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Mapping Ecotourism Potential in Bangladesh: The Integration of an Analytical Hierarchy Algorithm and Geospatial Data

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Abstract: The significance of ecotourism has been increasing due to its potential for biodiversity preservation, economic advancement, and the promotion of sustainability awareness. In this research, geospatial analysis and the Analytical Hierarchy Process (AHP) was employed to identify feasible ecotourism sites in Bangladesh. The study applied Geographical Information System–Remote Sensing (GIS-RS) parameters and weighted overlay techniques for selected ecotourism characteristics, such as natural attractiveness, topographic features, accessibility, proximity to facilities, and community characteristics. The study found that a significant proportion (around 44%) of Bangladesh's land exhibits high potential for ecotourism. Cox's Bazar, Chittagong, and Rangamati are particularly favorable ecotourism locations. However, some difficulties emerge in regions that are not easily reachable, such as mangrove forests, and in densely inhabited localities like Dhaka. The research also identified the ecological costs linked with ecotourism, such as the exhaustion of resources, the fragmentation of habitats, contamination, and the disruption of wildlife. The primary recommendations to address the adverse effects include educating the local populace, enforcing regulatory measures, implementing efficient waste management systems, enforcing a stringent code of conduct, providing economic incentives to the local communities, and addressing the issue of food security. The cartographically delineated potential zones have the potential to function as a navigational instrument for global travelers and facilitate the decision-making process of policymakers in the realm of sustainable land resource management in Bangladesh. This study enhances the understanding of the potential of ecotourism and offers valuable insights for advancing responsible and sustainable tourism practices within the nation.

Keywords: ecotourism; AHP; GIS; economy; Bangladesh

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1. Introduction

Ecotourism is a type of tourism that promotes environmental principles by focusing on visiting and exploring natural regions [1]. The range of ecotourism involves components based on the natural world, education, environmental preservation, economics, society and culture, and sustainable management [2]. It is primarily focused on seeing and learning about nature, its terrain, plants, wildlife, and their habitats, as well as locally produced artifacts [3]. It also aims to generate income from natural attractions, promote support for local people and protected regions, and provide tourists with enriching and educational experiences [4,5]. Ecotourism, or sustainable tourism, is rapidly being recognized as a method for promoting global biodiversity and forest protection [6]. It is also a well-known alternative tourism strategy that can help achieve the goal of sustainable tourist development [7]. Due to its significant potential for income generation, ecotourism has prompted several nations to spend money on this industry [8]. Additionally, as it promises to achieve environmental conservation and economic growth, "ecotourism" is one of the most quickly expanding sustainable land use concepts [9].

As it involves various factors and associated criteria, providing a definition of "ecotourism" is quite difficult. The topography of a possible scenic area, a landscape, or a topographic tourist destination is what tourists find most alluring. Elevation, slope, aspect, and surface area accessibility should therefore be considered when choosing a site for the construction of the tourism industry [10]. Generally, tourists choose to travel to places that are accessible and have good transportation systems [7]. Ensuring the availability of hotels, health facilities, and growth centers is a significant part of developing ecotourism [8,11], as tourists prefer places which are nearer such facilities. Natural attractiveness consists of proximity to forests, vegetation distribution, waterbody distribution, and wetland proximity. Being essential for fostering ecotourism, forests, natural assets, and protected areas preserve and showcase the beauty of nature [10]. Vegetation and plant diversity increases diversity in wildlife and natural resources, attracting tourists and giving scope for the development of ecotourism [7]. Water availability and wetlands are important for ecotourism, as these have natural attractions for tourists [12]. Proximity to settlements and settlement size are important factors in ecotourism, as people might harm conservation by using a protected area's resources in an unsustainable and illegal manner [13].

Compared to tourism, ecotourism has barely any negative impact on natural resources and the environment. Preservation and natural resource sustainability are greatly aided by ecotourism [10]. By promoting forest regeneration, particularly in rural contexts, ecotourism can be combined with conservation measures, such as protected areas, payment for ecosystem services (PESs), and monitoring/enforcement [14]. Ecotourism helps to conserve animals and protected places by diversifying incomes, encouraging environmental understanding and ethics, and enhancing resource management [15]. Ecotourism provides income while concurrently supporting activities for the protection and management of biodiversity, allowing for the integration of environmental wellness and economic growth [16,17]. Between 2009 and 2019, the actual increase in international tourist receipts (54%) outpaced the growth of the global GDP (44%), generating USD 1481 billion in total international tourism receipts alone [18]. The tourism business is now one of the fastest-growing sectors in the service economy. Tourism also plays a vital role in achieving the global Sustainable Development Goals (SDGs) [19].

In recent times, there has been a growing interest in employing Geographic Information System (GIS) and Remote Sensing (RS) techniques due to their ease of implementation, cost-effectiveness, and widespread availability [20]. As part of a creative approach to Multi-Criteria Decision Making (MCDM) integration in the GIS context, RS and GIS are indispensable nowadays for obtaining, evaluating, scrutinizing, and organizing spatial data [10]. The standard approach for dealing with the complexity of multiple parameters is the combination of GIS, RS, and MCDM [21,22]. There are several Multi-Criteria Decision Analysis (MCDA) approaches, the most effective and extensively utilized of which is the AHP [7]. The AHP procedure shows the comparability of each theme based on its relative value for classifying prospective zones [23]. GIS has been used by many researchers worldwide for potential ecotourism mapping because of its capability to accumulate, stock, repossess, organize, demonstrate, and examine geographical data. The AHP and GIS are used in combination to offer criteria and class weights for the efficient identification of ecotourism-suitable zones [7]. Mapping the possibilities for ecotourism using a GIS is both time- and money-efficient [24–27].

Five mentionable variables, namely, wildlife, ecological value, ecotourism appeal, environmental resiliency, and ecotourism diversity, have been acknowledged as factors relevant to the identification of potential ecotourism locations using GIS by Kumari et al.

(2010) [26]. Bunruamkaew (2011) used the AHP and GIS to identify ecotourism sites in Surat Thani Province, Thailand, based on nine themes from five criteria: landscape and naturalness, wildlife, geography, accessibility, and community features [25]. Mahdivi et al. (2014) used an AHP to evaluate site suitability for ecotourism utilizing fourteen themes from five primary parameters: climate, topography, geopedological, environmental, and socioeconomic aspects [24]. Ahmadi et al. (2015) mapped the ecotourism destinations in Iran's Ilam Province using GIS and the AHP [8]. Rafa et al. (2021) used the Normalized Difference Vegetation Index (NDVI) analysis of the Sitakunda Botanical Garden and Eco Park (SBGE) as an example to demonstrate the possibility of ecotourism in forest preservation methods in Bangladesh [6]. GIS has been utilized in Bangladesh to recommend ecotourism destinations in Sundarbans [28] and Cox's Bazar [27] also. The literature suggests that ecotourism programs like Chitwan National Park in Nepal [29], Belize's baboon sanctuary [30], Peru's ecotourism parks [31], and Mexico's Biosphere Reserve [32] help to preserve forests.

Particularly in developing countries with great biodiversity hotspots, ecotourism may be a crucial instrument for sustainable development [33–35]. Bangladesh, a developing nation in South Asia, has the potential to become a major ecotourism destination since it is home to several prominent natural places, such as the Sundarbans and Cox's Bazar, where there are not only breathtaking forests teeming with wildlife, rivers, waterfalls, and mountainous terrain but also several culturally significant sites [6]. Bangladesh's ecotourism sector is now governed by several laws and regulations, including the National Tourism Policy 2010 and the Ecotourism Development and Management Plan 2004 [36]. However, ecotourism is not effectively operationalized in Bangladesh, despite the internationally compatible guidelines provided by the aforementioned laws and acts and the Bangladesh Forest Department's (BFD) current plans to enhance and develop protected areas and ecological parks [6]. In addition, Bangladesh, a country in economic transition, is rapidly urbanizing [6], and, in the future, the built-up area will increase greatly [37]. The environmental biodiversity crisis will worsen in the following decades due to human population expansion and economic development [38]. Due to the growth of tourism, there are now more challenges to wildlife and a potential risk to sustainability and environmental protections [39]. Urbanization may not always result in widespread vegetation deterioration if vegetation restoration initiatives are coordinated with the rising demand for a high-quality urban environment [40]. Ecotourism can help preserve forests if it is combined with conservation practices, such as protected areas, payment for ecosystem services, monitoring, and enforcement [14]. Additionally, from an economic perspective, from 2015 to 2019, Bangladesh welcomed an average of 227,000 international tourists per year, with the highest number of 323,000 visiting in 2019. On average, each tourist spent USD 1277 during their visit [41]. So, tourism is an economically profitable sector for Bangladesh and the illustration of highly potential ecotourism spots using multi-criteria might attract more international sightseers and contribute to the overall economy of the country. Using GIS and the AHP, this study aimed to seek answers to the research question: "Which parts of the country are more suitable for ecotourism?" This research will contribute in the following ways:

- Act as a guiding tool for local policymakers and planners in identifying, planning, conserving, and developing potential ecotourism sites;
- Indicate suitable locations for tourists who are willing to make a nature-based trip.

2. Materials and Methods

2.1. Study Area

Tourists are drawn to the climate, wildlife, and overall beauty of several Asian countries, including India, Sri Lanka, Singapore, Maldives, Thailand, Malaysia, and Nepal [42]. Bangladesh, as the gateway to Southeast Asia, is connected to the rest of the globe by air, sea, and land. It has considerable geographical advantages, which undoubtedly contribute to the country's status as an ideal ecotourism destination [43]. This part of the Asian region holds a high potential for ecotourism [44]. Over the last few years, Bangladesh has made considerable strides toward establishing itself as an ecotourism destination. In comparison to many other countries that aim to promote ecotourism, it has a diverse collection of species [36]. The country lies between latitudes 20°34′ and 26°38′ North and longitudes 88°01′ and 92°41′ East [37]. Bangladesh has the world's largest mangrove forest environment, the world's longest sea beach, hilly areas (Bandarban, Khagrachari, and Rangamati), and a vast marine world, all of which can be readily promoted to attract ecotourism visitors [45].

Bangladesh (Figure 1) is an alluvial plain covering the lowlands of the Indo-Gangetic Basin, which is terminated by the Ganges and the Brahmaputra rivers. The Himalayan mountain range contains tertiary hill zones. Two hilly areas are visible: the Chittagong Hills in the Southeast, low hills in the Northeast, and highlands with a moderate altitude in the North and Northwest. The Sundarbans, a region with marshes and wetlands, is in Southwest Bangladesh. The Royal Bengal Tiger, leopard, Asian elephant, monkey, langur, gibbon (the only ape in the subcontinent), otter, and mongoose can all be found in this country. There are more than 600 different bird species, including the magnificent paradise flycatcher and kingfishers and fishing eagles [46]. India borders Bangladesh in the North and West, and the Bay of Bengal lies along Bangladesh's southern border. East of Bangladesh are Myanmar and India. The nation's total area is 147,570 km^2. The territorial sea is 200 nautical miles long [37].

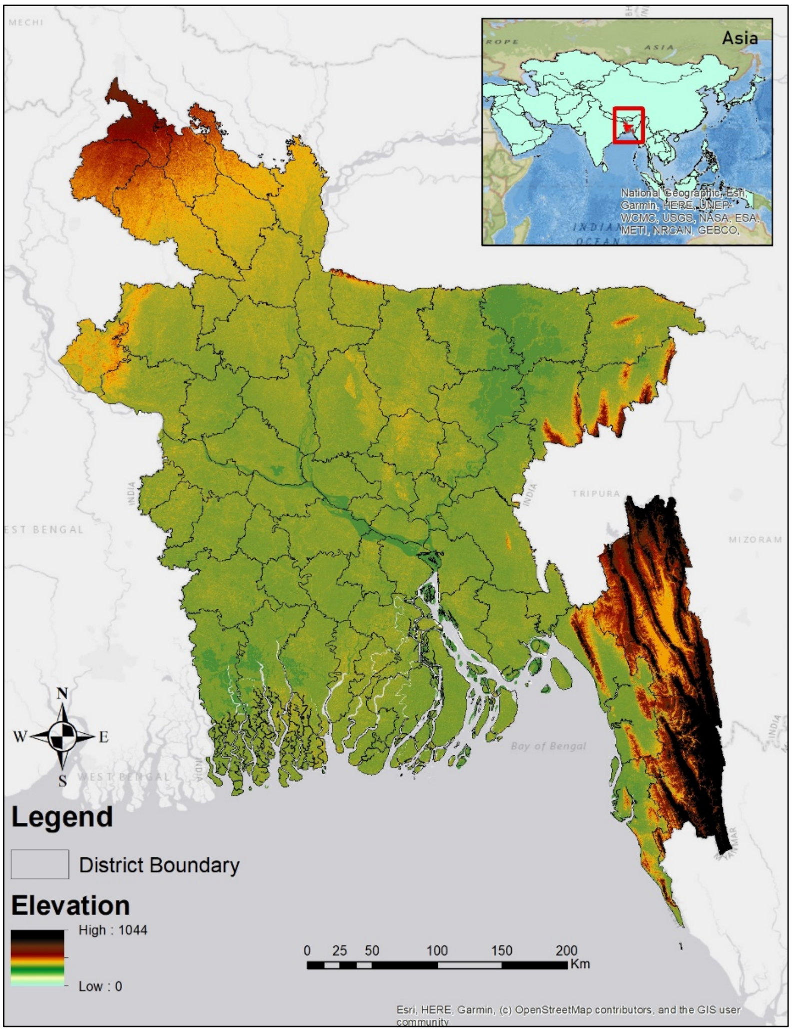


Figure 1. Study area: Bangladesh (Flat regions are most common.); The top corner box showed the inset map of Bangladesh on the Asia map.

2.2. Data Collection

The research is based on digital information technologies, such as RS and GIS. Data from both spatial and non-spatial sources were utilized to assess the area's prospective ecotourism site suitability and were obtained from both secondary and primary data sources. To identify criteria and sub-criteria for ecotourism mapping in Bangladesh, interviews in the form of questionnaire surveys with specialists, such as ecotourism experts, environmentalists, conservationists, and planners, and studies in the current literature were used [47]. The research proposal was reviewed and endorsed and ethical clearance was given by the university's local committee (DMC); the reference number is KUET/URP/22/05/125/(2). Spatial datasets were mostly obtained from various organizations and authorities (Table 1). To derive vegetation and waterbody data, Landsat-8 satellite imagery with a spatial resolution of 30 m was used. And to generate elevation, slope, aspect, and drainage data, the US Geological Survey (USGS) Earth Explorer and the Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) project with a spatial resolution of 30 m were used [7]. The SRTM is a NASA, National Geospatial-Intelligence Agency (NGA), and German Aerospace Center (DLR) initiative [48]. The mission's goal was to collect a DEM of all land between latitudes 60 N and 56 S, covering around 80% of the Earth's land surface [49]. Owing to its uniform resolution and precision over the majority of the Earth's surface, the SRTM DEM has been employed in a variety of study domains, yielding numerous noteworthy scientific results [48]. Data on existing forests, wetlands, roads, health centers, growth centers, hotels, tourist attractions, and settlements were acquired from the local government engineering department in Bangladesh. The settlement size data were collected from the Bangladesh Bureau of Statistics. As OpenStreetMap (OSM) is widely available and provides free geographic data on the world's road network, railway network, and airports [50], it was used in this investigation.

Table 1. Sources of spatial datasets.

Elements	Source	Year
Forests	Local Government Engineering Department, Bangladesh	2017
Vegetation	Landsat 8 Satellite Imagery	2022
Waterbodies	Landsat 8 Satellite Imagery	2022
Wetlands	Local Government Engineering Department, Bangladesh	2018
Elevation	SRTM DEM	2022
Slope	SRTM DEM	2022
Aspect	SRTM DEM	2022
Drainage	SRTM DEM	2022
Roads	Open Street Map	2022
Railway	Open Street Map	2022
Airports	Open Street Map	2022
Tourist Spots	Local Government Engineering Department, Bangladesh	2021
Hotels	Local Government Engineering Department, Bangladesh	2021
Growth Centers	Local Government Engineering Department, Bangladesh	2021
Health Centers	Local Government Engineering Department, Bangladesh	2018
Settlements	Local Government Engineering Department, Bangladesh	2018
Settlement Size	Bangladesh Bureau of Statistics	2022

The downscaling technique was used for raster data to provide homogeneity at different scales, whereas standard spatial resolution was used for data conversion from vector to raster. The ESRI ArcGIS 10.7 program was adopted for weighted overlay and geoprocessing for slope, aspect (using DEM), and vector operations (raster transition and buffering, etc.) [10].

2.3. Methodology

There are several MCDM methods. The Ordinal Priority Approach (OPA) is a relatively new method, and few research publications have used it so far [51]. Ataei et al. (2020)

proposed the OPA to address the shortcomings of standard multi-attribute decision-making strategies [52]. Mahmoudi et al. (2022) also presented a hybrid DEA-OPA model [53]. Although the classic OPA successfully dealt with the current disadvantages of MADM (Multiple Attribute Decision Making), it failed to include circumstances in which experts are unsure about their opinions. To address these shortcomings, a grey ordinal priority strategy has been proposed [54]. Since fuzzy sets play a vital role in many industries, a fuzzy OPA has been proposed for picking the resilient provider and reaching a decision in the post-COVID-19 era [55].

The OPA represents a linear programming-based technique introduced by Ataei et al. (2020) to assist decision makers in solving complicated situations, including preference relationships [52]. However, its reliance on ordinal information precludes it from dealing with linguistic information, rendering it incapable of dealing with problems characterized by impression or fuzziness. The OPA for Fuzzy Linguistic Information (OPA-F) has been extended to include linguistic information in problems [55]. In addition, the OPA method cannot examine several ranks throughout the decision-making process, and adopting an uncertainty approach seems strong [54]. Grey Systems Theory (GST) allows for uncertainty without requiring a large sample size or providing a membership function [54].

The DEA-OPA model can take into account expert judgments as well as quantitative data. It is worth noting that specialists do not need to supply incorrect information when they lack appropriate understanding. In fact, the DEA-OPA can deal with partial data if there is a shortage of information. According to experts, DEA-OPA can only tackle problems with incomplete data. Sometimes, the DEA's input data are also incomplete, which it cannot handle [53]. Thus, every MADM approach has its own limitations.

The AHP was used in this research as it has a well-established base in the research literature and has been frequently employed in ecotourism potential mapping. Its popularity and widespread use in similar research provide a foundation for comparison and benchmarking, allowing for better comparison and consistency with earlier work. The novelty of using the AHP in this research lies in the integration and consideration of the weighted value of each AHP criterion with the weighted overlay of the GIS analysis, as shown in Figure 2. This approach not only facilitates the identification of the most important and significant elements of ecotourism but also enables the spatial distribution and suitability mapping of these areas at the national level.

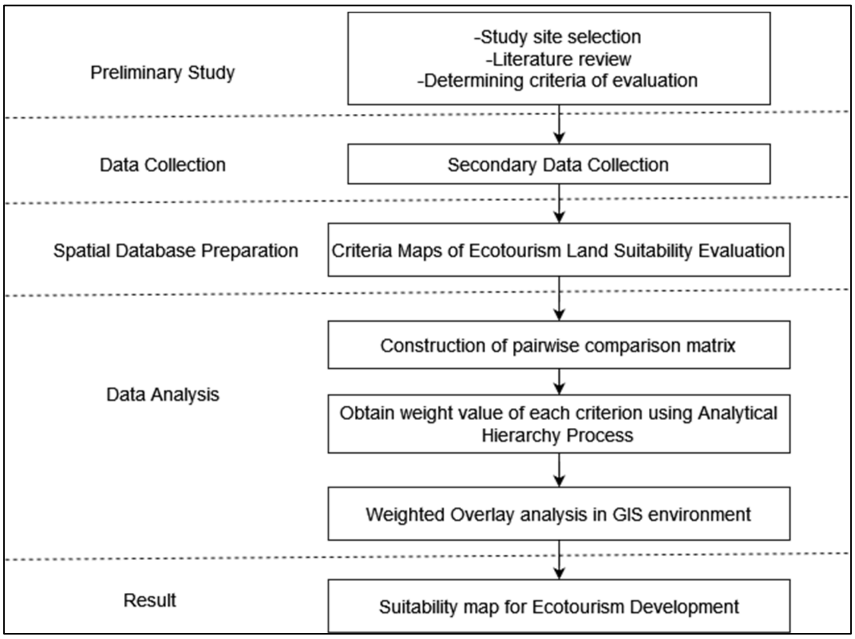


Figure 2. Methodological framework.

The AHP is a decision-making method that develops criteria and options and analyzes them in the most effective way to attain the goal. Both rating and comparison approaches are included in the AHP [56]. The AHP method, when combined with GIS applications, allows for the most appropriate and maximum benefit in accordance with certain parameters by comparing different options in the decision-making process in the most suitable manner [56].

The identification of suitable ecotourism sites consists primarily of five steps: the creation of a geographic database, the use of the AHP to normalize the value of each category, ecotourism zone production, model authentication, and the evaluation of the results [57]. However, as per [27], the evaluation of site appropriateness for ecotourism with the AHP and GIS has seven steps, which we followed in this study: pairwise comparison, constructing comparison matrices, matrix value standardization, verifying the consistency ratio and determining the respective weight values, converting weight values into a spatial database, and creating a composite map by an overlaying operation. Figure 2 shows the detailed methodological framework for this study.

2.4. Variable Descriptions

Elevation, slope, aspect, waterbodies, vegetation, surface water accessibility, settlement size, and proximity to roads, railways, airports, protected areas, hotels, growth centers, health facilities, and tourist destinations and settlements were all considered when identifying ecotourism prospective sites. These sub-criteria and the suitability ranges were chosen based on a literature review and interviews with environmentalists, tourism experts, and planners. The sub-criteria are grouped under 5 criteria: Natural Attractiveness, Topographic Characteristics, Accessibility, Proximity to Facilities, and Community Characteristics, as shown in Table 2.

Table 2. Criteria and sub-criteria used in the study.

Criteria	Sub-Criteria	Sources	Unit	Criteria Suitability Rating				
				Very High	**High**	**Moderate**	**Low**	**Very Low**
Natural Attractiveness	Proximity to Forests	[10]	km	<5	5~10	10~15	15~20	>20
	Vegetation Distribution	[7,10]		Very High	High	Moderate	Low	Very Low
	Waterbody Distribution	[58]		Very High	High	Moderate	Low	Very Low
	Wetland Proximity	[12]	m	<500	500~2000	2000~4000	4000~6000	>6000
Topographic Characteristics	Elevation	[8,59]	m	>100	50~100	25~50	0~25	<0
	Slope	[25,39]	Degree	<5	5~15	15~25	25~35	>35
	Aspect	[24,60]		Flat	East	South	North	West
	Surface Water Accessibility	[7,59,60]	m	<700	700~1400	1400~2100	2100~2800	>2800
Accessibility	Distance from Roads	[7,24,60]	m	<500	500~1000	1000~1500	1500~2000	>2000
	Distance from Railway	[61]	km	<10	10~20	20~30	30~40	>40
	Distance from Airports	[62]	km	<25	25~50	50~75	75~100	>1000
Proximity to Facilities	Proximity to Hotels	[8]	km	<5	5~10	10~15	15~20	>20
	Proximity to Growth Centers	[11]	km	<5	5~10	10~15	15~20	>20
	Proximity to Health Centers	[11]	km	<5	5~10	10~15	15~20	>20
Community Characteristics	Proximity to Settlements	[10,24,60]	m	<1000	1000~2000	2000~3000	3000~4000	>4000
	Settlement Size	[27]	Population per km^2		>500	500~1000	1000~5000	5000~10,000

2.4.1. Natural Attractiveness

(a) Proximity to Forests: As forests, natural assets, and protected areas preserve and showcase the beauty of nature, they are fundamental for fostering ecotourism [10]. The map of proximity to forests was created using the Euclidean Distance geoprocessing tool. According to the analysis, the map was divided into five distinct groups based on the distance from the forest region. The groups and their corresponding distances are as follows: very high (less than 5 km), high (5 to 10 km), moderate (10 to 15 km), low (15 to 20 km), and very low (more than 20 km).

(b) Vegetation Distribution: The NDVI was used to classify the vegetation coverage of the study area. Ecotourism and vegetation density have a beneficial association [7,10]. Vegetation and plant diversity increases diversity in wildlife and natural resources, attracting tourists and giving large scope for the development of ecotourism [7]. Fourteen sets of satellite images were downloaded from Landsat 8–9 OLI/TIRS. The following equation was used to determine the NDVI of the study area in ArcMap 10.7.

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

For Landsat 8, NIR represents the near-infrared band 5 (0.845–0.885 µm) and RED the corresponding band 4 (0.630–0.680 µm). NDVI values are straightforward visual indicators that may be used to examine remotely sensed data and determine if there is living, green vegetation present [63]. The NDVI ranges from -1.0 to $+1.0$, a positive value indicating dense and healthy vegetation. The research identified five unique vegetation distribution groups based on NDVI values, with greater values indicating a region with a greater potential for the development of ecotourism.

(c) Waterbody Distribution: As water availability boosts the variety of species and natural resources, which helps to attract tourists, an open body of water can be made to "stand out" against the ground and vegetation by using the Normalized Difference Water Index (NDWI) to emphasize it in a satellite picture that was chosen. The following equation was used to determine the NDWI of the study area using ArcMap10.7.

$$\text{NDWI} = \frac{\text{GREEN} - \text{SWIR}}{\text{GREEN} + \text{SWIR}}$$

The NDWI ranges from -1 to 1. Water bodies often have NDWI values greater than 0.4. Vegetation has substantially lower values than water bodies, making it simple to discern between the two [58]. To classify the distribution of waterbodies, NDWI values were divided into five groups, with higher values indicating the presence of water features.

(d) Wetland Proximity: Wetlands are important for ecotourism as they have natural attractions for tourists [12]. Based on distance from wetlands, the area was divided into 5 suitability zones: very high (less than 500 m), high (500–2000 m), moderate (2000–4000 m), low (4000–6000), and very low (more than 6000 m).

2.4.2. Topographic Characteristics

According to earlier research, the topography of a possible scenic area, a landscape, or a topographic tourist destination is what tourists find most alluring. Elevation, slope, aspect, and drainage proximity should therefore be considered when choosing a site to construct the tourism industry [10].

(a) Elevation: The height of a location above or below Mean Sea Level(MSL) and the various reliefs in a region are both described by elevation [7]. Elevation is essential for establishing an ecotourism location [8]. To assess elevation in the study region, the DEM created five elevation groups: less than 0 m, 0–25 m, 25–50 m, 50–100 m, and beyond 100 m from the mean sea level. Based on these elevation groups, the study area was classified into five suitability zones: very high, high, moderate, low, and very low, respectively.

(b) Slope: The flatness and steepness of a region is determined by the slope estimation provided by the DEM. This criterion component in the feasibility study for ecotourism is crucial due to the site's complexity in terms of slope and distribution [10]. Due to their accessibility, lower slopes are more suitable for the expansion of ecotourism [39].

The entire area was divided into five slope classifications for ecotourism suitability after computing the slope from the DEM: very highly suitable (0–5°), very suitable (5–15°), moderately suitable (15–25°), less suitable (25–35°), and unsuitable (above 35°) [25].

(c) Aspect: Aspect influences the amount of sunshine received and the formation of microclimates. North-facing slopes are typically steeper, have inferior flora, are more prone to erosion, and are unsuitable for long-term tourist activities due to lower temperatures. South-facing areas have bigger surface areas, descent slopes, ideal microclimates, and more diverse flora and fauna compared with north-oriented areas [59,60].

After computing the aspect from the DEM, it was categorized into five suitability classes: very high (Flat), high (East), moderate (South), low (North), and very low (West).

(d) Surface Water Accessibility: One of the most essential components in establishing an ecotourism site is surface water accessibility. When choosing an ecotourism destination, more importance is given to the area that is closer to the drainage system [7].

After finding the drainage network from the DEM, a proximity analysis was performed to determine the best area to establish an ecotourism site based on the distance from the drainage network. Five appropriate zones were established for the area: very high (less than 700 m), high (700–1400 m), moderate (1400–2100 m), low (2100–2800 m), and very low (more than 2800 m).

2.4.3. Accessibility

(a) Distance from Roads: Generally, tourists choose to travel to places that are accessible and have good transportation systems [7]. Five buffer zones were created from the current road network, each measuring less than 10 km, 10 to 20 km, 20 to 30 km, 30 to 40 km, and more than 40 km; extremely high, high, moderate, low, and extremely low suitability zones were used to identify these areas.
(b) Distance from Railway: The propensity to travel by rail is influenced by the level and quality of accessibility. As tourists are attracted to good transportation systems, rail transport is also very important [61]. The study utilized buffer distances of 10 km, 10–20 km, 20–30 km, 30–40 km, and over 40 km to establish five suitability zones for buffer areas around railway stations: very high, high, moderate, low, and very low.
(c) Distance from Airport: Air transport and airport accessibility have a significant impact on a country's tourism [62]. As tourists are drawn to a variety of transit options, air transportation is also quite vital [61]. In this study, airport accessibility zones were defined as very high, high, moderate, low, and very low using buffer zones of 25, 25, 50, 75, 100, and greater than 100 km.

2.4.4. Proximity to Facilities

Euclidean distances were employed for proximity analysis of hotels, growth centers, and health centers depending on the degree of benefit or harm these parameters had on ecotourism suitability.

(a) Proximity to Hotels: The availability of hotels is a prominent factor in embryonic ecotourism [8]. Areas that are nearer to hotels are more suitable for ecotourism. The study conducted a proximity analysis using GIS and divided the area into five suitability zones based on distance from hotels: very high (less than 5 km), high (5–10 km), moderate (10–15 km), low (15–20 km), and very low (greater than 20 km).
(b) Proximity to Health Centers: Distance from the nearest health facility is also important for ecotourism [11]. The less the distance from health facilities, the more the area is suitable for ecotourism. Based on distance from medical facilities, the area was categorized into five suitability zones: very high (less than 5 km), high (5–10 km), moderate (10–15 km), low (15–20 km), and very low (more than 20 km).
(c) Proximity to Growth Centers: Physical and cultural aspects could be included in geo-ecotourism zoning as well, as the anticipated expansion of growth centers for

tourism is high [11]. The study area was categorized into five suitability zones based on their proximity to the growth center: very high (less than 5 km), high (5–10 km), moderate (10–15 km), low (15–20 km), and very low (greater than 20 km).

2.4.5. Community Characteristics

Living close to protected areas puts conservation at risk because nearby residents might exploit resources in an unsustainable or illegal way [13].

(a) Proximity to Settlements: Highly populated locations were chosen for the construction of buffer zones based on their accessibility to nearby places because of the impact that developed populations have on natural surroundings [10]. The entire region was divided into five groups based on distance from settlements: less than 1000 m was considered very highly suitable, 1000–2000 m was considered highly suitable, 2000–3000 m was considered moderately suitable, 3000–4000 m was considered less suitable, and beyond 4000 m was considered unsuitable in this regard.

(b) Settlement Size: Settlement size is one of the essential factors when developing a site for ecotourism [27]. The area was divided into four zones based on population density. Areas with fewer than 500 people were considered highly suitable, those with 500–1000 people moderately suitable, those with 5000–10,000 people less suitable, and those with more than 10,000 people unsuitable for ecotourism.

2.5. Ecotourism Suitability Mapping Using the AHP

The AHP was a popular MCDA approach in the field of natural resource and environmental management. The method proposed by Saaty (1987) was used in the AHP for constructing judgment matrices to give weights to the multiple thematic levels of each criterion and sub-criterion and measuring their relative importance [64]. This analysis considered 16 thematic layers of geomorphic, ecological, sociocultural, and infrastructure parameters, including elevation, slope, aspect, waterbodies, vegetation, accessibility to surface water, settlement size, and distance from highways, railroads, airports, protected areas, lodging establishments, growth centers, and tourist destinations.

A pairwise comparison of different thematic layers was performed using Saaty (1987) [64]. Scores on a scale of 1 to 9 showed the relative prominence of each subject, with 1 designating equal relevance and 9 designating great importance [65], and, additionally, a comparison matrix was developed to identify possible ecotourism destinations. Using a structured questionnaire, the authors interviewed seven experts with prior knowledge of tourist activities, involvement in tourism management, and expertise in ecotourism development to determine the key parameters and sub-parameters used in Bangladeshi ecotourism development. Using the consistency ratio criteria, the responses of four of the seven experts who were chosen for the study were appropriate for further examination. For the analysis, a review of the pertinent literature on ecotourism, tourism, and its components were also assessed.

Steps for Calculation Using the AHP Method

The initial step of the AHP involves conducting pairwise comparisons between each criterion. The pairwise comparison step involved comparing each parameter against every other parameter to establish their relative importance.

The research employed a relative importance scale ranging from 1 to 9 (Likert scale) as proposed by Saaty [64,65]. The scale was defined as follows: 1 = Equally Important, 2 = Equally to Moderately Important, 3 = Moderately Important, 4 = Moderately to Strongly Important, 5 = Strongly Important, 6 = Strongly to Very Strongly Important, 7 = Very Strongly Important, 8 = Very Strongly to Extremely Important, 9 = Extremely Important.

The second phase of the AHP is to complete the matrix. The decision maker assigns values to the matrix entries depending on their assessment of the pairwise comparisons.

The third phase involves normalization. The goal of normalization is to be sure that the sum of the values allocated to the selected criterion equals 1. This normalizing method is implemented with the pairwise comparison matrix by dividing each criterion's score from the column by the sum of the associated columns. The resulting normalized numbers represent the weights or priority of the criteria, indicating how important they are in the decision-making process [11].

Calculating the Consistency Ratio (CR) is the final stage in the AHP. The CR is calculated by dividing the Consistency Index (CI) by the Random Consistency Index (RI), which is a value based on the size of the matrix. The CR is used to evaluate the consistency of the decision makers in pairwise comparisons. According to Saaty (1987) [64], if the CR is less than 0.10, the consistency degree is satisfactory. As a result, if it is larger than 0.10, it indicates that there are inconsistencies in the evaluation process, and the AHP model may produce insignificant findings. CR values were calculated for all the sub-criteria and were less than 0.10. The pairwise comparison matrix and the weights of the criteria are shown in Tables 3 and 4. It was shown that the preferences used to produce the comparison matrices were reliable.

Table 3. Pairwise comparison matrix of criteria for ecotourism in Bangladesh.

Criteria	Natural Attractiveness	Topographic Characteristics	Accessibility	Access to Facilities	Community Characteristics
Natural Attractiveness	1	6	3	4	8
Topographic Characteristics	1/6	1	$\frac{1}{4}$	1/3	4
Accessibility	1/3	4	1	3	6
Access to Facilities	1/4	3	1/3	1	5
Community Characteristics	1/8	1/4	1/6	1/5	1

Table 4. Weights of the criteria.

Criteria	Weight
Natural Attractiveness	48
Topographic Characteristics	8
Accessibility	17
Access to Facilities	15
Community Characteristics	12

2.6. Weighted Overlay Analysis

The calculation of the appropriateness index for ecotourism site development, which standardizes and reclassifies the entire criterion layer in accordance with the opinions of experts and professionals as well as the pertinent literature in this area, was the focus of this phase of the study. The AHP was used to compute the weight of each criterion, their consistency was assessed, and they were found to be in the acceptable range according to Saaty (1987) [64]. Using weighted overlay analysis in Arc GIS Modular, the final layer was constructed and categorized among five acceptable suitability zones.

2.7. Validation

Among different methods, the most popular approach for determining the area under the curve (AUC) of a receiver operating characteristic (ROC) curve was used to test if a region is suitable for ecotourism [10,66,67]. The ROC is a graphic representation that depicts the false-positive (Y-axis) and false-negative (X-axis) values for each conceivable threshold value [68]. The AUC numbers range from 0 to 1.0. While a value of 1.0 denotes absolute discrimination, a value of 0 suggests that the model outcomes were less than random [10,69,70].

By dividing ecotourism destinations into test and training datasets, the validity of the model findings was evaluated. Three hundred background spots with a random distribution were produced and they were cross-referenced with ecotourism sites. An error matrix was created using these ecotourism location coordinates and created random points, and it was then validated using observed versus predicted values [10,70].

Additionally, the final map of the indicated ecotourism-suitable sites was confirmed using Google Earth images and fieldwork. A comparison between potential ecotourism destinations and those that exist in the research area was also carried out. In the current investigation, each of the anticipated distribution outputs using background points and the statistical method of the area under the ROC curve were examined [10].

3. Analysis and Results

In this study, Bangladesh was divided into ecotourism suitability zones based on various criteria. Table 5 provides the areal and percentile distribution of the suitability zones across the country.

Table 5. Areal and percentile distribution of the selected criteria and subclasses.

Criteria	Sub-Criteria	Unit	Criteria Suitability Rating				
			Very High	High	Moderate	Low	Very Low
Natural Attractiveness	Proximity to Forests	(Km^2)	48,698	28,038	23,611	19,184	28,038
		(%)	33	19	16	13	19
	Vegetation Distribution	(Km^2)	23,611	73,785	35,417	10,330	4427
		(%)	16	50	24	7	3
	Waterbody Distribution	(Km^2)	2951	8854	23,611	87,066	25,087
		(%)	2	6	16	59	17
	Wetland Proximity	(Km^2)	1476	7379	10,330	14,757	113,629
		(%)	1	5	7	10	77
Topographic Characteristics	Elevation	(Km^2)	7379	7379	13,281	116,580	2951
		(%)	5	5	9	79	2
	Slope	(Km^2)	122,483	19,184	4427	1033	443
		(%)	83	13	3	0.7	0.3
	Aspect	(Km^2)	13,281	35,417	33,941	30,990	33,941
		(%)	9	24	23	21	23
	Surface Water Accessibility	(Km^2)	97,396	-	45,747	2951	1476
		(%)	66	-	31	2	1
Accessibility	Distance from Roads	(Km^2)	60,504	33,941	17,708	8854	26,563
		(%)	41	23	12	6	18
	Distance from Railway	(Km^2)	51,650	39,844	20,660	10,330	25,087
		(%)	35	27	14	7	17
	Distance from Airports	(Km^2)	13,281	36,893	47,222	32,465	17,708
		(%)	9	25	32	22	12

Table 5. *Cont.*

Criteria	Sub-Criteria	Unit	Criteria Suitability Rating				
			Very High	High	Moderate	Low	Very Low
Proximity to Facilities	Proximity to Hotels	(Km^2)	13,281	29,514	28,038	26,563	50,174
		(%)	9	20	19	18	34
	Proximity to Growth Centers	(Km^2)	20,660	50,174	44,271	17,708	14,757
		(%)	14	34	30	12	10
	Proximity to Health Centers	(Km^2)	95,921	36,893	5903	2951	5903
		(%)	65	25	4	2	4
Community Characteristics	Proximity to Settlements	(Km^2)	17,708	42,795	22,136	14,757	50,174
		(%)	12	29	15	10	34
	Settlement Size	(Km^2)	-	22,136	39,844	84,115	1476
		(%)	-	15	27	57	1

3.1. Natural Attractiveness

(a) Proximity to Forests: The analysis identified five distinct ecotourism suitability zones in Bangladesh based on their proximity to forested areas, as shown in Table 5 and Figure 3A. The results show that 33% of the country's territory, covering an area of 48,698 km^2, is categorized as very highly suitable for ecotourism, while 19% of the territory (28,038 km^2) is classified as highly suitable. Moreover, 16% of the territory (23,611 km^2) falls under the moderately suitable zone, and approximately 13% of the territory (19,184 km^2) is classified as having low suitability for ecotourism. Finally, 19% of the territory, covering an area of 28,038 km^2, is designated as a very low suitability zone. Furthermore, the southeastern region of Bangladesh, specifically the Chittagong Hill Tracts, is home to a significant expanse of forest cover, making it a prime destination for ecotourism. The central region boasts dense SAL forests, while the southwestern region is known for its thriving mangrove forests. The forested areas in Bangladesh are distributed in a cluster pattern, featuring diverse forest types, which enhances the potential for ecotourism.

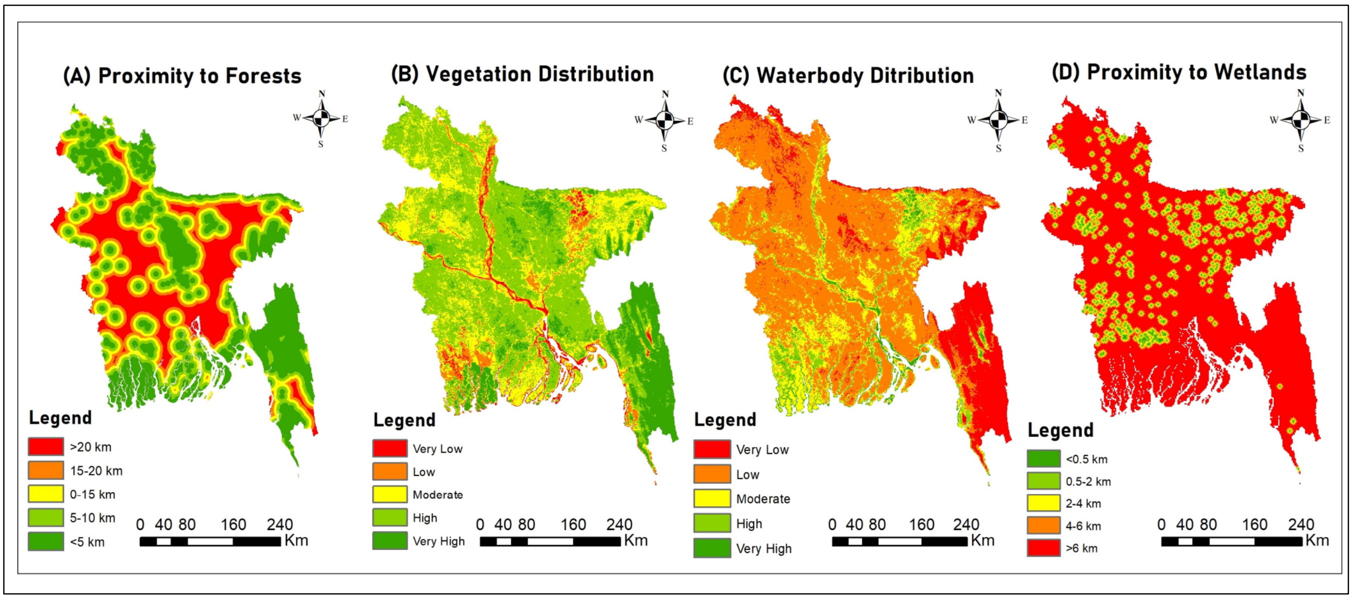


Figure 3. Visual representations of natural attractiveness in ecotourism mapping.

(b) Vegetation Distribution: The research identified five unique vegetation distribution groups: very high, high, moderate, low, and very low suitability zones, and they covered 16%, 50%, 24%, 7%, and 3% of the land, respectively. Specifically, the very high suitability zone covered 23,611 km^2, the high suitability zone covered 73,785 km^2, the moderate suitability zone covered 35,417 km^2, the low suitability zone covered 10,330 km^2, and the very low zone covered about 4427 km^2 of land, as shown in Table 5 and Figure 3B. Notably, the vegetation distribution map highlights the unique environmental conditions present in Bangladesh, with a significant amount of vegetation concentrated in the southeastern region, including the Chittagong Hill Tracts, and the thriving mangrove forest in the southwestern region.

(c) Waterbody Distribution: Five categories—very high, high, moderate, low, and very low—were used to categorize the distribution of waterbodies. These groups cover 2%, 6%, 16%, 59%, and 17% of the total land area, respectively. The very high category covered 2951 km^2 of land, the high category covered 8854 km^2, the moderate type covered 23,611 km^2, the low category covered 87,066 km^2, and the very low category covered 25,087 km^2 of land, as shown in Table 5 and Figure 3C. The northeastern region, including Sylhet and Sunamganj, and the Mangrove Forest, are characterized by the presence of waterbodies. The presence of water in these regions offers a unique opportunity for ecotourism activities, such as birdwatching, boating, fishing, and enjoying the natural beauty. Additionally, Bangladesh is home to a network of rivers that flow throughout the country.

(d) Wetland Proximity: The area was divided into five suitability zones according to its proximity to wetlands—very high (1%), high (5%), moderate (7%), low (10%), and deficient (77%)—that cover, respectively, 1476 km^2, 7379 km^2, 10,330 km^2, 14,757 km^2, and 113,629 km^2 of the land in Bangladesh, as shown in Table 5 and Figure 3D. The northeastern region has the highest number of wetlands. These wetlands are crucial habitats for a wide range of flora and fauna and provide vital ecosystem services, such as flood control, water purification, and carbon storage. As such, the northeastern region offers a unique opportunity for ecotourism activities centered around wetland conservation and appreciation, including birdwatching, nature walks, and educational tours focused on wetland ecology.

3.2. Topographic Characteristics

(a) Elevation: Five suitability zones spanning 5%, 5%, 9%, 79%, and 2% of the total land area were identified for the area based on elevation: very high, high, moderate, low, and very low. Specifically, the very high zone covered 7379 km^2 of land, the high zone covered 7379 km^2, the moderate zone covered 13,281 km^2, the low zone covered 116,580 km^2, and the very low zone covered 2951 km^2, as shown in Table 5 and Figure 4A. The regions with the most significant elevations can be found in the northwestern and southeastern parts of Bangladesh. Among these areas, the districts of Panchagarh, Bandarban, Rangamati, and Khagracchari boast the highest elevations, making them particularly well-suited for ecotourism activities. These regions offer a unique landscape for tourists to explore, with breathtaking views and the opportunity to experience the traditional lifestyles and cultures of the indigenous people.

(b) Slope: Based on the slope classes, the area was divided into five suitability zones: very high, high, moderate, low and very low, covering 83%, 13%, 3%, 0.7%, and 0.3% of the land, respectively. Specifically, the very high suitability zone covered 122,483 km^2, the high zone covered 19,184 km^2, the moderate zone covered 4427 km^2, the low zone covered 1033 km^2, and the very low zone covered 443 km^2, as shown in Table 5 and Figure 4B. Certain areas within the southeastern regions are less suitable for ecotourism activities in Bangladesh, specifically parts of Rangamati, Khagracchari, and Bandarban, exhibiting steep slopes that may pose a challenge for ecotourism activities.

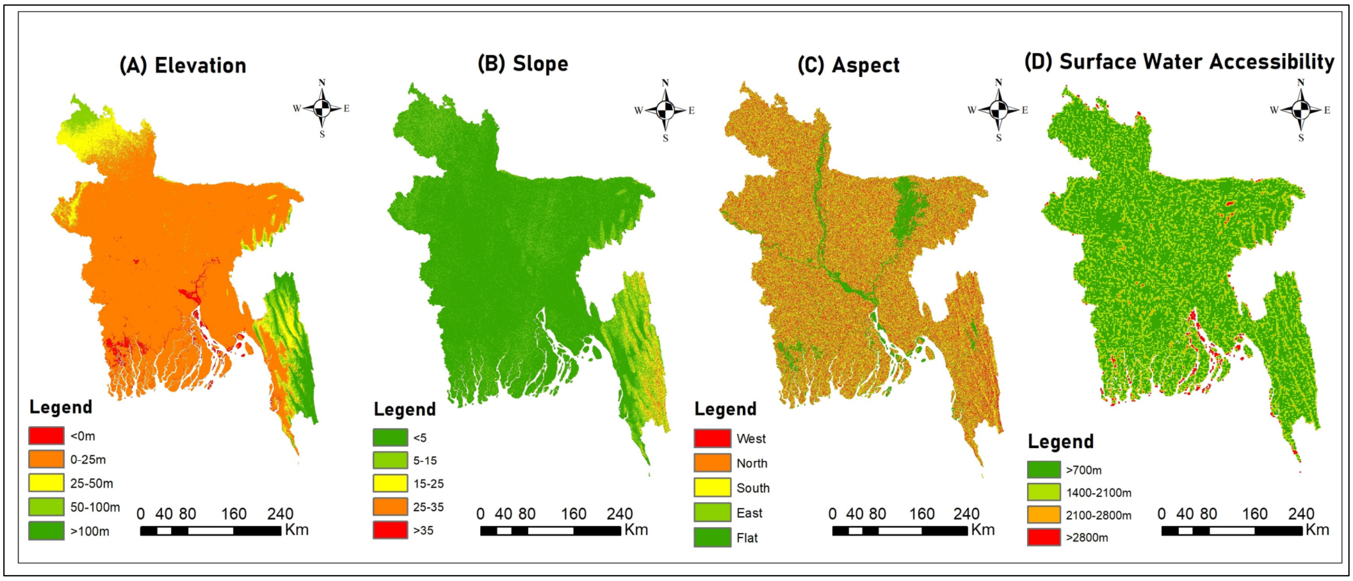


Figure 4. Visual representations of topographical conditions in ecotourism mapping.

(c) Aspect: According to aspect, the area has been divided into five suitability zones: very high (9%), high (24%), moderate (23%), low (21%), and very low (23%), covering 13,281 km^2, 35,417 km^2, 33,941 km^2, 30,990 km^2, and 33,941 km^2, respectively, as shown in Table 5 and Figure 4C. Notably, suitable zones with flat and east-facing aspects can be found in various regions of Bangladesh, providing opportunities for ecotourism activities across the country.

(d) Surface Water Accessibility: The area was divided into five suitability zones based on the accessibility of surface water: very high, high, moderate, low, and very low. These suitability zones span 97,396 (66%) km^2, 45,747 km^2 (31%), 2951 km^2 (2%), and 1476 km^2 (1%), respectively, as shown in Table 5 and Figure 4D. Bangladesh is blessed with abundant surface water resources which cover a significant portion of its land area. The widespread accessibility of surface water not only makes it ideal for various economic activities but also renders it a suitable destination for ecotourism, with opportunities for its development scattered across the country.

3.3. Accessibility

(a) Distance from Roads: For closeness to roadways, there are five separate appropriateness zones: very high, high, moderate, low, and very low. The very high suitability zone covered 60,504 km^2 (41%), the high suitability zone covered 33,941 km^2 (23%), the moderate suitability zone covered 17,708 km^2 (12%), and the low and very low suitability zones covered 8854 km^2 (6%) and 26,563 km^2 (18%), respectively, as shown in Table 5 and Figure 5A. Our analysis reveals that the southeastern part of the country, specifically the Rangamati and Bandarban areas, and the southwestern part, specifically the Sundarbans, are characterized by lower levels of road accessibility compared to other regions. While this may pose logistical challenges for tourism activities in these areas, it also offers a unique opportunity for ecotourism experiences focused on wilderness exploration and adventure. Promoting ecotourism activities, such as trekking, camping, and wildlife safaris, that are compatible with the natural environment can develop these regions into unique and sought-after ecotourism destinations.

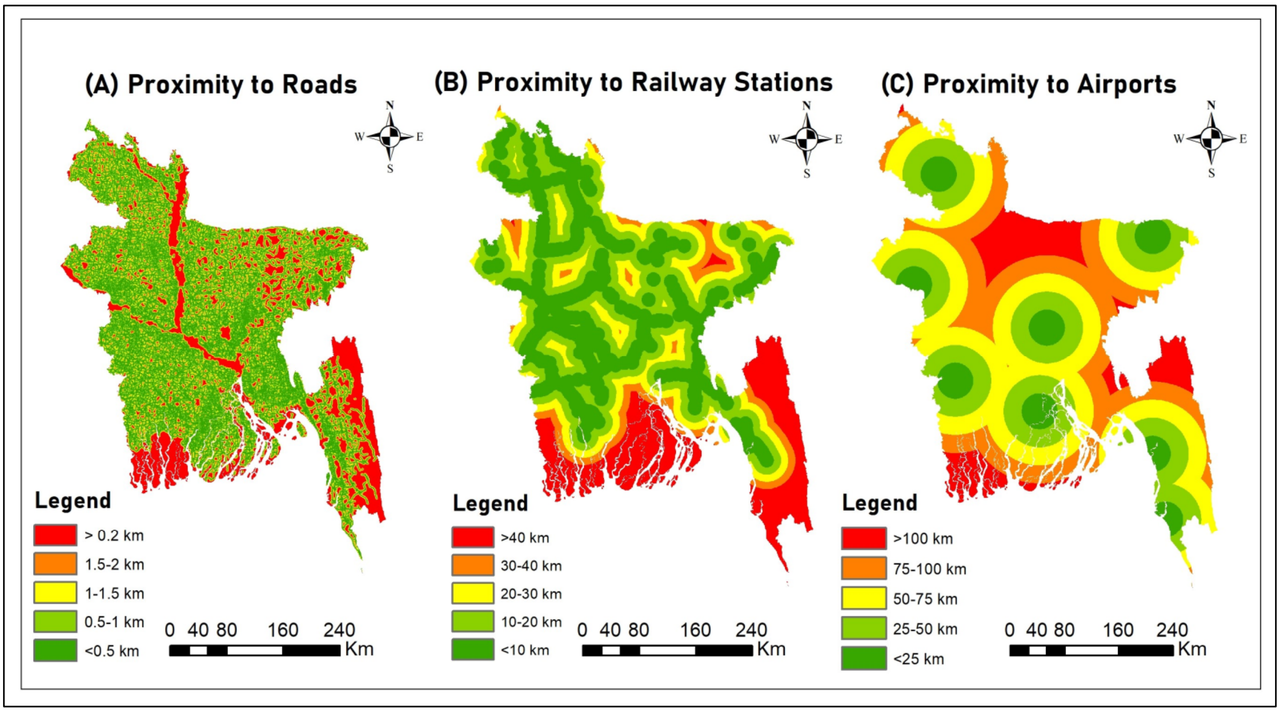


Figure 5. Visual representations of accessibility options in ecotourism mapping.

(b) Distance from Railways: Our analysis based on proximity to railway stations revealed that 35% of the total land area falls within the very high suitability zone, followed by 27% in the high suitability zone, 14% in the moderate suitability zone, 7% in the low suitability zone, and 17% in the very low suitability zone. These zones, respectively, cover 51,650 km^2, 39,844 km^2, 20,660 km^2, 10,333 km^2, and 25,087 km^2 of the territory, as shown in Table 5 and Figure 5B. Our analysis also revealed that the Sundarbans, Bandarban, Rangamati, and Barisal regions have relatively lower levels of proximity to railway stations, which may pose challenges for tourism development in these areas. Thus, it is essential to consider alternative modes of transportation and infrastructure development that can enable access to these regions while minimizing negative impacts on the environment.

(c) Distance from Airports: The results indicate that 9% of the total land area falls under the very high category, 25% under the high category, 32% under the moderate category, 22% under the low category, and 12% under the very low category for proximity to airports. These zones cover 13,281 km^2, 36,893 km^2, 47,222 km^2, 32,465 km^2, and 17,708 km^2 of the territory (see Table 5 and Figure 5C for details). Most of the airports are located in the central and southern regions of the country. Areas in the Mymensingh division, parts of the Rangamati and Khagrachhari districts, and the Sundarbans have a lower level of proximity to airports, indicating lower suitability for ecotourism activities.

3.4. Proximity to Facilities

(a) Proximity to Hotels: Based on hotel accessibility, Bangladesh can be divided into five appropriateness categories: very high, high, moderate, low, and very low, which cover 13,281 km^2 (9%), 29,514 km^2 (20%), 28,038 km^2 (19%), 26,563 km^2 (18%), and 50,174 km^2 (34%) of the total land area, respectively, as shown in Table 5 and Figure 6A. Several regions of Bangladesh, including parts of Netrakona, Sunamganj, and Kishoreganj in the Southeast, as well as sections of Panchagarh, Jamalpur, Sirajganj, and Pabna in the Southwest, and some areas in the South, such as parts of Sundarbans, Satkhira, Gopalganj, Shariatpur, Madaripur, and Bhola, have limited hotel accessibility, which could negatively impact their appeal as destinations for ecotourism.

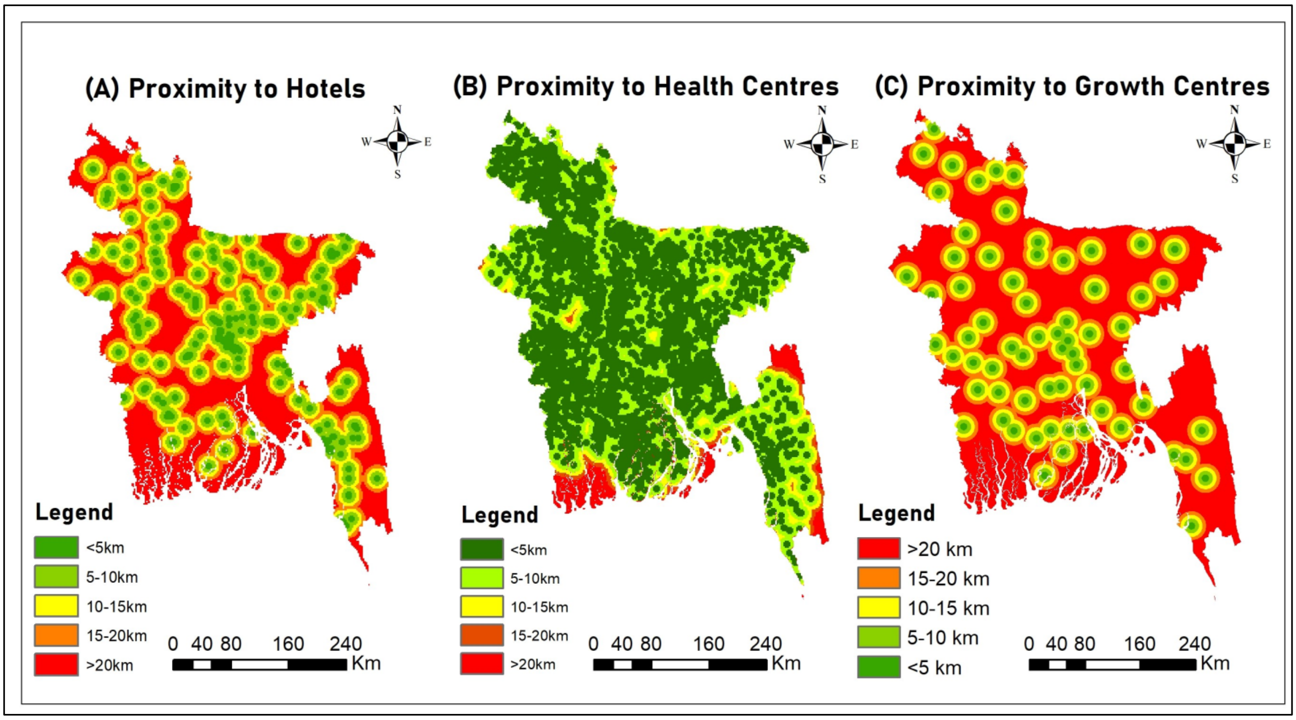


Figure 6. Visual representations of primary facilities in ecotourism mapping.

(b) Proximity to Health Centers: Five appropriateness zones were established for the area based on its closeness to health facilities: very high: 65%, high: 25%, moderate: 4%, low: 2%, and very low: 4%, which cover 95,921 km^2, 36,893 km^2, 5903 km^2, 2951 km^2, and 5903 km^2, respectively, as shown in Table 5 and Figure 5B. It is noteworthy that, except for the Sundarbans and small areas in Khagrachhari and Bandarban, most of Bangladesh's land is near health centers. However, the limited availability of healthcare resources in these regions may hurt their potential as attractive destinations for ecotourism.

(c) Proximity to Growth Centers: The study revealed that the five suitability zones: very high, high, moderate, low, and very low based on proximity to growth centers cover 14.31%, 33.73%, 29.57%, 12.46%, and 9.93% of the total land area, respectively, spanning 20,660 km^2, 50,174 km^2, 44,271 km^2, 17,708 km^2, and 14,757 km^2 (see Table 5 and Figure 6C for details). The regions close to growth centers are dispersed throughout Bangladesh, offering multiple opportunities for ecotourism activities. These areas provide easy access to urban amenities and economic activities, making them attractive destinations for ecotourists.

3.5. Community Characteristics

(a) Proximity to Settlements: The study classified Bangladesh into five suitability zones based on proximity to settlements: very high, high, moderate, low, and very low, covering 12%, 29%, 15%, 10%, and 34% of the region, respectively, which amounts to 17,708 km^2, 42,795 km^2, 22,136 km^2, 14,757 km^2, and 50,174 km^2 (see Table 5 and Figure 7A for details). We found that the Sundarbans, along with Bandarban, Khagrachhari, Rangamati, Sunamganj, and various other regions scattered throughout Bangladesh, are well-suited for ecotourism due to their remote locations and distance from settlements.

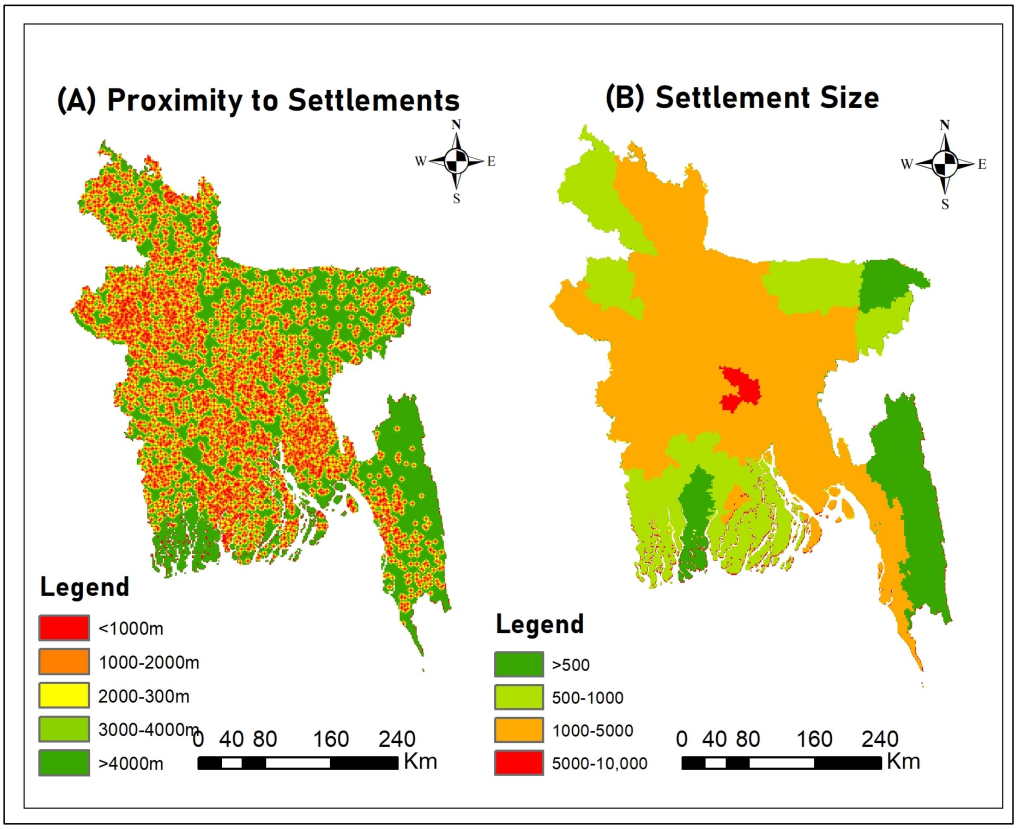


Figure 7. Visual representations of community stats in ecotourism mapping.

(b) Settlement Size: The study categorized the region into five suitability zones based on settlement size: very high (15%), high (27%), moderate (57%), low (1%), and very low (12%), spanning 22,136 km^2, 39,844 km^2, 84,115 km^2, and 1476 km^2, respectively, as shown in Table 5 and Figure 7B. The study highlights that the regions with smaller settlement sizes, such as Panchagarh, Thakurgaon, Dinajpur, and Naogaon in the Northwest, Netrokona, Sunamganj, Sylhet, and Moulavibazar in the Northeast, Satkhira, Khulna, Bagerhat, Narail, Gopalganj, Pirojpur, Jhalokati, Barisal, Bhola, Patuakhali, and Barguna in the Southwest, as well as Rangamati, Khagrachhari, and Bandarban in the Southeast, are particularly well-suited as ecotourism destinations.

3.6. Ecotourism Suitability Mappings

The weights of several thematic layers and their unique properties were used in GIS to build the map of ecotourism potential zones. The results demonstrated an uneven distribution of ecotourism development sites in Bangladesh. The prospective zones in Bangladesh were classified as high, moderate, and low. Table A1 in the Appendix A provides a list of upazilas under their respective districts that are suitable for ecotourism.

Numerous areas across the nation are suitable for the development of ecotourism sites. The presence of dense and semi-dense woods, including mangrove forests, sal forests, and hill forests, in the country's northwest, southeast, and southwest regions makes them ideal locations for ecotourism development. Several districts have been recognized as being ideally suited for ecotourism, including Cox's Bazar, Chittagong, Rangamati, Khagrachhari, Feni, portions of Khulna and Satkhira (districts with large numbers of mangroves), Dhaka, Gazipur, Maulvibazar, Dinajpur, Panchagarh, and Kurigram. These areas have the necessary natural attractiveness, topographic characteristics, accessibility, proximity to facilities, and community characteristics for the development of sustainable ecotourism activities. Figure 8 categorizes suitability zones for ecotourism development into three categories: extremely appropriate, moderately suitable, and not suitable. An area of 64,931 km^2, or 44% of the entire area, is covered by the extremely appropriate category. Approximately 23% of the entire land, or 33,941 km^2, falls under the fairly appropriate category. Finally, the not-appropriate group encompasses 48,698 km^2 or 33% of Bangladesh's entire land area.

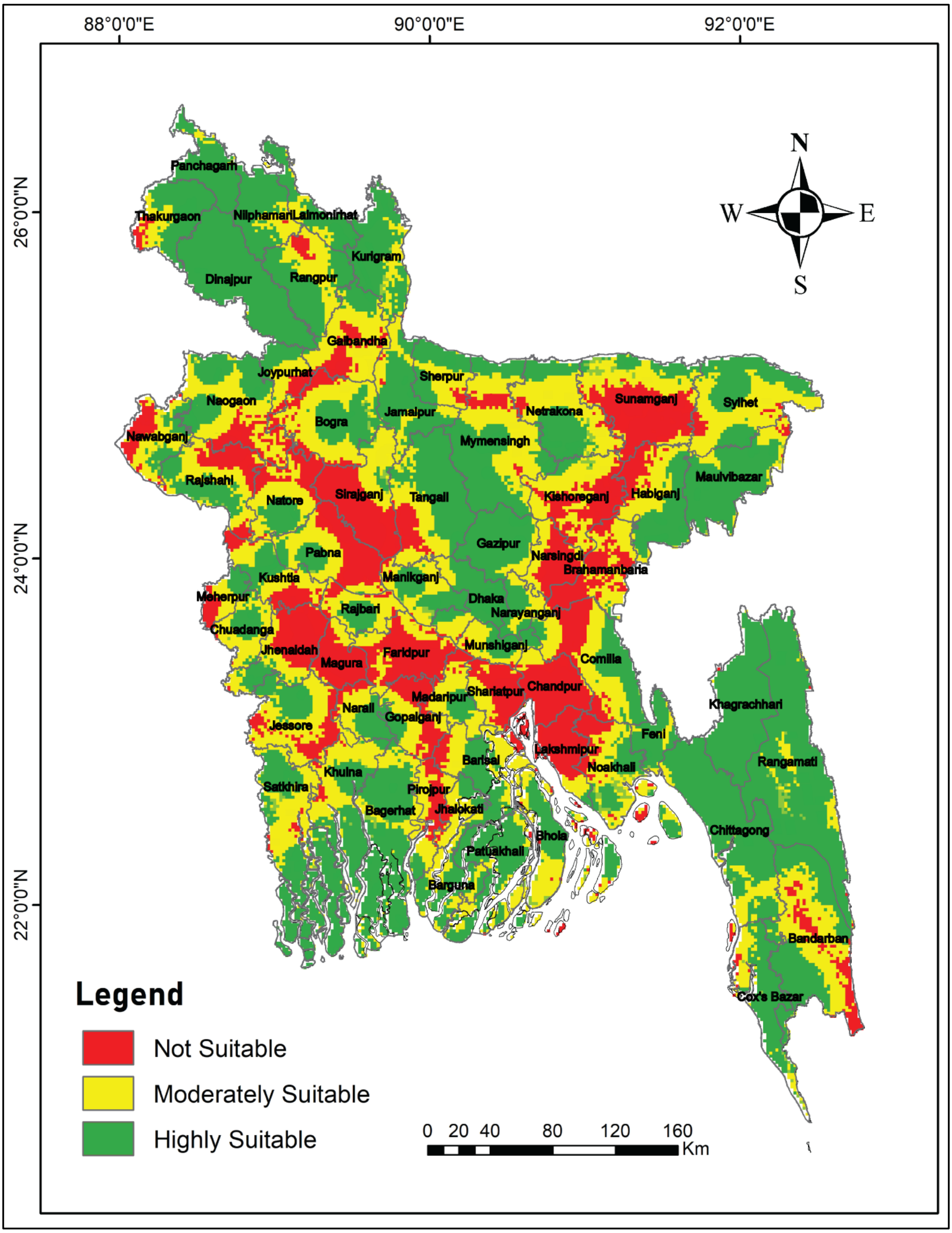


Figure 8. Prospective ecotourism territories in Bangladesh.

4. Discussion

Based on several factors, such as natural attractiveness, topographic characteristics, accessibility, proximity to facilities, and community characteristics, potential ecotourism zones, including Cox's Bazar, Chittagong, Rangamati, Khagrachhari, Feni, the mangrove-dominated parts of Khulna and Satkhira, Dhaka, Gazipur, Maulvibazar, Dinajpur, Panchagarh, and Kurigram, were found to constitute 44% of the area of Bangladesh. Hilly forested regions, mangrove forest regions, and sal forest regions are highly suitable environments, being the most desirable destinations for ecotourists. Due to their low forest cover density and adverse conditions, many forest regions are not particularly suitable, e.g., the coastal tree covers in Bhola and Noakhali. Improved forest management can increase the areas' high suitability coverage. On the other hand, some highly populated urban areas like Dhaka and Gazipur are marked as suitable for potential ecotourism zones, having proximity to sal forests and great access to roads, airports, and services like hotels and healthcare. So, conserving and developing potential sites in these districts are equally important. Instead of highly suitable places, some well-known existing tourist destinations come within the moderately good category because of their having little or no influence from wildlife and topography and the impact of a dense population. Owing to differences in physical, social, cultural, and infrastructural qualities, the potential locations for ecotourism sites were found to be unevenly spread across the country and inside protected areas.

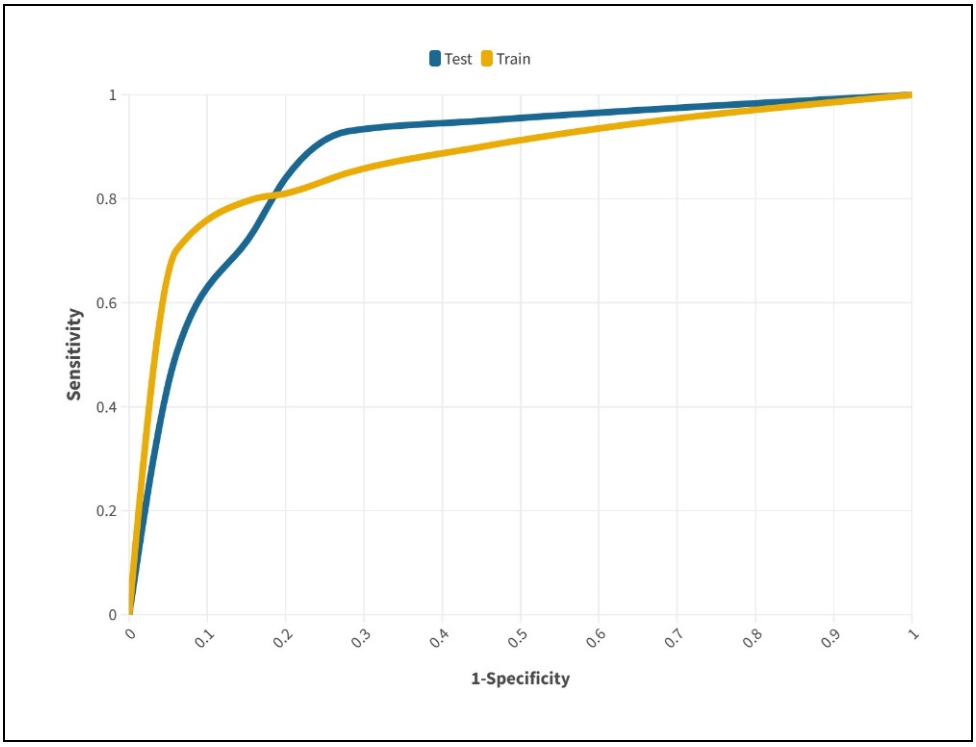
According to the knowledge of the authors, no similar study has been conducted in Bangladesh, taking into consideration the whole country. The results could be compared with those obtained for the neighboring country of India in the same subcontinent. In a study conducted by Sahani (2020) in Kullu District, Himachal Pradesh, India, the potential ecotourism sites were identified using the AHP andGISs [7]. The findings indicated that approximately 41% of the district's total land area was classified as highly suitable or very highly suitable for the development of ecotourism sites. Similarly, Chaudhary et al. (2022) aimed to identify potential ecotourism sites in the Garhwal Himalayan region using the AHP and GIS-RS techniques [10]. The results revealed that around 21.12% of the area in the region was categorized as highly suitable or very highly suitable for ecotourism development. According to a study conducted by Gigovic et al. (2016) on the "Dunavski kljuc" region of Serbia, it was found that a significant proportion, specifically 6.1%, of the area exhibits a high level of suitability [39]. In Mahdavi et al. (2015)'s study on the Khorramabad province of Iran, the results revealed that 6.57% and 38.65% of the surveyed area exhibited outstanding and favorable potential, respectively, for the development of ecotourism [59].

The results from this model have been validated by creating the ROC curve for appropriate ecotourism potentiality and estimating the AUC. Existing ecotourism areas and the generated ecotourism potential map of the AHP model were compared in order to verify the potentiality of ecotourism using ROC curves according to Regmi et al. (2014) [71]. Figure 9 shows the ROC curve plots and the corresponding AUC value of 81.18% using the AHP method, indicating that the potential maps were predicted with a good level of accuracy.

Additionally, the ecotourism potentiality map created using the AHP and Google Earth pictures was used for confirmation. In order to conduct the analysis, several sites from both sources were chosen and put up against one another [10]. The outcomes demonstrated a high degree of accuracy, which provided further evidence for the reliability of the prediction process. These findings contribute to the credibility of the study's results and reinforce the validity of the research methodology.

As a fundamental component of tourism quality, the assurance of safety and security is necessary [72]. The Chittagong Hill Tract area was mainly found to be highly suitable in the analysis; however, upazilas like Alikadam, Rowangchhari in the Bandarban district, and Belai Chhari in the Rangamati district had local and international tourism restrictions imposed by the government of Bangladesh due to security issues [73,74]. Previously, due to security considerations, security personnel have restricted tourist access to the Chittagong

Hill Tracts [75], which might affect the decisions of international and local tourists. Future studies could integrate safety and security issues with ecotourism potentiality mapping, this not having been undertaken in this study. Tourist confidence might grow if authorities provide open and accurate information regarding security risks.



Ecotour	Area
Test	0.8118
Train	0.8102

Figure 9. The ROC curve, with the AUC value of 0.818 indicating a high level of accuracy.

Furthermore, accessibility to improved sanitation and drinking water, as well as technical support to ensure complete hygiene safety, are critical for visitors' comfort and health [76]. However, drinking-water scarcity is acute in Bangladesh's coastal areas because freshwater aquifers are not available at adequate depths and surface water is very saline [77], such that international and local tourists might find it difficult to access pure drinking water, and this factor alone might affect their choice of destinations.

One of the determinants of international tourist influx is culture [78]. For international tourists, the desire for social connection, getaway, relaxation, the destination image, and quality are the most essential aspects [79]. Additionally, economic variables, such as GDP, comparative pricing, currency rates, and interest rates, are particularly relevant, affecting the number of tourist arrivals [80]. These social, economic, and psychological factors were not integrated into this study. Future studies can integrate all factors to design an all-inclusive approach in order to avoid these limitations.

As evident from past studies, many poor people in ecotourism areas, such as boatmen, tour guides, rickshaw pullers, eco-cottage owners, etc., find tourism to be a reliable source of income [81]. Ecotourism can contribute to community development by creating job opportunities and generating revenue for local communities. By mapping ecotourism potentiality, local communities can be involved in the planning and development of eco-tourism activities, ensuring that they are compatible with the needs and values of the local people. This can contribute to the achievement of SDG 8 (decent work and economic growth). So, the identification of potential ecotourism zones might attract tourists and positively impact local economies, ultimately boosting the economy of the country, and identify areas with high ecological value as well. This information can be used to create sustainable tourism activities that promote conservation and minimize negative impacts on the environment, such as pollution and habitat destruction. Thus, ecotourism can contribute to the achievement of SDG 12 (sustainable consumption and production) and SDG 14 (life below water).

There are several environmental costs associated with providing large numbers of visitors' access to natural areas, such as the use of limited resources (e.g., water), infrastructure construction, habitat fragmentation, and human waste and litter, and chemical, light, and noise pollution can harm wildlife, especially if they are close to tourist infrastructures [82]. Ecotourism infrastructures, such as roads, recreational trails, and resorts, contribute to physical habitat degradation by reducing and fragmenting wildlife habitats [83]. Solid waste and chemical pollution in the air and water also endanger wildlife [82]. Noise pollution has received increased attention in the last two decades due to its effects on a diverse spectrum of land and aquatic wildlife [82]. There is clear evidence that tourism can be a valuable instrument in effective conservation initiatives. However, it is critical to identify and properly manage the impacts of human presence while also addressing the plethora of other issues that threaten wildlife's long-term survival. We can achieve a balance that optimizes the positive consequences of tourism while reducing its ecological imprint by implementing sustainable management methods and taking a holistic approach to conservation. This necessitates collaboration among stakeholders, stringent restrictions, and continual monitoring and adaptation to guarantee that tourism remains a catalyst for positive change in biodiversity protection.

The government must be committed to supporting investments in the ecotourism sector and making sure that favorable conditions and regulations are in place to support the sector's efficient implementation and growth [84]. Investing in developing the infrastructure of and establishing adequate connectivity to ecotourism locations is important. The long-term success of ecotourism destinations depends on taking the necessary precautions to ensure visitor safety and security [45]. The government should put safeguards in place to protect visitors, such as well-trained guides, emergency response systems, and efficient surveillance. Creating a safe and secure atmosphere will increase tourist trust and encourage return visits, thus contributing to the sustainability of the ecotourism industry.

To reduce the negative effects of ecotourism, the following measures could be implemented:

- Educate locals about ecotourism and their participation in its maintenance, encouraging environmentally conscious behavior;
- Ensure the tranquility and integrity of ecotourism areas by ensuring compliance through efficient law enforcement;
- Establish effective waste management procedures to prevent contamination and ensure clean tourist destinations;
- Enforce a tight code of conduct for ecotourists, including severe measures for infractions, to limit environmental and wildlife harm;
- Ensure that ecotourism economically benefits local and indigenous communities by creating job opportunities and supporting local businesses;
- Address the food security needs of ethnic groups living near ecotourism areas by ensuring access to nutritious food.

5. Conclusions

Using the weights of several thematic layers and their unique characteristics, a final map of Bangladesh's most suitable ecotourism areas was produced effectively in the current study by employing the AHP and GIS. This integrated approach aimed to identify potential ecotourism sites targeting international tourists who are willing to make a nature-based trip. The results show that 44% of the country's area has potential for ecotourism, including Cox's Bazar, Chittagong, Rangamati, Khagrachhari, Feni, mangrove-dominated parts of Khulna and Satkhira, Dhaka, Gazipur, Maulvibazar, Dinajpur, Panchagarh, and Kurigram. This research suggests that GIS-based multi-criteria decision making integrates and analyzes spatial aspects, such as natural resources, biodiversity, accessibility, infrastructure, and cultural heritage, to assess ecotourism site appeal potential. GIS-based decision-making helps sustain ecotourism locations by evaluating several variables in a geographical context.

The findings of the current study provide planners with useful information for making decisions about where to protect and/or utilize land resources in Bangladesh in a more sustainable way. If locals are not proactively involved in the process of planning and developing ecotourism sites, interest in the industry will diminish and the profits gained from the ecotourism sites would suffer [85]. Local participation can boost ecotourism because local participation in ecotourism enhances the destination's authenticity and cultural diversity, attracting tourists seeking authentic experiences and fostering a feeling of place. Local involvement can also boost job, income, and community development, helping ecotourism thrive sustainably. The people living in ecotourism areas profit directly and indirectly from tourism. This study is an important and pioneering effort in this field of study, and it should be used as an ideal roadmap for ecotourism planners to develop ecotourism sites. It may be utilized to make decisions and save time for visitors and tourists as well as for planning for the future. Sustainable resource policies may contribute to Bangladesh's ecotourism industry's success story. Additionally, by promoting ecotourism, Bangladesh can contribute to the achievement of multiple SDGs, leading to a more sustainable and equitable future for all.

When it comes to modeling and solving complicated problems, any MCDM has limitations. The AHP is no different. The AHP is based on decision makers' judgements and preferences, which might introduce subjectivity and prejudice [86]. A structured approach was used to collect and validate expert opinions (through interviews) to address this restriction. Decision makers may struggle to maintain consistency between comparisons, resulting in inconsistent results in the AHP [86]. To address this issue, consistency checks were used to ensure that the pairwise comparisons were sufficiently consistent. When dealing with many criteria or options, the AHP can become complex and time-consuming, and the experts may lose interest in the interviews [87]. The decision hierarchy was streamlined by aggregating or grouping relevant criteria to address this shortcoming. The AHP entails several pairwise comparisons and calculations that may be opaque to experts [86]. The AHP process was fully documented and presented to the experts to address these constraints, including the reasoning behind pairwise comparisons, weight assignments, and overall decision-making procedures.

While protecting nature is one of the primary purposes of ecotourism, it is important to acknowledge the environmental consequences of allowing large numbers of visitors' access to natural areas, potentially harming wildlife. This paper recommends ways to mitigate such negative impacts. This study is limited by only focusing on environmental issues. Future research could integrate socioeconomic and psychological factors as well as incorporate ground-truthing to provide a more comprehensive and inclusive approach.

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Appendix A

Table A1. Districts and upazilas suitable for ecotourism.

District	Upazila
Panchagarh	Atwari, Boda, Panchagarh Sadar, Debiganj, Tentulia
Thakurgaon	Baliadangi, Thakurgaon Sadar, Birganj
Dinajpur	Kaharole, Biral, Birampur, Birganj, Bochaganj, Chirirbandar, Dinajpur Sadar, Fulbari, Ghoraghat, Hakimpur, Kaharole, Khansama, Nawabganj, Parbatipur
Gaibandha	Sundarganj
Kurigram	Bhurungamari, Char Rajibpur, Chilmari, Kurigram Sadar, Nageshwari, Phulbari, Rajarhat, Raumari, Ulipur
Lalmonirhat	Aditmari, Hatibandha, Kaliganj, Lalmonirhat Sadar, Patgram
Rangpur	Badarganj, Kaunia, Mitha Pukur, Pirgachha, Pirganj, Taraganj
Nilphamari	Dimla, Domar, Nilphamari Sadar
Joypurhat	Panchbibi
Naogaon	Badalgachhi, Niamatpur, Patnitala
Nawabganj	Nawabganj Sadar
Rajshahi	Charghat, Godagari, Matihar, Boalia, Paba, Rajpara, Shah Makhdum
Bogra	Bogra Sadar, Dhunat, Gabtali, Sariakandi, Shajahanpur
Jamalpur	Bakshiganj, Islampur, Jamalpur Sadar, Madarganj, Melandaha
Sherpur	Jhenaigati, Sreebardi
Mymensingh	Bhaluka, Dhobaura, Fulbaria, Muktagachha
Netrakona	Atpara, Durgapur, Kendua, Madan
Sunamganj	Tahirpur, Dowarabazar
Sylhet	Gowainghat, Jaintiapur, Companiganj, Fenchuganj, Sylhet Sadar
Maulvibazar	Juri, Kamalganj, Kulaura, Maulvi Bazar Sadar, Rajnagar, Sreemangal
Habiganj	Nabiganj, Chunarughat, Madhabpur, Bahubal, Nabiganj
Gazipur	Gazipur Sadar, Kaliakair, Kapasia, Sreepur
Tangail	Basail, Bhuapur, Gopalpur, Madhupur, Mirzapur, Sakhipur
Sirajganj	Sirajganj Sadar
Natore	Bagati Para, Baraigram
Kushtia	Bheramara
Pabna	Ishwardi, Pabna Sadar
Narayanganj	Rupganj, Sonargaon, Gazaria
Dhaka	Dohar, Nawabganj, Keraniganj, Savar, Dhamrai
Manikganj	Ghior, Shibalaya, Singair
Rajbari	Balia Kandi
Chuadanga	Chuadanga Sadar
Munshiganj	Tongibari
Jhenaidah	Maheshpur
Comilla	Burichang, Comilla Adarsha Sadar, Comilla Sadar Dakshin, Chauddagram

Table A1. *Cont.*

District	Upazila
Madaripur	Madaripur Sadar
Narail	Kalia
Jessore	Chaugachha, Kotwali
Satkhira	Satkhira Sadar, Kalaroa, Shyamnagar, Debhata
Khulna	Batiaghata, Dacope, Koyra
Bagerhat	Bagerhat Sadar, Kachua, Fakirhat, Morrelganj, Rampal, Sarankhola
Pirojpur	Patharghata
Jhalokati	Jhalokati Sadar
Barisal	Babuganj, Bakerganj, Barisal Sadar (Kotwali), Gaurnadi
Barguna	Barguna Sadar
Bhola	Tazumuddin, Burhanuddin, Daulatkhan
Noakhali	Hatiya, Kabirhat, Companiganj, Subarnachar
Feni	Daganbhuiyan, Feni Sadar, Fulgazi, Parshuram
Chittagong	Banshkhali, Boalkhali, Chandanaish, Fatikchhari, Hathazari, Lohagara, Mirsharai, Patiya, Rangunia, Raozan, Sandwip, Satkania, Sitakunda, Anwara
Cox's Bazar	Cox's Bazar Sadar, Ramu, Teknaf, Ukhia
Bandarban	Alikadam, Naikhongchhari, Rowangchhari
Khagrachhari	Dighinala, Khagrachhari Sadar, Lakshmichhari, Mahalchhari, Manikchhari, Matiranga, Panchhari, Ramgarh
Rangamati	Baghai Chhari, Barkal, Belai Chhari, Jurai Chhari, Kaptai, Kawkhali (Betbunia), Langadu, Naniarchar, Rajasthali, Rangamati Sadar

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