in these areas (Jahan & Akhter, 2018). These patterns of land cover transformation are illustrated in Figure 4, which presents the LULC transitions between 2016 and 2024. The transition matrix summarizes the conversion of each land cover class to another over the eight-year period, highlighting the dominant pathways of landscape change within the RSF.

The land-use change detection analysis of RSF from 2016 to 2024 revealed both degradation and recovery patterns. Deforestation remained the dominant process, with 10.29 ha of forest converted to bare land, likely driven by a combination of agricultural expansion, logging, and infrastructure development, resulting in soil erosion and biodiversity loss (Figure 5). Canopy loss resulting from the conversion of forest to bare land also altered the microclimate of the RSF by increasing forest floor temperatures and reducing humidity. These changes threaten the habitats of amphibians, reptiles, and freshwater fish species that depend on the dense canopy of dominant swamp trees such as *Pongamia pinnata* and *Barringtonia acutangula* (Akter et al., 2024).

Furthermore, the expansion of bare land exposes highly vulnerable hydromorphic soils to intense monsoon rainfall. Without root systems to stabilize the soil, severe erosion becomes inevitable, and the resulting sediment is transported into the forest's internal water channels, accelerating siltation (Akter et al., 2024). Therefore, re-establishing natural vegetation is essential to mitigate further canopy loss in the RSF. In contrast, only 1.29 ha of bare land was revived to forest during the study period, indicating that rehabilitation of degraded ecosystems remains limited.

Similarly, 10.96 ha of forest found to be degraded to shrubland but 13.25 ha of shrubland was upgraded to forest. This loss to recovery proves that passive natural regeneration is entirely failing to keep pace with human-driven degradation, signaling an urgent need for targeted, active silvicultural intervention (Fahim et al., 2025). Changes in water body were minimal, with 0.86 ha of forest lost to water and only 0.102 ha of water reclaimed to forest (Figure 5). This might because of channels fill with sediment, they shallow out and expand outward, flooding larger superficial areas with shallower water tables, hence alters the hydrological regime that specialized swamp tree species rely on for survival. These trends demand sustainable land management, afforestation and policy intervention for rehabilitating ecological equilibrium (Akter et al., 2024; Humayun-Bin-Akram & Masum, 2020).

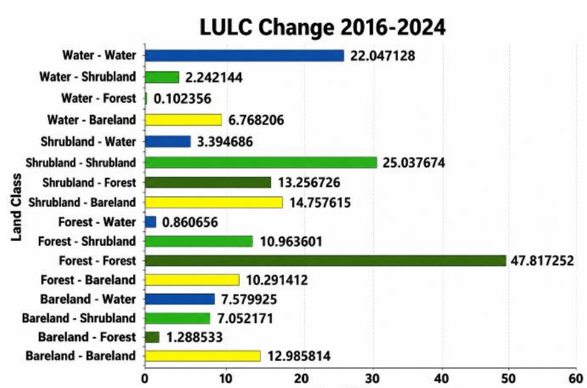

Figure 5. LULC Transition Areas in the RSF from 2016 to 2024

3.3. Accuracy Assessment

The accuracy assessment demonstrated that the supervised classification achieved satisfactory performance for both study years (Table 3). The overall accuracy, Kappa coefficient, producer's accuracy, and user's accuracy indicate that the LULC maps are sufficiently reliable for subsequent change detection analysis.

The overall accuracy values were 85% and 96% for images from 2016 to 2024 respectively. For the 2016 images, the producer's accuracy for all classes was found to be higher than 81%. The user's accuracy for the 2016 images for all classes was higher that 79%, except for water body. For images from 2024, the producer's accuracy, and the user's accuracy for all the classes were found to be higher than 93%.

Table 3. Classification Accuracy of the LULC Maps

Year	Overall Accuracy (%)	Kappa	P_Accuracy (%)	U_Accuracy (%)
2016	84.78	0.78	81–100	60–94
2024	95.65	0.94	93–100	93–100

3.4. Watershed Analysis and Dam Site Feasibility Analysis

Sentinel-2 Earth observation data has been coupled with hydrological modeling tools to produce a replicable framework for evaluating structural interventions in these perennially flooded wetlands. Insights into the overall water supply within the swamp forest ecosystem have been obtained by analyzing the watershed area. This information facilitates to evaluation of the potential benefits and challenges of dam construction.

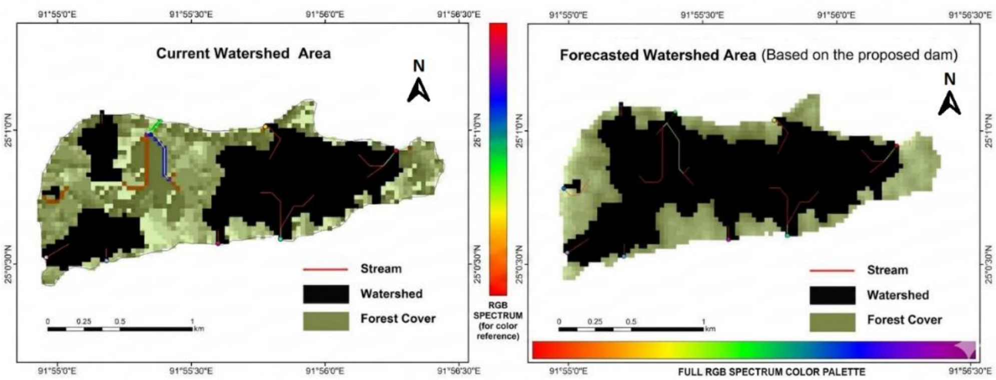

Figure 6. Current Watershed Area (in Winter) and Forecasted Area (based on Dam Placement) of RSF

Dam location in RSF has been suggested considering the unique vegetation adaptation and hydrological characteristics of these ecosystems (Figure 6). Careful analysis of the watershed area and meaningful engagement with local communities were the key steps in proposing a dam that respects and protects the invaluable freshwater swamp forest ecosystem. The size of the watershed area plays a significant role in assessing water supply potential and its subsequent impact on forest vegetation during dry seasons. Despite the presence of a dam in nearby watch tower, it does not cover sufficient areas of the forest land. The projected dam area covers the additional watershed of 41 hectares in winter (Figure 7).

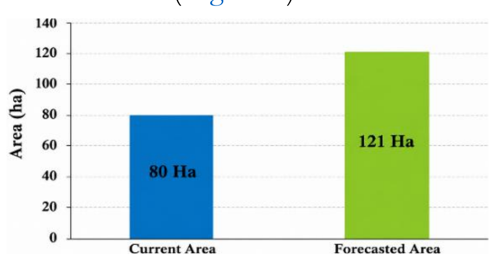

Figure 7. Current and Projected Watershed Area based on New Dam Placement

Humayun-Bin-Akram & Masum (2020) evaluated that the water cover area decreases by 11-13 % during winter season. According to the Forest Department, the maximum number of visitors arrive during November, December, and January. However, low water levels during this peak period restricts the space available to fully explore the forest due to. Because the water level is low, many visiting tourists cannot fully meet their expectations, return disappointed, which ultimately decrease tourist attraction of the site (Nahian et al., 2018). Consequently, public interest in visiting the area is steadily declining.

The study indicates that the current watershed area in dry seasons area covers 80 hectares, while the projected dam would cover an additional area 41 hectares within the catchment (Figure 8). Following the constructing the dam (Figure 6), projection indicates an increase an expansion of water bodies to a total water area of 121 hectares (Figure 7). This additional water will be retained in Chengir Khal's winter dried portion of the catchment area. To facilitate this, a sluice gate is proposed (Figure 8) to hold water in Chengir khal, thereby regulating water flow along the forest streamline in dry seasons. Because, it only holds the channel water, the infrastructure (proposed dam) will not harm the surrounding vegetation of forest. Constructing the dam alongside a sluice gate allows for the controlled retention of regulated throughout the dry season.

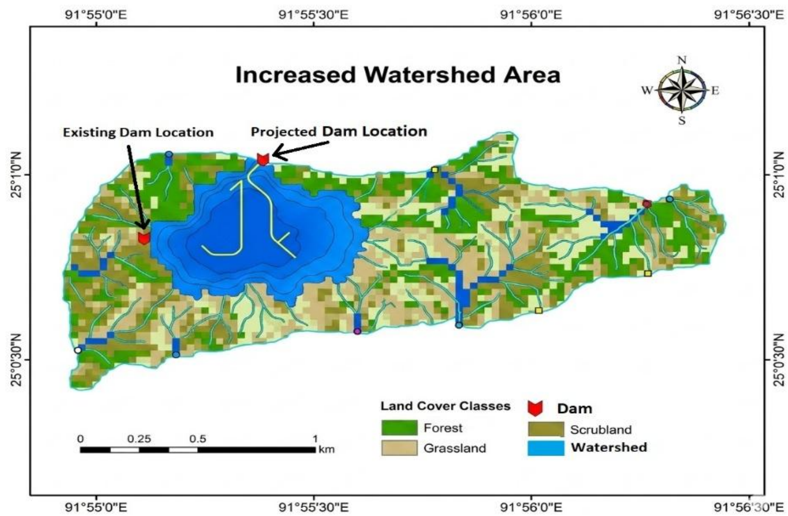

Figure 8. Forecasted Increment of Watershed Area based on Dam Placement

According to Humayun-Bin-Akram & Masum (2020) and Das et al. (2020) forest degradation in RSF were driven by local communities that use the land for agricultural purposes, as well as engage in illegal fishing activities to exploit fishery resources (Das et al., 2020). Additionally, Mree et al. (2020) and Kiss (2004) demonstrated that ecotourism can significantly aid biodiversity conservation. The benefits associated with ecotourism play a crucial role in shaping the positive community attitudes toward nearby natural areas (Manesha et al., 2021; Refat et al., 2024). This dynamic can potentially boost tourism revenue, which can then be used to financially support and improve the conservation of the natural environment. Furthermore, ecotourism offers a unique opportunity to create employment in diverse areas beyond the direct roles within national parks and information centers (Mree et al., 2020). However, water scarcity during the dry season leads to a decline in tourist interest, thereby reducing income opportunities for local communities that rely heavily on tourism. Consequently, In the absence of tourism revenue, local communities often turned to unauthorized resource collection, ultimately driving a decrease in forest cover.

4. Conclusion

The Land Use and Land Cover (LULC) analysis of the Ratargul Swamp Forest (RSF) between 2016 and 2024 revealed substantial ecological degradation, characterized by declining forest cover, canopy thinning, and increasing landscape fragmentation. Forest cover decreased from 69.45 ha to 56.62 ha over the study period, largely associated with anthropogenic pressures, including agricultural expansion, overfishing, and illegal logging. The conversion of forest to bare land has altered the forest microclimate, increased soil erosion, and accelerated sedimentation within internal water channels, highlighting the need for effective conservation and rehabilitation of degraded ecosystems. Hydrological analysis further indicated that reduced dry-season water availability constrains both ecosystem functions and ecotourism activities. As a potential mitigation strategy, the proposed dam and sluice gate system could increase the winter watershed area from 82.13 ha to 120.90 ha by improving water retention within the Chengir Khal, thereby supporting ecosystem resilience and enhancing ecotourism opportunities. Overall, the findings demonstrate that integrating a set of interventions for rehabilitation of degraded ecosystems with sustainable water resource management may provide an effective approach to improving the long-term ecological condition of the RSF while reducing pressure on forest resources. Future research should incorporate detailed hydrological modeling, environmental impact assessment, and climate change scenarios to evaluate the long-term feasibility and ecological implications of the proposed intervention. These findings also provide practical insights for policymakers and conservation practitioners in developing integrated forest management strategies that promote biodiversity conservation, sustainable water management, and ecotourism development in the RSF.

5. Acknowledgments

The authors would like to thank the Chief Conservator of Forests, Forest Department, Bangladesh, for granting permission to conduct this research in the protected areas. The authors also thank Pulok Kanti Das and Kazi Al Muktadir for their technical assistance during data collection and processing.

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