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Evaluation of Environmental Changes of Sal Forest Land Cover Using GIS and Remote Sensing Techniques: An Empirical Study on Arankhola, Madhupur Sal Forest in Bangladesh

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Abstract: Bangladesh is a developing country in South Asia that has some forest cover. An estimated 17.1% of the country's land surface is covered by forests. Using Landsat satellite pictures of the Madhupur Sal forest (Arankhola) taken in 1990, 2005, and 2023, we mapped and evaluated changes in the forest's cover over the years 1990 to 2023. We examine variation in forest cover dynamics over the period 1990–2023 using Landsat TM image of 1990, TM+ of 2005, and OLI-TIRS of 2023. This forest is a tropical deciduous stand in the Tangail Forest Division of Bangladesh. The mapping for 1990, 2005, and 2023 indicates that the forest cover accounts for 3714.6 (ha) (22.9%), 2837.4 (ha) (17.55%), and 2202.4 (ha) (13.6%) respectively. The study found that forest cover decrease rate was (-24%), and (-22%) within 1990-2005 and 2005-2023. The Rubber plantation/ Pineapple/ Lemon Cultivation increased by (+49%) within 1990-2005. The detection of land cover change resulted in a major rise in bare land/cropland/settlement (+28%) from 1990 to 2023. Based on our research findings, we have observed a significant rise in the cultivation of rubber, pineapple, and lemon crops, as well as an increase in bare land and settlements. In contrast, both robust and open forest cover declined over the study period. The factors leading to the evolution of the 'Sal Forest' were investigated using GPS-based ground verification and interviews with local residents. Hence, the study proposes the urgent implementation of restrictions on human activities and commercial logging within the forest area, along with the need for policy reforms facilitated by government initiatives.

1. Introduction

Forests are crucial for the survival of Earth's various species. Forests encompass vast areas and have diverse compositions and traits, and they play an important role in maintaining plant and animal life.. Each forest has its own climate, soil characteristics, plant and animal species, precipitation pattern, temperature profile, and sunlight, creating a balanced ecosystem where various plants flourish together (Salam & Pramanik, 2017). However, with the ever-increasing human population and limited natural resources, the environment faces constant threats. To maintain ecological balance, every country is advised to allocate at least 25 percent of its total area as forested land (Abdullah Al Faruq et al., 2016). In the context of Bangladesh, this becomes particularly crucial, as the nation strives to preserve its ecosystem with the least possible forest area and the rapid growth of the population has led to significant degradation of its forest reserves (Kibria & Saha, 2011). Bangladesh's Madhupur Sal forest is a huge, environmentally varied region with a wealth of species (Roy *et al.,* 2014). It is located between the Mymensingh and Tangail districts and represents the country's largest natural Sal Forest covering approximately 0.12 million hectares, which accounts for 4.7% of the country's total wooded area (Abdullah Al Faruq *et al.*, 2016; Hossain *et al.*, 2013). Currently, much of Madhupur's forestland has been cleared, degraded, or taken over for commercial purposes like pineapple and banana production, as well as the cultivation of rubber and exotic fuel-wood species, leading to a rapid shift in the traditional land-use pattern due to the increasing popularity of banana monoculture among the Garo community (Dey, 2007). Commercial plantations of bananas, pineapples, ginger, and papayas, along with long-standing rubber cultivation, now exist within the Madhupur Sal forest. The replacement of palm trees with exotic eucalyptus and acacia species has led to reduced wildlife presence and the degradation of various plant and medicinal species due to excessive fertilizer use in agriculture (Redwanur Rahman, 2015). Land Cover Changes portray how humans interact with the environment in a specific area, influenced by climate change and socio-economic factors (Juliev *et al.,* 2019). Deforestation in the Sal Forest is mainly caused by agricultural expansion, exotic plants logging, and firewood harvesting, while the local population's reliance on small-scale agriculture leads to land cover changes (Salam & Pramanik, 2017). These changes have raised concerns about the impact on the forest ecosystem and its biodiversity, calling for effective management strategies to ensure its preservation and sustainable use. Analyzing land cover changes is crucial for understanding the extent of human activities and their impact on the environment at different spatial and temporal scales (Hena *et al.*, 2023). Utilizing advanced technologies like geographic information system and remote sensing is crucial for understanding the LULCC patterns and developing sustainable management strategies to address the environmental impacts of forest degradation (Roy *et al.*, 2022). By using remote sensing data, we can effectively assess forest inventories, monitor changes in forest cover, and evaluate forest damage in a non-destructive manner, thereby supporting sustainable forest management efforts (Mani & Varghese, 2018). The objective of this research is to use geographic information system (GIS) and Remote Sensing to assess land cover changes in the Sal Forest of Arankhola, Madhupur, Bangladesh. It specifically aims to analyze the extent and impact of environmental changes within the Sal Forest landscape and to identify the root causes of Sal Forest degradation. The significance of the study lies in its exploration of the essential ecosystem services and biodiversity conservation within the Sal Forest. It addresses pressing human-induced threats, such as deforestation and showcases the efficacy of Geographic Information System (GIS) and remote sensing (RS) techniques for non-destructive monitoring.

2. Materials and Methods

2.1. Study Area

The study carried out in the Madhupur Sal forest, the biggest belt of sal forests in Bangladesh (also known locally as Madhupur Garh). The Madhupur Sal forest is located in Madhupur upzilla, which is part of the Tangail district. It is 80 kilometers to the northeast of Dhaka. It lies between 23°50′ and 24°50′ N and 89°54′ and 90°50′ E. Jamalpur district is located in the northwest of the forest, Madhupur and Dhonbari upzilla are in the southwest, and Muktagacha and Fulbaria upzilla are in the east of the forest (Salam and Pramanik, 2017). The Madhupur Sal forest covers 45,565.18 acres, of which 2525.14 acres have been classified as reserved forest and the rest of the 43039.04 acres are at present being constructed (Subhan Mollick *et al.,* 2018). The government declared Madhupur national park on

February 24, 1982, with a gazette notification, for the purpose of biodiversity conservation (Abdullah Al Faruq *et al.*, 2016). The 20837.23 acres are divided into two sections: 20244.23 acres in Tangail district and 593.00 acres in Mymensing district (Mahbub & Ahmed, 2008). When dry, the soil is compact and hard, but when it rains, it melts and becomes soft and tenacious (Kibria & Saha, 2011).

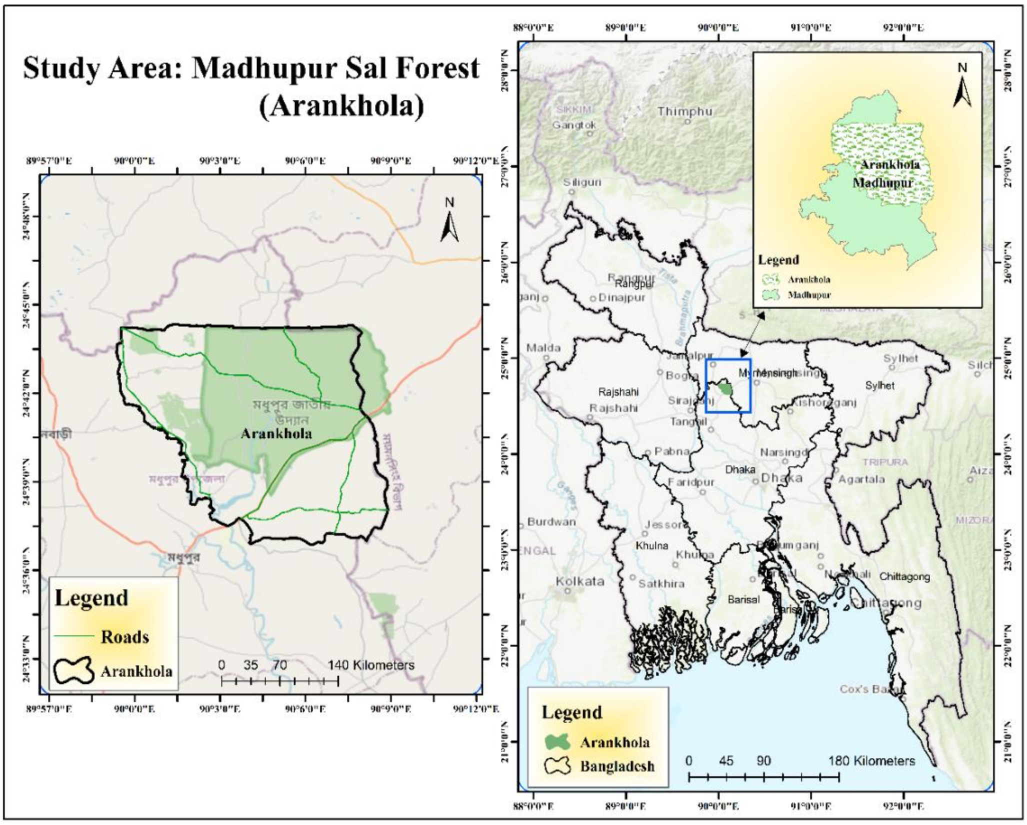

Figure 1. **Study area (areas of Arankhola Union; adjoining fringe areas) under Mymensingh Division**

2.2. Data Sets

The Landsat satellite imagery data sets were obtained from the US Geological Survey (USGS) open access service at https://earthexplorer.usgs.gov. Three Landsat data sets were selected for this study: Landsat TM 30m (1990), TM+ 30m (2005), and OLI-TIRS 30m (2023). The Landsat TM 30m data set was acquired on January 2, 1990, and had a cloud cover of 2.00%. The Landsat TM+ 30m data set was acquired on January 16, 2005, and had a cloud cover of 1.00%. The most recent data set, Landsat OLI-TIRS 30m, was acquired on January 7, 2023, and had a cloud cover of 0.05%. To ensure the accuracy of the classification work, the selection of imagery for the study was based on the criteria of cloud-free and unwanted shade-free imagery. The presence of clouds can significantly reduce the accuracy of classification work. Therefore, imagery with clouds was excluded from the study. The spatial resolution of the Landsat data sets used in the study was 30m, which is considered to be high resolution (López-Serrano *et al.*, 2016). The 30m resolution was sufficient for identifying the changes in the Sal Forest land cover. The data sets were in the World Geodetic System (WGS84) datum, which is a widely used reference system for geographic information.

Bangladesh experiences winter season from December to March, followed by an interim period of winter to summer in March. The monsoon season in Bangladesh is known for its cloudy weather, while the winter season is typically cloud-free. Therefore, for this study, the main sources of data were the winter season images. It was expected that the acquisition period of the images would have minimal seasonal variation due to the choice of winter season images. This approach ensured that the study obtained the most reliable and consistent data possible for the analysis of environmental changes in the Madhupur Sal Forest.

Table 1. Information about picked up Landsat Satellite Images used in this study

Satellite Data	Datum	Sensor	WRS Path	WRS Row	Cloud Cover	Spatial resolution	Data Acquired
Landsat -5	WGS84	TM	137	43	2.00	30	1990-01-02
Landsat -5	WGS84	TM	137	43	1.00	30	2005-01-16
Landsat -9	WGS84	OLI-TIRS	137	43	0.05	30	2023-01-07

2.3. Data Preparation

In this study, prior to image processing, the Landsat images were stacked to create multiband composite images and then subset according to the study area to reduce computation and image analysis time (refer to Table 1 for details). The layer stacking process was performed using ArcGIS 10.8 software, which combined three bands for each Landsat image (bands 8, 5, 4, 3, 2 for Landsat-8, 4, 3, 2, 1 for Landsat-5, and 5, 4, 3, 2, 1 for Landsat-5) into a single layer. This process was applied to all three images used in the study. As the study used three different images from different time periods, they needed to be registered first through proper Ground Control Point (GCP) alignment. The Landsat-8 scene from 2023 (path 137, row 43) was selected as the reference image, and the images from 1990 and 2005 were registered to it. After registration, the images underwent pre-processing, which included atmospheric, radiometric, and geometric corrections. Atmospheric correction is a crucial step that needs to be monitored because the presence of gases, solid and liquid particles in the atmosphere can affect the signal measured by the satellite. Radiometric corrections were applied to correct the data for sensor irregularities, unwanted sensor or atmospheric noise, and clouds (Abdullah Al Faruq *et al.*, 2016).

2.4. Accuracy Assessment

The accuracy assessment reflects the real difference between our classification and the reference map or data (Lillesand M. Thomas *et al.*, 2015). If the reference data is highly inaccurate, assessment might indicate that classification results are poor.

Producer's accuracy refers to the map accuracy from the perspective of the map maker, or producer (Lillesand M. Thomas *et al.*, 2015). It is the measure of how often the real features on the ground are correctly represented on the classified map or the likelihood that a particular land cover of an area on the ground is classified accurately. This is calculated by dividing the number of reference sites that are accurately classified by the total number of reference sites for that particular class (Eq. 1). In other words, producer's accuracy is a measure of the probability that a specific class is correctly classified on the map, as determined by the producer.

$$\textbf{Producer Accuracy} = \frac{\textbf{Total number of pixels in a category}}{\textbf{Total number of pixels of that category derived from the reference data (i.e.,row total)}} \ldots\ldots\ldots\ldots \quad (1)$$

The user's accuracy is an important metric used in remote sensing and image classification to evaluate the accuracy of a classification model from the perspective of the end-user of the map (Rahman *et al.*, 2008). It represents the percentage of correctly classified pixels or areas on the map that are also correctly classified in reality. To calculate the user's accuracy for a particular class, we need to divide the number of correctly classified pixels for that class by the total number of pixels in that class, including both correct and incorrect classifications. The user's accuracy is complementary to the commission error, which represents the percentage of incorrectly classified pixels or areas on the map that are not actually present in reality. The sum of the user's accuracy and the commission error should add up to 100% (Lillesand M. Thomas *et al.*, 2015). In summary, the user's accuracy is an important measure of the reliability of a classification model and indicates how well the map represents the actual ground conditions. It is a key metric for ensuring that remote sensing and image classification applications are accurate and effective. The formula for calculating the user's accuracy is:

$$\boldsymbol{User's\ Accuracy} = \frac{\textbf{Number of Correctly Classified Pixels for a Class}}{\textbf{Total number of pixels of that category derived from the reference data (i.e.,column total)}} \ldots\ldots(2)$$

Overall accuracy was used to calculate a measure of accuracy for the entire image across all classes present in the classified image (Eq. 3) (Lillesand M. Thomas *et al.*, 2015). The collective accuracy of map for all the classes can be described using overall accuracy, which calculates the proportion of pixels correctly classified.

$$\boldsymbol{Overall\ accuracy} = \frac{\textbf{Sum of the diagonal elements}}{\textbf{Total number of accuracy sites pixels (column total)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The kappa statistics value is a measure of the agreement between classification and reference data (Wang *et al.*, 2012). (Landis & Koch, 1977) ranked the kappa values, ranging from −1 to 1, into three groups: (1) greater than 0.80 represented strong agreement (2) between 0.40 and 0.80 represented moderate agreement, and (3) less than 0.40 represented poor agreement between the classification and reference data. According to Wongapakaran et al. (2013), the Kappa coefficient lies typically ranged from 0 to 1.00 where the latter indicates substantial agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy.

Accuracy assessment is prime important for pre and post classified images. Likewise, Kappa coefficient values between 0.61-0.80 signify the substantial agreement (Landis & Koch, 1977). In this study, user, producer and overall accuracy as well as Kappa coefficient are calculated in following equations:

$$\boldsymbol{Kappa\ Coefficient\ (T)} \frac{((\boldsymbol{TS}\times\boldsymbol{TCS}) - \sum(\textbf{column total}\times\textbf{Row total}))}{(\textbf{TS\^{}2} - \sum(\textbf{Column Total}\times\textbf{Row Total}))\times\textbf{100}} \ldots\ldots\ldots\ldots\ldots(4)$$

Table 2. **Accuracy assessment of the classified images**

Images reference year	Classified image	Overall classification accuracy (%)	Overall kappa statistics
1990	Landsat-5 TM	82.90%	0.76
2005	Landsat-5 TM	87.15%	0.81
2023	Landsat-8 OLI	95. 37%	0.89

2.5. Methodology:

The flow chart of the methodology for the present work has been shown in Figure 2.

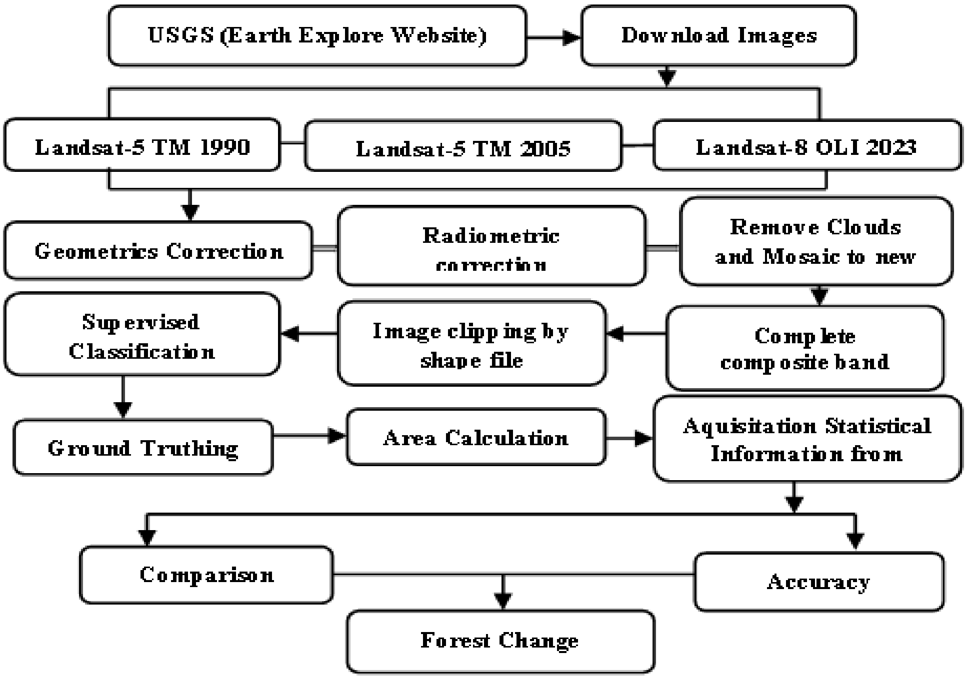

Figure 2. Shows the whole methodology of the research

3. Result and Discussions

The table 3 provided presents the land use distribution in a specific region for the years 1990, 2005, and 2023. The land cover categories considered are forest, rubber plantation/pineapple/lemon cultivation, waterbody, and bare land/cropland/settlement. Here is a description of the land use dynamics observed in the region based on the given data:

Table 3. Land Use Land cover areas(ha)

Year	Forest		Rubber plantation/ Pineapple/ Lemon Cultivation		Waterbody		Bare land/Cropland/ Settlement	
	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)
1990	3714.6	22.9	2830.2	17.4	300.8	1.9	9401.7	57.9
2005	2837.4	17.5	4223.7	26	503.5	3.1	8680.6	53.43
2023	2202.4	13.6	2386.1	14.7	505.2	3.1	11137.2	68.6

In 1990, the region had a total forest area of 3714.6 hectares, accounting for 22.9% of the total land area (Table 3). The second largest land use category was rubber plantation/pineapple/lemon cultivation, covering an area of 2830.2 hectares (17.4%). Waterbodies occupied a smaller area of 300.8 hectares (1.9%), while the largest land use category was bare land/cropland/settlement with an area of 9401.7

hectares (57.9%). By 2005, there was a noticeable decrease in the forest area, which reduced to 2837.4 hectares, representing 17.5% of the total land area. The area dedicated to rubber plantation/pineapple/lemon cultivation increased to 4223.7 hectares (26%). Waterbodies covered 503.5 hectares (3.1%), Water bodies were increased due to flooding, or little man-made lake ponds and the largest land use category remained as bare land/cropland/settlement, occupying 8680.6 hectares (53.43%).

In the most recent year, 2023, the forest area further decreased to 2202.4 hectares, accounting for 13.6% of the total land area. The area utilized for rubber plantation/pineapple/lemon cultivation was 2386.1 hectares (14.7%). Waterbodies covered 505.2 hectares (3.1%), while the largest land use category continued to be bare land/cropland/settlement, with an area of 11137.2 hectares (68.6%). The data suggests a decline in forest cover over the observed period, with a corresponding increase in land allocated to rubber plantation/pineapple/lemon cultivation. The expansion of bare land/cropland/settlement has also been significant (Figure 3), occupying the largest portion of the region. These changes indicate potential impacts on biodiversity, ecosystem services, and the overall landscape of the region.

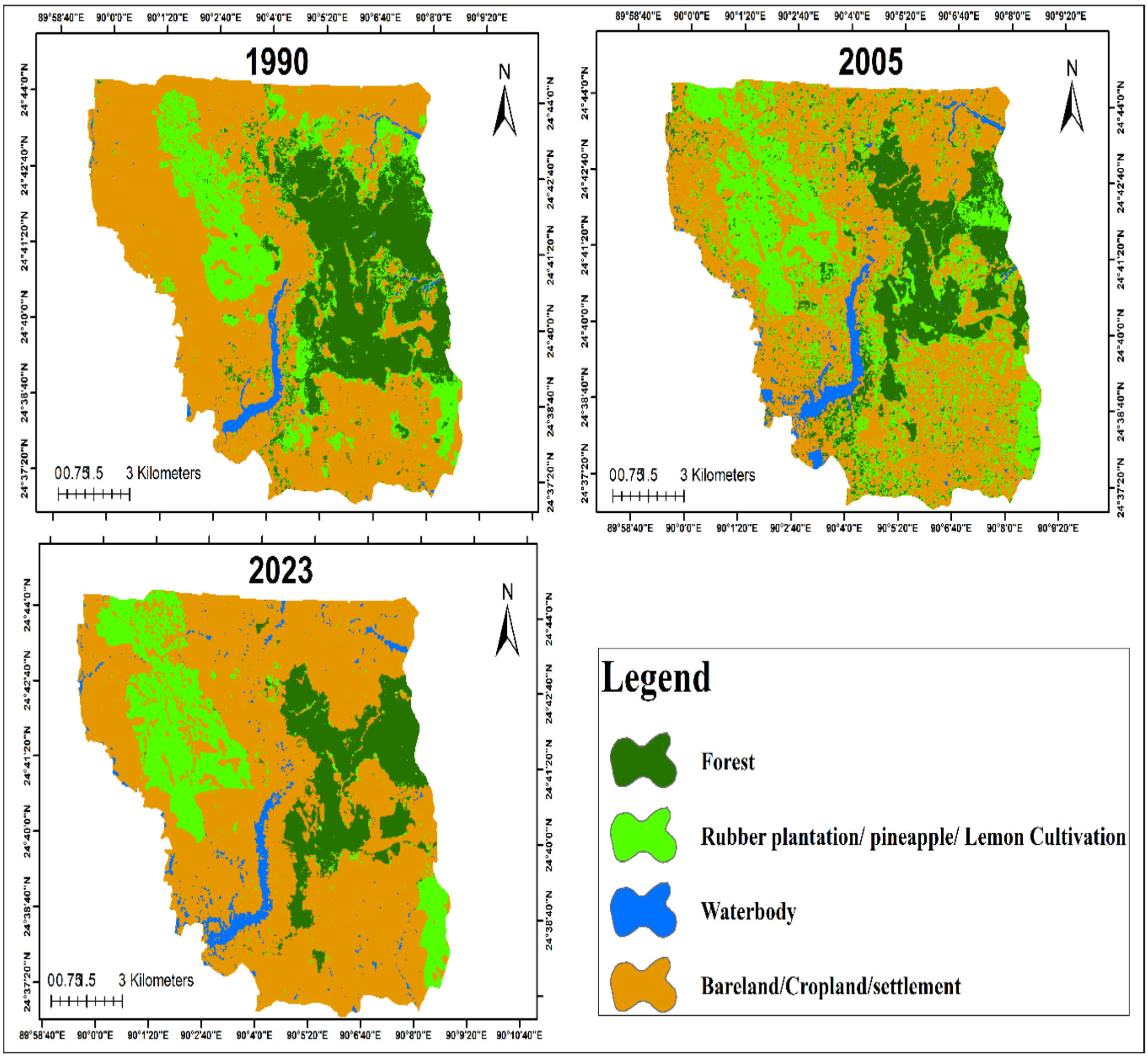

Figure 3. **Land use land cover map of 1990, 2005 and 2023**

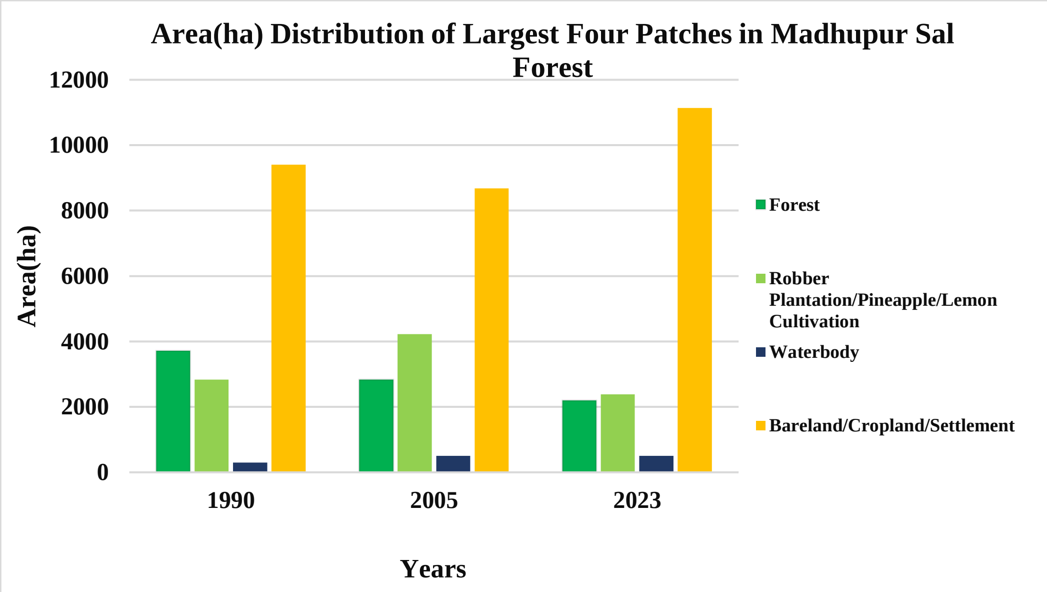

Figure 4. Distribution of largest four paths in Madhupur Sal Forest

3.1. Socio-Demographic Profile Analysis of Arankhola Zone

The survey method is a practical study, where public opinion, observation and calculation methods are mainly used. According to the survey, 63% of respondents were men and 37% were women. The study's results reveals that 32% of the respondents were illiterate. Day labor made up the majority of the respondents' occupations, according to the survey (33%).

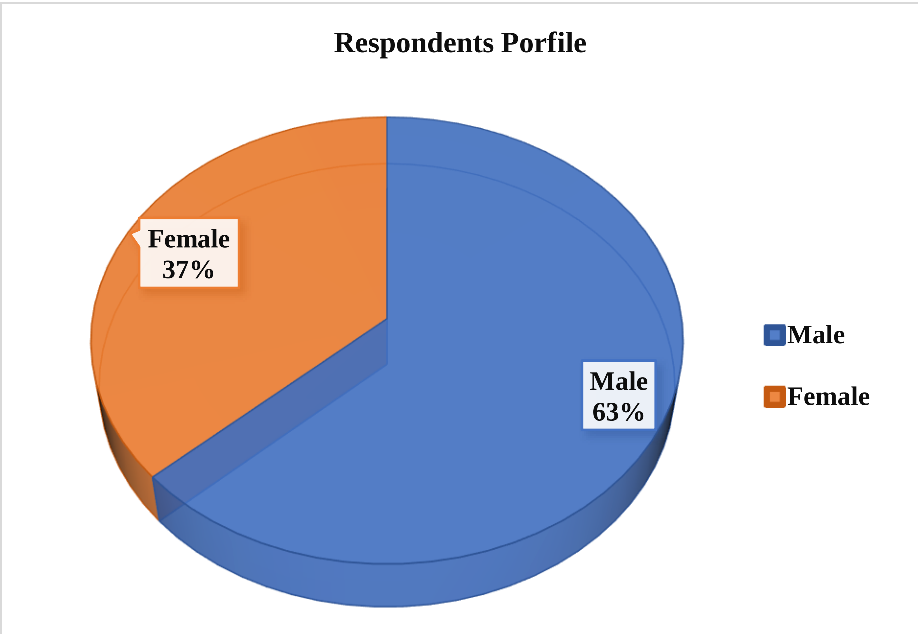

Figure 5. Respondents' percentage

3.2. Causes of Degradation of Madhupur Sal Forest

3.2.1. Agriculture Activities

According to a study conducted on the Madhupur Sal Forest, agricultural activities, particularly cash crop cultivation, corn production, and other related activities, have been identified as the primary drivers of deforestation in the region. The study found that approximately 57% of the deforestation was attributed to cash crop activities, while fruits production accounted for 30%. The remaining 13% was attributed to various other agricultural activities (Figure 8). Here are some of the key factors contributing to the clearing of the forest for agricultural purposes: Expansion of Agricultural Land, Shifting Cultivation, Commercial Agriculture, Illegal Logging, Population Pressure, Lack of Awareness and Enforcement.

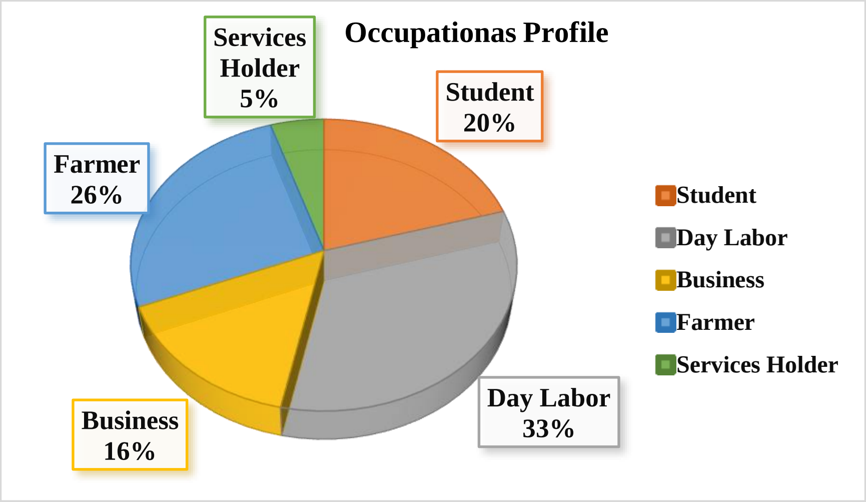

Figure 6. Occupations profile of the respondents

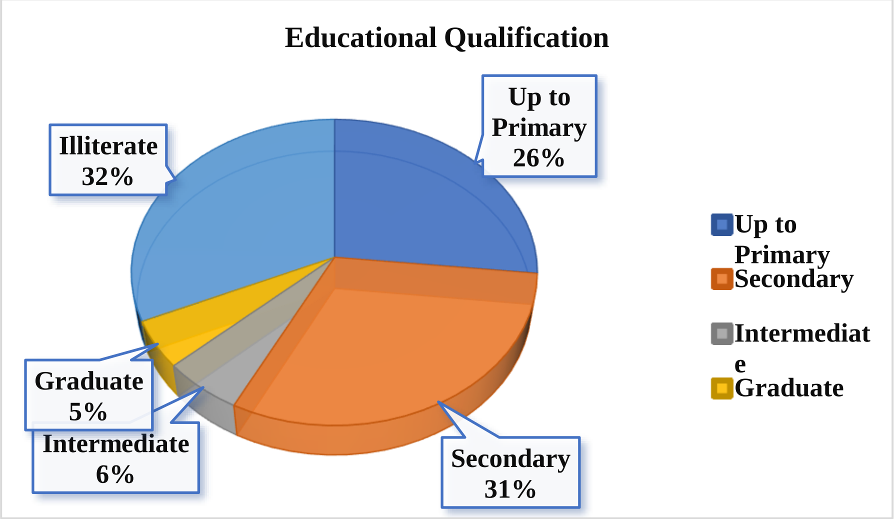

Figure 7. Educational qualification of the respondents

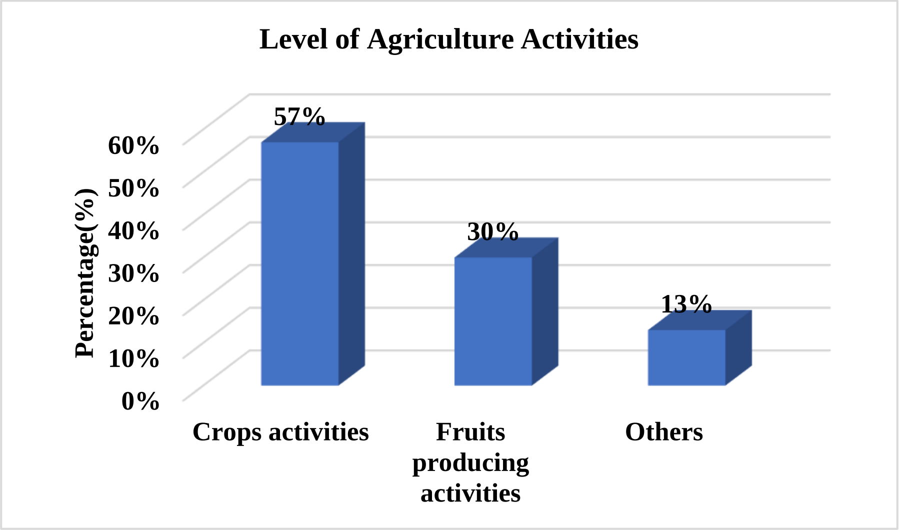

Figure 8. Show that agriculture activities

3.2.2. Wood Collection for Development Activities

According to the study, the majority of the wood collected from the forest is utilized for development purposes. The findings indicate that the Shaw mill engagements 57% of the wood for their development activities, while the Brick field utilizes 26% of the wood. The remaining 17% is allocated to various other uses in (Figure 9).

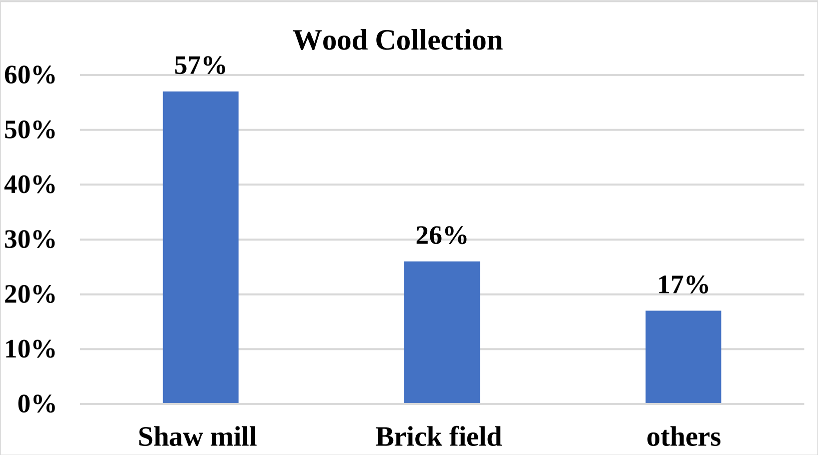

Figure 9. Wood collection for development activities (daily)

3.2.3. Wood Collection for Cooking Purpose

Figure 10 the study exposes that a majority of the respondents (47%) use 6-10 kg of wood for their daily cooking needs. Following this, 35% of the respondents specified using 1-5 kg of wood, while 18% indicated using 11-15 kg of wood collected from the existing forest for their cooking purposes. If wood collection is not done sustainably, it can lead to overexploitation of the forest resources. Excessive cutting of trees for fuelwood can deplete the forest cover, disrupt the ecosystem, and hinder the forest's ability to regenerate.

Reliance on the Madhupur Sal Forest for fuelwood is often driven by the lack of alternative energy sources for cooking in nearby communities. However, this dependence on the forest for wood can contribute to its degradation, potentially affecting the availability of fuelwood in the long run and impacting the livelihoods of local communities.

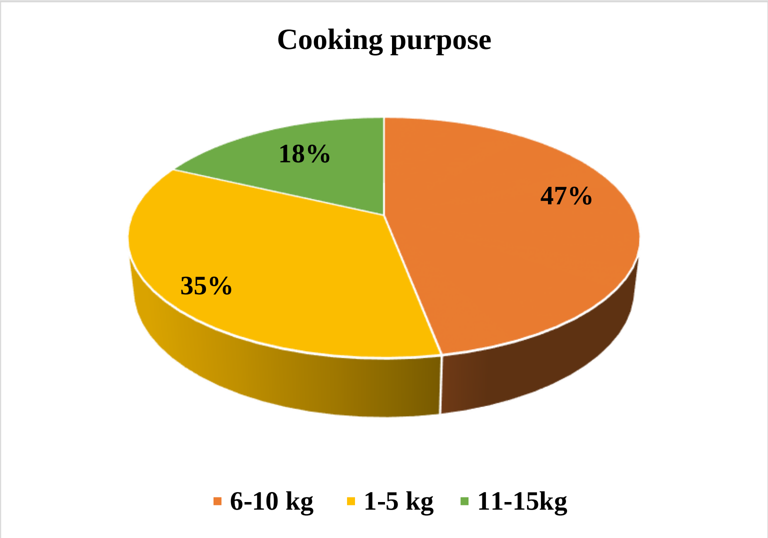

Figure 10. Wood collection for cooking purpose (daily)

3.2.4. People's Livelihood Depends on the Forest

The forest serves as the primary source of livelihood for the majority of the impoverished individuals residing in the surrounding forest area. These individuals rely on the forest for various resources that sustain their daily lives. They engage in activities such as collecting honey, gathering leaves, and collecting tree branches for cooking purposes. Additionally, in order to meet their immediate financial needs, some individuals resort to cutting down trees within the forest. Deforestation is primarily driven by factors such as economic underdevelopment, inadequate forest policies, and other related influences. A study revealed that commercial logging is the leading cause of deforestation, accounting for 40% of the total deforestation. Agricultural expansion (30%) and the presence of sawmills and brickfields in the neighboring forest areas contribute to around 17% of deforestation. Cattle ranging activities also play a significant role, accounting for approximately 13% of deforestation. (Figure 11).

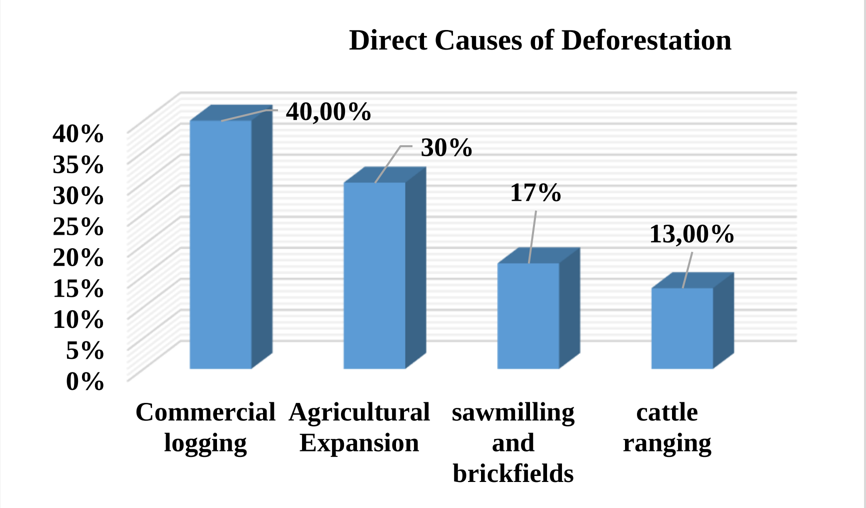

Figure 11. **Direct causes of deforestation in Madhupur Sal Forest**

3.2.5. Construction and Transportation

As our country is become developed in recent years, construction and transportation are necessary for maintaining the condition of the developing countries. For this, roads and various types of institutions are built here and there in the forest area. As a result, the people of that area are being benefited. But when people get benefitted, they also make some problems to the environment. Birds and animal species in the particular area are being migrated themselves by finding a better location. They are bound to migrate themselves because of noise and also by losing their shelter. When they migrate themselves, the ecosystem of the forest area is changed and it makes a negative impact on the people as well as the environment.

3.2.6. Cattle Ranching in the Forest Area

According to a study, cattle ranching was identified as a significant contributor to deforestation in forest areas. The study surveyed a majority of respondents (76%) who reported the presence of diverse cattle breeds being raised in these regions. The findings indicated that 86% of respondents considered the cattle involved in ranching to be domestic animals, while 14% believed that wild animals were also utilized. This suggests that the majority of respondents associated cattle ranching with familiar livestock species, but a notable portion mentioned the potential involvement of non-domesticated or exotic animals. The study underscores the role of cattle ranching in forested areas as a leading cause of deforestation and raises concerns about its environmental impact and biodiversity loss.

3.2.7. Effects of Deforestation on the Forest Environment

According to the study, the main effect of deforestation is biodiversity loss in the Sal Forest, followed by threats to indigenous people's livelihood (17.6%), increased greenhouse effect (12.43%), lower ground water levels (6.28%), soil erosion (5.0%), and biodiversity loss (58.69%) (Figure 12). The most catastrophic effect of deforestation is the elimination of numerous plant and animal species, many of which are unknown and whose benefits will go unnoticed. Furthermore, deforestation is responsible for soil deterioration and fertility, floods, exposing land to heat and rain, and displacing indigenous tribes and their traditional way of life.

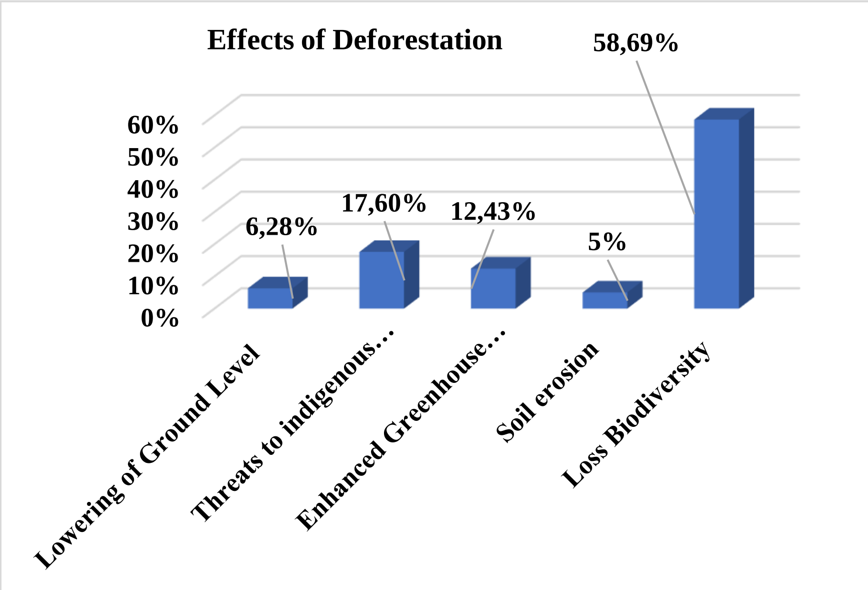

Figure 12. Effects of deforestation on the forest environment

3.2.8. Forest Resources Degradation Pattern

Different Forest species degradation pattern of Madhupur Sal forest is shown in the below table 4. Extraction and Human settlement are most responsible for the degradation of the Plants and medicinal, Birds, Insects, and Animals species. Deforestation, Construction, and Population growth are other responsible reasons for the Plant and medicinal, Bird and Animals species degradation.

Table 4. Forest resources degradation pattern

Species / Reasons	Plants and medicinal plants	Birds	Insects	Fruits	Animals
Extraction	√	√		√	√
Deforestation	√	√			√
Human settlement	√	√	√		√
Construction	√	√			√
Encroachment	√				√
Population growth	√	√			√
Agricultural activities	√		√	√	

When agricultural activities are done in the forest area for a long time and with the increase of human settlement the Insect species are mostly degraded. Extraction and Land erosion are responsible for the

Fruit species degradation because the perspective of other reason fruit species is cultivated inside the forest area. Plants and medicinal species degrade a lot of encroachment activity. From this, it is evident that Plant & medicinal and Animal species are mostly degraded due to several anthropogenic activities. If this degradation process continues, it gives much negative impact on the people as well as on the environment.

3.2.9. Present Status of Flora and Fauna of Madhupur Sal Forest

The Madhupur Sal forest in Bangladesh, which was once a rich habitat for numerous species including medicinal plants, fruit trees, and diverse vegetation, has undergone significant transformation. The forest has been converted into plantations for rubber, fuel-wood, and crops such as banana, pineapple, and papaya. This exploitation of the forest by human activities is leading to a gradual decline in its resources. Many plant and animal species in the Madhupur Sal forest are now endangered or on the brink of extinction, and some have already disappeared entirely.

Table 5. Present status of flora and fauna of the Madhupur Sal forest, Arakhola.

Resource types	Name of the Forest Resources	Status of Forest Resources (√)		
		Good	No Change	Bad
Trees	Sal, Amlochi, Bohera, Gadila, Gutum, Koroi, Hortoki, Chapalish, Ajuli. Shimul, Tendu, Kodom, Bamboo, Asoth, Litchi, Mango, Amlaci, neem, Joyna, Polash, jam, Jarul, Shiduri etc.			√
Animals	Deer, Lizard, Monkey, Fox, Wild Cock, Lemur, Snake, Meso bagh, Wild Boar etc.			√
Birds	Doel, Tuntuni, Seven Sister, Bulbuli, Crain, Shalik, Cuckoo, Dahuk, Dove, Pigeon, Parrot, Pat, Pabui etc.			√
Fruits	Pineapple, Papaya, Banana, Lemon, Amloki etc.	√		
Insects	Butter fly, Catter Filler, Dragon fly, Ant etc.			√
Medicinal plants	Shoti, Kuch, Bashok, Shorpogonda, Ulotkombol, Shotomoli, Arjun, Lozzaboti etc.			√

Source: Madhupur Forest Office.

3.3. Comparison of Deforestation Rate of Last 33 Years

The study conducted by 100 respondents reveals a concerning trend regarding deforestation in the Madhupur Sal forest over the past 33 years. All respondents unanimously agreed that the forest is being cleared for purposes such as development and exotic plant cultivation. Furthermore, they noted that the extent of this clearing has exceeded that of the previous 23 years, indicating an accelerated rate of deforestation. According to Figure 13, the clearing of the sal forest has intensified significantly in recent years. This observation suggests that the rate of deforestation has increased compared to previous periods, potentially indicating a heightened level of human activities causing forest degradation. The study also provides an estimate of the current pace of deforestation, which is reported to be between 1-4% per year. If this rate continues unchecked, the entire Madhupur Sal forest could be completely eradicated within a time frame of 30 to 50 years. This projection highlights the urgency of addressing the issue to prevent the irreversible loss of this valuable ecosystem.

The findings underscore the need for immediate action to mitigate deforestation in the Madhupur Sal forest. Effective measures should be taken to balance development and conservation, ensuring the preservation of this biodiverse habitat. Sustainable land management practices, afforestation efforts, and stricter regulations on forest exploitation could help mitigate the detrimental effects of deforestation and protect the remaining forest cover.

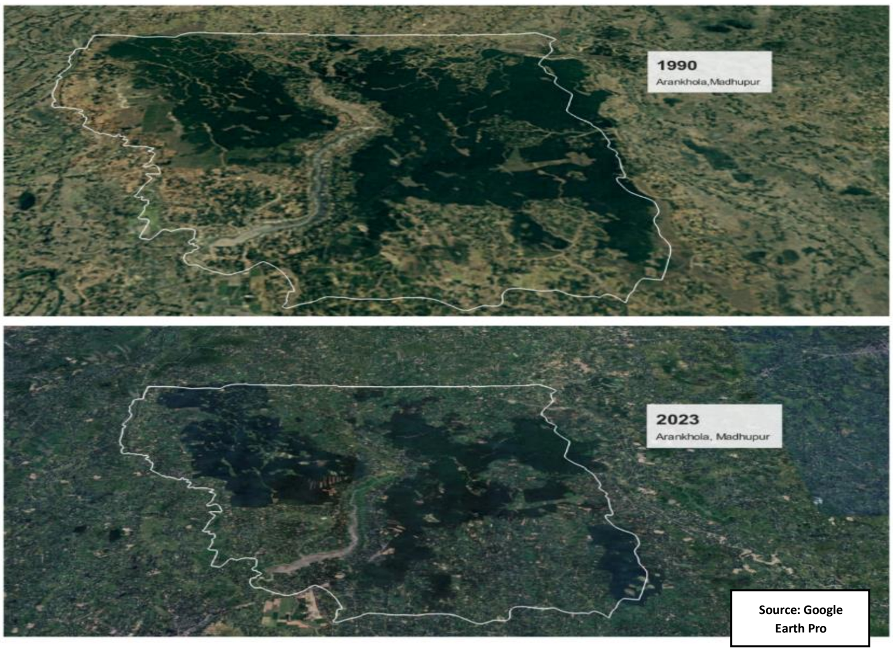

Figure 13. Comparison of deforestation rate of last 33 years.

Conclusions

The Sal forests in Bangladesh are incredibly diverse and valuable ecosystems, but unfortunately, their level of biodiversity remains largely unknown to scientists, politicians, and local communities. As a result, there is limited documentation regarding the extent of diversity within these forests. The forests are under significant threat due to human activities, as people who depend on forest resources for their well-being directly or indirectly disturb the ecosystem. Deforestation is a significant global problem that has detrimental impacts on the environment and ecology of a region. The Madhupur Sal forest in Bangladesh has been facing this same threat for several decades. The disturbances caused by people who depend on or claim to depend on forest resources for their livelihood pose a severe threat to the forest. This leads to various environmental and ecological problems, resulting in the depletion of forest cover and changes in land use patterns in the Madhupur forest Arankhola Zone. Temporal analysis of satellite data has revealed the alarming degradation and reduction of the forest area in Arankhola. This has resulted in the loss of natural habitats for wildlife such as wild pigs, monkeys, deer, lizards, squirrels, pythons, and birds. Consequently, these animals are venturing out of the forest and encroaching on human settlements. The local communities residing in and around the Madhupur Sal forest have limited awareness of the importance of conserving these forests. Forest resources are being exploited without considering sustainable practices. It is crucial to raise awareness among the local population about the need for nature conservation and involve them in forest protection efforts. For severely disturbed areas, forest management should focus on community-based forestry programs, engaging local people in activities related to forest management. Afforestation practices using the same species as the surrounding areas could be implemented in less disturbed regions under the supervision of the forest department. These measures would help control the extinction of rare forest species and restore the Madhupur Sal forest for future generations. It is essential for the relevant authorities to take necessary measures to protect the valuable flora and fauna of the Madhupur Sal forest in Bangladesh. The approach adopted in this study clearly demonstrated the potential of GIS and remote sensing techniques in measuring the change pattern of land use/cover in forest area.

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