International Journal of Ecology and Environmental Sciences 51: 95-110, 2025
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2025.0454

New Horizons for Ecotourism in Sikkim: An Integrated MCDA Approach

DEEPA RAI, KRISHNAIAH, Y.V.*, KAUSIK PANJA, ATOSHI CHAKMA, MANIKA MALLICK, DEBASIS DAS AND MOUMITA HATI

Department of Geography and Disaster Management, Tripura University (A Central University), Suryamaninagar, 799022, Tripura, India

E-mail: rai09deepa@gmail.com, yvkrishna09@gmail.com, yvkrishnaiah@tripurauniv.ac.in, kausikpanja89@gmail.com, atoc.chakma@gmail.com, mnkmlik14@gmail.com, debasisdas379@gmail.com, moumitahati421997@gmail.com

***Corresponding author**

ORCID ID: 0009-0008-2532-6396 (DR); 0000-0002-8335-6533 (YVK); 0009-0007-5098-2056 (KP); 0009-0008-7438-3370 (AC); 0000-0003-2768-2673 (MM); 0009-0000-0175-1445 (DD); 0009-0000-8699-0890 (MH)

ABSTRACT

The present paper is an attempt to explore the new horizon of potential ecotourism in Sikkim by analysing thirteen key factors, including elevation, NDVI, protected areas, slope, rainfall, temperature, proximity to cultural heritage sites, roads, urban areas, lakes, rivers, waterfalls, and international boundaries with using the Analytical Hierarchy Process (AHP) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) techniques. Further, it assigns weight to each factor to determine their importance in assessing and mapping the potential of ecotourism using Geographic Information System (GIS) technology to identify the best suited for ecotourism. The potential ecotourism map is reclassified into four categories that are high, moderate, low, and unsuitable. The outcome indicates that 62% of the state's total geographical area is categorized as highly to moderately suitable (4390 km2) for the development of ecotourism largely distributed across the southern and central parts of the state, whereas 33% under low and remains at 5% of the total geographical area is unsuitable for practicing ecotourism. In addition, the investigator has identified 14 new horizons for developing potential ecotourism in Sikkim.

Key words: Ecotourism, Integrated MCDA approach, New Horizons, Sikkim

INTRODUCTION

Ecotourism's genesis is rooted in environmental conservation, focusing on showcasing and preserving local culture (Wood 2002, Das and Chatterjee 2015). Since the 2002 declaration by the United Nations as the 'Year of Ecotourism', two decades have passed, and it has been serving as an alternative to the conventional type of tourism (Weaver and Lawton 2007). Community involvement is crucial for successfully implementing ecotourism principles, making their participation in planning and management essential (Garrod 2003, Scheyvens 1999). Unlike the conventional type of tourism, ecotourism involves principles of conservation and preservation of resources (Goodwin 1996). Ecotourism in Sikkim is opening up new horizons in the state, focusing on community-based initiatives and eco-friendly practices that preserve the environment and promote local culture. Many places have already been identified as Sikkim's ecotourism zone; others are still emerging. The identification of new ecotourism zones becomes significant because an inevitable threat is posed by conventional tourism to the environment, society, and economy (Sunlu 2003, Podhorodecka and Dudek 2019).

Until 1975, Sikkim was a kingdom under the Namgyal dynasty. After the merger with India, tourism took almost three decades to gain a remarkable status in the state. From 2002 to 2007, by the 10th Five-Year Plan (7th objective), tourism was recognized as an industry in Sikkim. As a result, there was a notable rise in the number of tourist arrivals to the region. The growth in the number of tourists in Sikkim is noteworthy and influences the economic and cultural conditions. However, a pragmatic approach is necessary to monitor the impacts of tourism. The concept of ecotourism serves as a viable and beneficial solution to combat the negative influence of tourism. In Sikkim, there exist eleven ecotourism zones, which include Khecheopalri, Hee-Bermiok, Okhrey, and Uttarey in the West district, Nampong-Lingdok and East Pendam in the East district, Lingee and Kitam in the

South district, Lachung, Lachen and Dzongu in the North district. The management and maintenance are done by 159 Joint Forest Management Committees (JFMSs) and 49 Ecotourism Development Committees (EDCs).

In our daily lives, decisions are frequently made and sometimes these decisions require a profound understanding of the problems at hand and the ability to connect all the relevant criteria and sub-criteria (Satty 2008). During decision-making, emotions, and influential judgments often occupy significant roles, sometimes overshadowing sound analysis and rational thinking (Satty 1984). The AHP, developed by Satty in 1980, stands out as one of the most extensively employed MCDA techniques in research and decision-making contexts. (Pathmanandakumar et al. 2023, Das and Pal 2020). AHP is the most effective method in which the problem components are arranged in a hierarchy followed by the pairwise comparison of the matrix; the highest in the synthesized priority are considered for the decision-making (Bayazit 2005, Ariff et al. 2008). Satty's scale is between 1 to 9, with varying degrees of significance. DEMATEL is another MCDA technique extensively used. Between 1972 and 1976, the DEMATEL method was first developed in the Science and Human Affairs Program of the Batelle Memorial Institute of Geneva (Tzeng et al. 2007). DEMATEL technique helps identify the causative factors and the interdependence of the various factors involved (Adegoke et al. 2021). Additionally, the usage of Geographical Information System has been made in this study as the researchers globally use this technique for mapping due to its robust ability to process spatial data with significant acknowledgment of GIS's role in ecotourism mapping and development (Fung and Wong 2007, Ahmadi et al. 2014, Sahani 2020).

The current paper aims to explore the new horizons of ecotourism in Sikkim by employing two different multicriteria decision analysis techniques (AHP and DEMATEL). For this study, thirteen factors have been selected: elevation, NDVI, protected areas, slope, temperature, rainfall, proximity to cultural heritage sites, roads, urban areas, lakes, rivers, waterfalls, and international boundaries.

DATABASE AND METHODOLOGY

Study area

Sikkim, a Himalayan state in northeastern India, is situated between 27°04'46" to 28°07' 48" N latitude and 88°00'58' to 88°55'25" E longitude (Fig. 1). It covers an area of 7,096 km^2, Sikkim has a population of 610,577, making it the second smallest state by area and the least populated according to the 2011 Census. Despite its small size, Sikkim is rich in biodiversity, offers stunning landscapes, and has a vibrant culture. This mountainous state borders China to the north and northeast, Nepal to the west, Bhutan to the southeast and the Indian state of West Bengal to the south. Encompassing this region is a range of elevations, extending from 280 m from mean sea level to an impressive 8586 m, with the iconic Mt. Kanchenjunga, the world's third-highest mountain, located within its boundaries (Hazra and Krishna 2019). Sikkim's two major rivers, the Teesta and Rangeet, originate from the Chho Lhamu and Rathong glaciers, respectively, and flow through a landscape rich in biodiversity and forest cover. According to the 2019 Forest Survey of India Report, Sikkim's forests span 3,342 km^2, making up 47.11% of the state's total area. The natural beauty and unique environmental initiatives, such as Sikkim's recognition as the world's first fully organic state and the designation of Kanchenjunga National Park as a UNESCO World Heritage Site, have significantly boosted tourism. This is reflected in tourist arrivals, which jumped from 200,111 in 2001 to 1,694,218 in 2022.

Database

Quantitative and qualitative data were used to determine the ecotourism potential in Sikkim. Elevation and slope maps were created using the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with a 30-meter spatial resolution obtained from BHUVAN, ISRO's geo-platform. The NDVI map was generated from Landsat-8 OLI imagery with a 30-meter resolution. Temperature data from 2002 to 2022 was sourced from NASA Power. Gridded rainfall data (2002 to 2022) with a spatial resolution of 0.25^o x 0.25^o was acquired from the India Meteorological Department (IMD) in Pune. Proximity maps for roads, urban

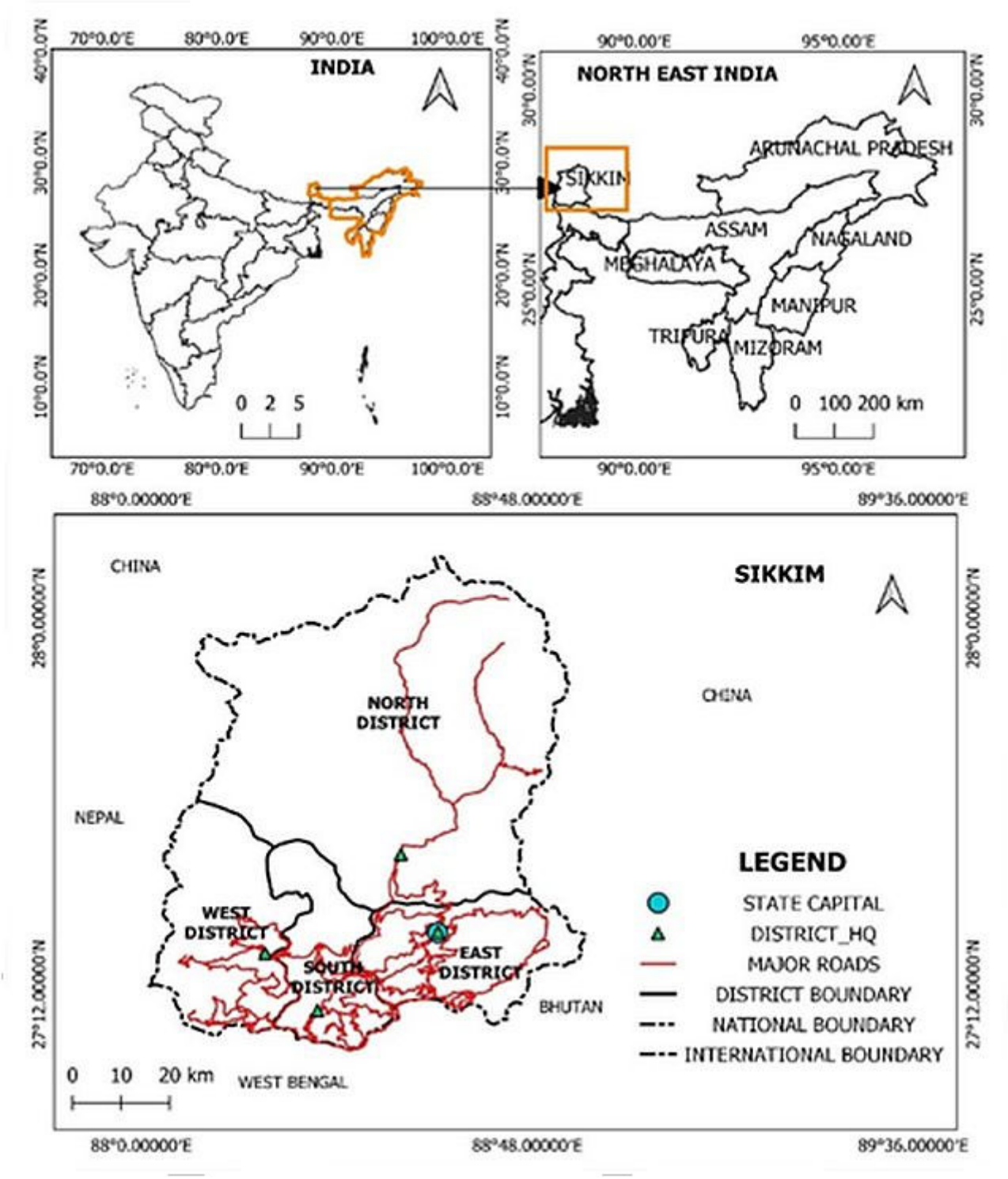

Figure 1. Location map of Sikkim

areas, international boundaries, cultural heritage sites, lakes, and waterfalls were digitized using Google Maps in GIS software. The proximity map for rivers was developed using the Hydro SHED database, and the protected area map was prepared by digitizing data from the ENVIS-Hub Sikkim map (Table 1).

Methodology

Using a literature review and expert consultations, 13 factors were selected for this study, and thematic raster layers were prepared. The data was reclassified, converted into a 30 m resolution, and projected using the UTM 45N WGS 1984 coordinate system for consistency. The average values from

Table 1. Selected factors for determine ecotourism potential

Sl. no.	Factors	Source
1	Elevation	SRTM DEM, Bhuvan
2	NDVI	Landsat-8 OLI image, USGS Earth explorer, 2023
3	Protected areas	ENVIS Hub: Sikkim
4	Slope	SRTM DEM, Bhuvan
5	Temperature	NASA Power (2002 to 2022)
6	Proximity to cultural heritage sites	Digitised from Google maps
7	Proximity to roads	
8	Proximity to urban areas	
9	Proximity to lakes	
10	Proximity to rivers	Hydro SHED database
11	Proximity to waterfalls	Digitised from Google maps
12	Rainfall	India Meteorological Department (2002 to 2022)
13	Proximity to international boundaries	Digitised from Google maps

AHP and DEMATEL were used to assign weights for the Weighted Overlay Analysis, which produced the composite map. The map's accuracy was validated using a ROC curve by comparing samples from Google images with the final map.

AHP was used to determine the weight of the thematic layers for decision-making. This method organizes the factors into a hierarchical structure and assesses the relative importance of each pair of factors. Satty's scale, ranging from 1 to 9, indicates different significance levels (Table 2).

Weightage the factors using AHP

In the present work, we followed the five-step procedure suggested by Satty (1980), and the indices used are given in Table 2. A group of 30 experts has given the scale rating of each factor against the other for formulating a pairwise comparison matrix and normalized weightage matrix, and the consistency ratio is presented in Table 3.

Weightage of the factors using DEMATEL

Another multi-criterion decision-making technique used to assign weights to the factors was DEMATEL (Decision-Making Trial and Evaluation Laboratory). Experts assigned scores ranging from 0 to 4 (Table 4) to evaluate the relationships between the factors. In the DEMATEL analysis, the same group of experts was employed to derive the average matrix. The process involved normalizing the matrix for direct relations, computing the total relation matrix, and determining the levels of prominence and net cause-and-effect values. The DEMATEL matrix (Table 5) utilized an influence scale ranging from 0 to 4.

After computing both MCDA techniques, the average values for each factor related to ecotourism potential in Sikkim were calculated to assign weights. These weights were then applied to the rasterized factors to perform the Weighted Overlay Analysis (WOA), producing the composite map for ecotourism potential. WOA is a common technique for combining multiple layers into a single composite layer, particularly for suitability assessments. In this analysis, 13 reclassified thematic layers were integrated, and the average values from AHP and DEMATEL were used to assign weights to each layer in the process.

RESULTS AND DISCUSSION

Determination of influencing factors

The factors vary across distinct geographical landscapes, shaped by the natural ecosystem and cultural environments (Abrehe et al. 2021). In the mountainous state of Sikkim, India, where the landscape and local culture significantly influence ecotourism, 13 factors were selected for the study. The average scores of each factor are classified into four groups, i.e., very high, high, moderate, and unsuitable (Table 6). The ecotourism potentiality map

Table 2. Degree of significance and description of scales for pair-wise comparison for AHP

Scale	Degree of significance	Description
1	Equally significant	The pair is equally important in the objective
3	Moderately significant	Experience and judgement slightly favour one element over another
5	Highly significant	Experience and judgement strongly favour one element over another
7	Very highly significant	Experience and judgement very strongly favour one element over another
9	Extremely significant	Experience and judgement extremely favour one element over another
2,4,6,8	Intermediate values	Used to compromise between two judgements

Table 3. Normalised weightage matrix of the factors

Factors	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
[1]	0.18	0.17	0.17	0.15	0.27	0.19	0.23	0.16	0.16	0.16	0.16	0.16	0.15
[2]	0.18	0.17	0.17	0.15	0.18	0.19	0.16	0.16	0.16	0.14	0.15	0.14	0.13
[3]	0.18	0.17	0.17	0.15	0.18	0.19	0.16	0.16	0.14	0.14	0.13	0.12	0.13
[4]	0.18	0.17	0.17	0.15	0.09	0.19	0.12	0.13	0.14	0.12	0.09	0.12	0.12
[5]	0.06	0.09	0.08	0.15	0.09	0.07	0.12	0.13	0.12	0.12	0.13	0.12	0.13
[6]	0.06	0.06	0.06	0.05	0.09	0.07	0.12	0.11	0.12	0.12	0.11	0.10	0.10
[7]	0.03	0.04	0.04	0.05	0.03	0.02	0.04	0.05	0.07	0.08	0.07	0.07	0.07
[8]	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.04	0.06	0.05	0.05
[9]	0.03	0.02	0.03	0.03	0.02	0.01	0.01	0.03	0.02	0.02	0.04	0.05	0.05
[10]	0.02	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03
[11]	0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
[12]	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
[13]	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02

1=Elevation, 2=NDVI, 3=Protected areas, 4=Slope, 5=Temperature, 6=Proximity to cultural heritage sites, 7=Proximity to roads, 8=Proximity to urban areas, 9=Proximity to lakes, 10=Proximity to rivers, 11=Proximity to waterfalls, 12=Rainfall, 13= Proximity to international boundaries

Table 4. Influence score and degree of influence for DEMATEL

Influence score	Degree of influence
0	No influence
1	Very low influence
2	Low influence
3	High influence
4	Very high influence

of Sikkim has been prepared by integrating the average scores of AHP and DEMATEL techniques into the selected factors in the GIS environment.

Elevation

In Sikkim, elevations are lower in the southern regions and rise to very high levels in the northern and northwestern areas. For this study, locations with elevations below 4,000 m are deemed very highly suitable for ecotourism, those between 4,000 and 4,800 m are considered highly suitable, elevations from 4,800 to 5,400 m are categorized as moderately suitable, and areas above 5,400 m are deemed unsuitable for ecotourism (Fig. 2a). The higher elevation areas have low air pressure and difficulty in accessibility (Sahani 2019). The comfort of access at lower elevations promotes the growth of ecotourism (Ronizi et al. 2020). However, the majestic view of Kanchenjunga and other adjoining mountain peaks is better from the altitudes located at the higher elevation.

NDVI

Higher positive values of NDVI indicate denser

Table 5. Total relation matrix of the potential ecotourism zone factors

Factors	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
[1]	0.03	0.11	0.26	0.14	0.14	0.23	0.16	0.16	0.06	0.08	0.13	0.10	0.04
[2]	0.01	0.05	0.14	0.10	0.05	0.04	0.19	0.07	0.10	0.11	0.11	0.03	0.00
[3]	0.02	0.06	0.07	0.20	0.01	0.15	0.07	0.01	0.02	0.02	0.01	0.16	0.00
[4]	0.05	0.07	0.22	0.06	0.05	0.09	0.04	0.02	0.05	0.06	0.02	0.08	0.00
[5]	0.01	0.12	0.08	0.04	0.01	0.06	0.04	0.06	0.01	0.14	0.15	0.02	0.00
[6]	0.09	0.02	0.14	0.08	0.02	0.04	0.11	0.02	0.01	0.02	0.02	0.11	0.00
[7]	0.01	0.07	0.08	0.08	0.01	0.06	0.03	0.09	0.05	0.05	0.06	0.02	0.00
[8]	0.01	0.11	0.08	0.11	0.01	0.02	0.15	0.02	0.02	0.02	0.02	0.02	0.00
[9]	0.01	0.09	0.07	0.06	0.01	0.06	0.03	0.01	0.01	0.01	0.01	0.02	0.00
[10]	0.05	0.06	0.08	0.07	0.01	0.02	0.02	0.02	0.01	0.01	0.10	0.02	0.00
[11]	0.00	0.10	0.07	0.07	0.01	0.01	0.03	0.05	0.01	0.01	0.01	0.01	0.00
[12]	0.00	0.01	0.10	0.06	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.00
[13]	0.00	0.05	0.02	0.06	0.01	0.01	0.06	0.05	0.01	0.01	0.01	0.01	0.00

1=Elevation, 2=NDVI, 3=Protected areas, 4=Slope, 5=Temperature, 6=Proximity to cultural heritage sites, 7=Proximity to roads, 8=Proximity to urban areas, 9=Proximity to lakes, 10=Proximity to rivers, 11=Proximity to waterfalls, 12=Rainfall, 13= Proximity to international boundaries

Table 6. Reclassification of the factors for ecotourism potential in Sikkim

Factors	**Categories**			
	Very high	**High**	**Moderate**	**Unsuitable**
1	< 4000 m	4000 - 4800 m	4800 - 5400 m	> 5400 m
2	0.40 to 0.25	0.25 to 0.14	0.14 to 0.04	0.04 to -0.25
3	KNP + buffer zones	KNP transition zone	Wildlife sanctuaries	Unprotected areas
4	0° - 20°	20° – 35°	35° – 45°	> 45°
5	Above 8°	6° – 8°	3° – 6°	< 3°
6	< 8 km	8 – 14 km	14 – 19 km	> 19 km
7	0 – 2 km	2 – 6 km	6 – 10 km	> 10 km
8	3 – 20 km	20 – 25 km	>3 km & 25 – 35 km	> 35 km
9	0 – 5 km	5 – 10 km	10 – 15 km	15 – 34 km
10	< 500 m	500 – 800 m	800 – 1400 m	> 1400 m
11	0 – 5 km	5 – 10 km	10 – 15 km	> 15 km
12	< 3000 mm	3000 – 3300 mm	3300 – 3600 mm	> 3600 mm
13	>25 km	15 – 25 km	10 – 15 km	< 10 km

Factors: 1=Elevation, 2=NDVI, 3=Protected areas, 4=Slope, 5=Temperature, 6=Proximity to cultural heritage sites, 7=Proximity to roads, 8=Proximity to urban areas, 9=Proximity to lakes, 10=Proximity to rivers, 11=Proximity to waterfalls, 12=Rainfall, 13= Proximity to international boundaries

vegetation, while negative values suggest water bodies or barren land. Ecotourism positively correlates with NDVI, as Sikkim's rich vegetation enhances its biodiversity and attracts ecotourists seeking natural experiences. This study classifies NDVI reflectance values: 0.40 to 0.25 as very highly suitable, 0.25 to 0.14 as highly suitable, 0.14 to 0.04 as moderately suitable, and below 0.04 as unsuitable (Fig. 2b). Reflectance values are higher in the lower Teesta and Rangeet river basins, while lower values

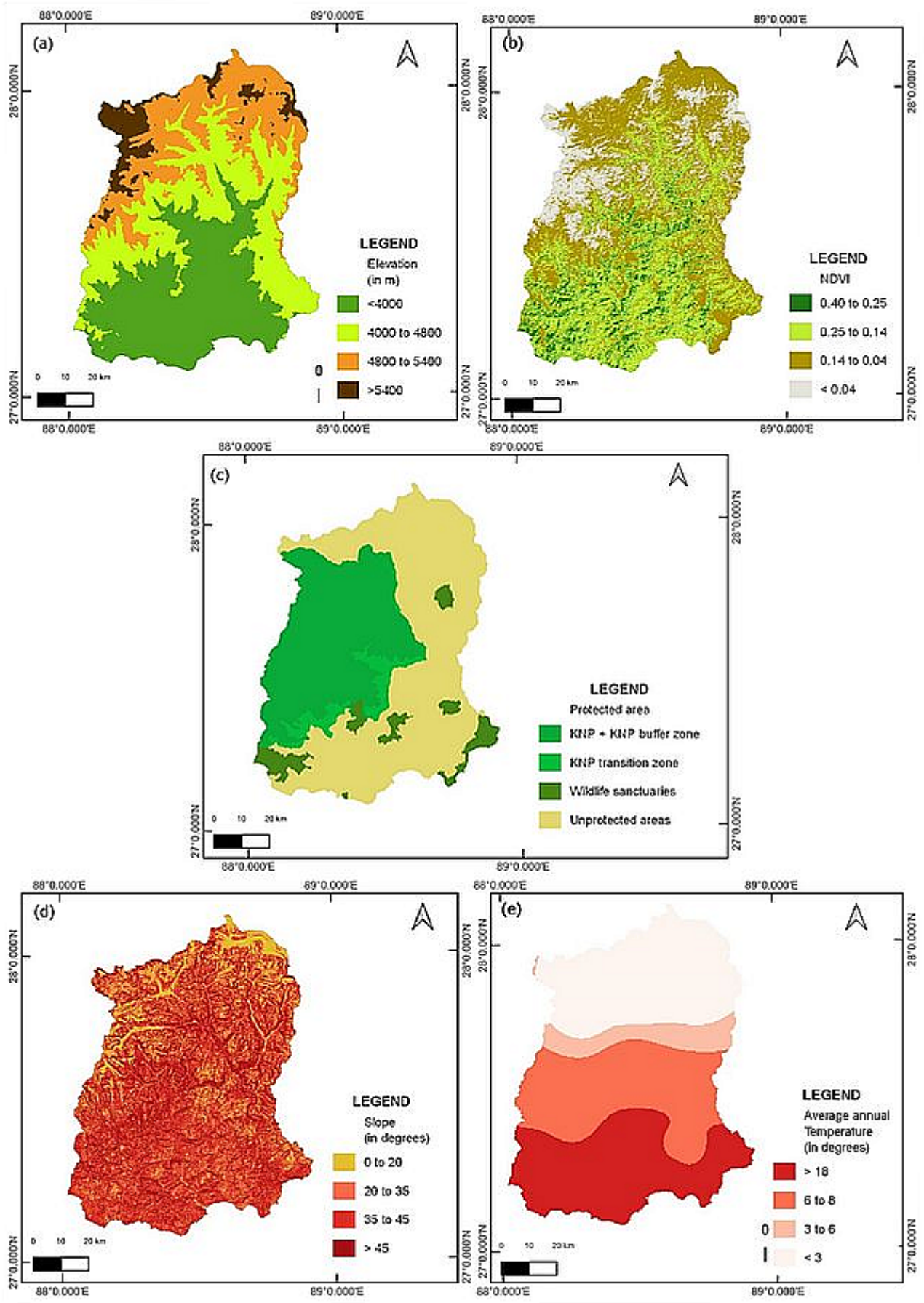

Figure 2. (a) elevation, (b) NDVI, (c) protected area, (d) slope, (e) average annual temperature

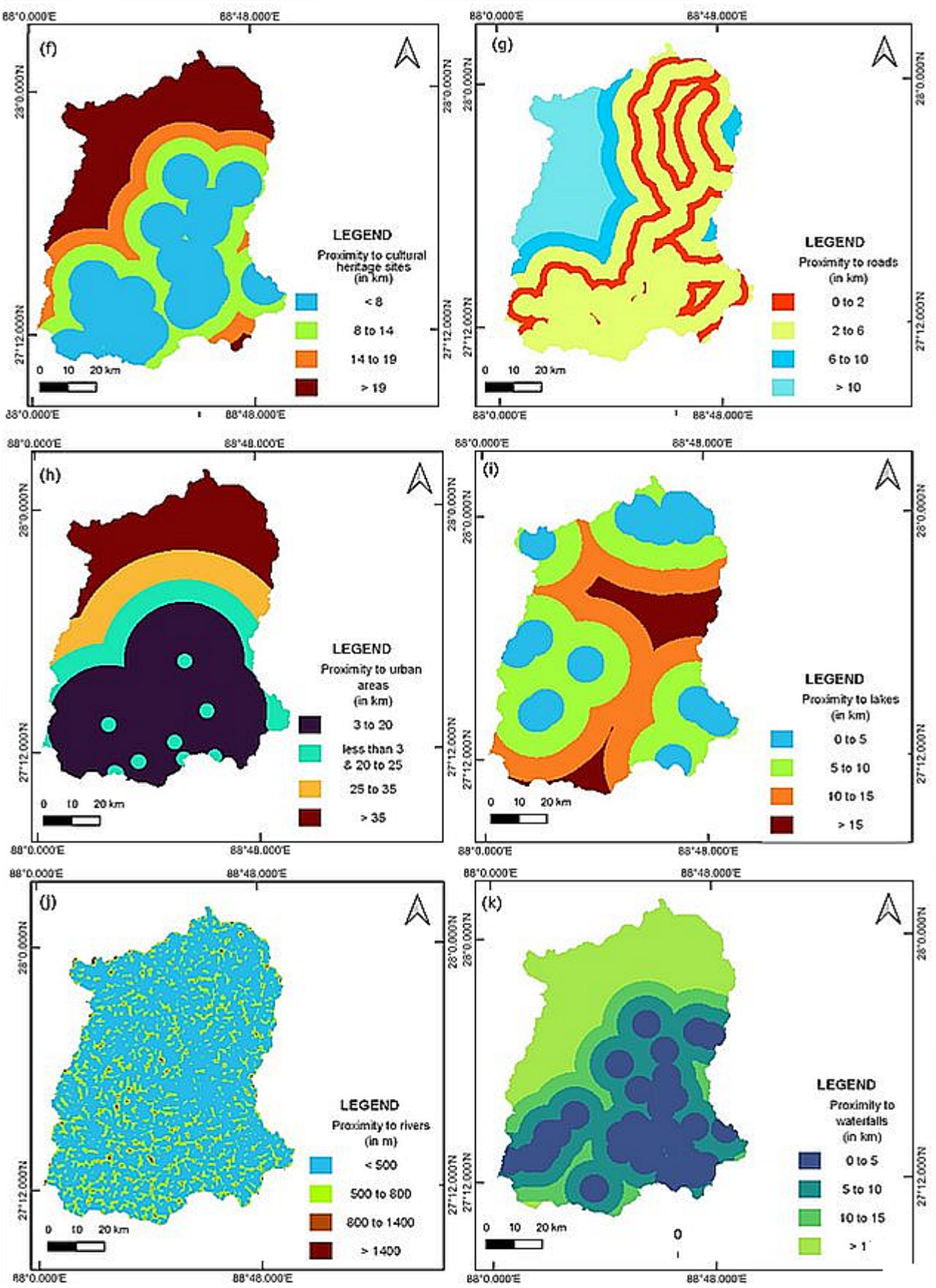

Figure 2. (f) proximity to cultural heritage sites, (g) proximity to roads, (h) proximity to urban area, (i) proximity to lakes, (j) proximity to rivers, (k) proximity to waterfalls,

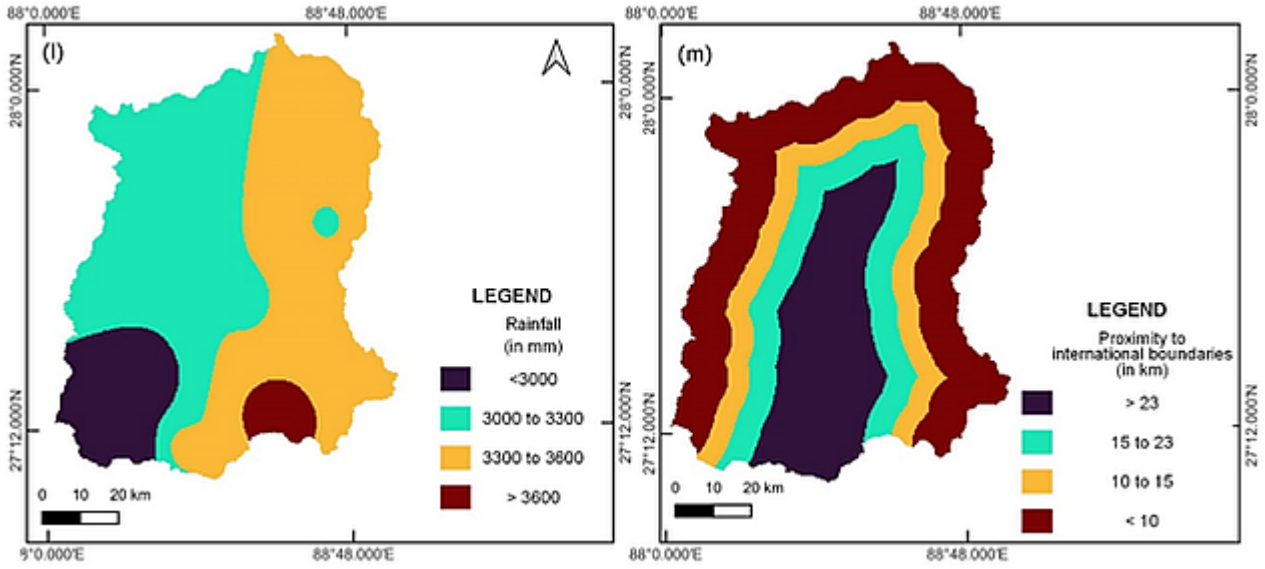

Figure 2.(l) rainfall, and (m) proximity to international boundary

are found in higher elevation regions of Sikkim.

Protected area

Ecotourism can play a crucial role in supporting the conservation of the environment, including protected areas, by promoting responsible tourism practices. Sikkim is home to seven wildlife sanctuaries and one national park, where a diverse range of exotic flora and fauna can be found (Singha and Chakma 2013). Kanchenjunga National Park (KNP) and the seven wildlife sanctuaries cover approximately 31% of Sikkim's total geographical area. In this study, the KNP and its buffer zones are classified as very highly suitable for ecotourism, the KNP transition zone as highly suitable, wildlife sanctuaries as moderately suitable, and unprotected areas as unsuitable (Fig. 2c). The wildlife sanctuaries are mainly located in the southern part of Sikkim, except for Singba Wildlife Sanctuary in the north. At the same time, KNP is situated in the western region.

Slope

The gentle slopes are preferred over steeper ones due to the latter's reduced capacity to retain water and soil, leading to limited control over the land for supporting vegetation and human activities to thrive (Wu et al. 2015). Lower slopes are necessary for developing ecotourism sites because steeper slopes hinder the possibility of building infrastructure. In Sikkim, the slope angle is relatively low in the northern and southeastern regions. For assessing potential ecotourism zones, slopes ranging from flat land to 20° are considered very highly suitable, 20 to 35° are highly suitable, 35 to 45° are moderately suitable, and slopes above 45° are considered unsuitable (Fig. 2d).

Temperature

Temperature plays a crucial role in Sikkim's ecotourism, given the state's inviting climate for visitors. An average annual temperature above 8°C is classified as very highly suitable for engaging in ecotourism, while 6 to 8°C is considered highly suitable; such temperatures provide an ideal environment for a wide range of ecotourism pursuits, including trekking, wildlife viewing, and nature walks. Moderately suitable conditions exist between 3 to 6°C while suitable for some outdoor activities; these areas may face challenges during winter or at higher elevations. Temperature below 3°C regarded as unsuitable as they often indicate harsh climatic conditions that may limit visitor engagement and accessibility to natural attractions (Fig. 2e). The southern area tends to be warmer, whereas the northern part, due to its elevated terrain and snow, experiences progressively lower temperatures.

Proximity to cultural heritage sites

Local people's culture and ecotourism are inevitable; ecotourism involves the active participation of the local communities closely tied to their culture (Adom 2019). The state has over 200 Buddhist monasteries in Sikkim (Sattar 2018) and numerous other cultural heritage sites. For the study of the ecotourism

potentiality in Sikkim, places less than 8 km are classified as very highly suitable, 8 to 14 km as highly suitable, 14 to 19 km as moderately suitable, and farther than 19 km from the cultural heritage sites as unsuitable (Fig 2f). Cultural heritage sites are notably concentrated in the southwestern and eastern parts of the state. The minimal human habitation in the northern part of Sikkim results in a few cultural heritage sites in that region. The coronation throne in Yuksom, Kabi Lungtsok, Dubdi monastery, Rabdentse ruins, and Pemayangtse monastery are some of Sikkim's most famous cultural heritage sites.

Proximity to roads

While Sikkim has one airport and helicopter service available, their usage is limited due to challenging weather conditions and the region's high terrain; therefore, the roads are significant transportation means in Sikkim, which are prominently concentrated in the southern part of the state. The Border Roads Organisation (BRO) has expanded road connectivity to a considerable elevation near the international border with China in the north. Places in closer proximity to the roads are categorised as more suitable for ecotourism; therefore, for this study, 0 to 2 km from the roads are considered very highly suitable, 2 to 6 km as highly suitable, 6 to 10 km as moderately suitable and beyond 10 km as unsuitable (Fig. 2g). Transportation plays a crucial role in accessing destinations. However, it can also adversely affect delicate and vulnerable regions (Sorupia 2005).

Proximity to urban areas

Ecotourism is founded on fostering a connection with nature, and maintaining a balanced relationship between urban areas and ecotourism destinations is essential. There are eight statutory towns and one census town in Sikkim, with a total urban population of 153,578 (Anonymous 2011). Places that are between 3 to 20 km from these urban areas are categorised as very highly suitable, between 20 to 25 km as highly suitable, places between 0 to 3 km and 25 to 35 km are considered moderately suitable, and places beyond 35 km are unsuitable (Fig. 2h). In this study, practicing ecotourism is ideal neither in places too close nor too far from the urban areas. Urban areas in Sikkim are predominantly concentrated in the state's southern regions, which are marked by lower elevations and relatively warmer temperatures compared to the northern areas.

Proximity to lakes

Lakes stand as an alluring landscape that beckons ecotourism enthusiasts. Sikkim boasts numerous lakes, almost all of which hold sacred significance (Acharya and Dokham 1998, Jain et al. 2004). The major lakes in Sikkim are Gurudongmar, Chho Lhamu, Khecheopalri, Aritar, South Lhonak, Memencho, Elephant, and Kathok. According to the data from the Remote Sensing Cell, Forest, Environment and Wildlife Management Department, and the Government of Sikkim, there are 521 big and small lakes across the state. These lakes in Sikkim encompass various types, including glacial, man-made, wetland, and high-altitude lakes. Twenty lakes have been chosen for the study, representing a diverse range of sizes and renowned for their significance within the region. The places within the proximity of 5 km from the lakes are categorized as highly suitable for the study, between 5 to 10 km as highly suitable, 10 to 15 km as moderately suitable, and beyond 15 km as unsuitable (Fig. 2i).

Proximity to rivers

Throughout the history of human civilization, rivers have played a crucial role in shaping human life and serving as a source of energy. Recently, tourists in rivers have been growing interest in ecotourism due to the therapeutic and rejuvenating experiences they offer (Goharipour 2016). The state is dominated by two main river basins: the Teesta River basin and the Rangeet River basin. For ecotourism practices, places half a km closer to these river basins are considered very highly suitable, between 500 to 800 m as highly suitable, 800 to 1400 m as moderately suitable, and more than 1400m as unsuitable (Fig. 2j). All the rivers in Sikkim originate from melting glaciers, ensuring their perennial flow throughout the year.

Proximity to waterfalls

Waterfalls are among the most favored tourist destinations worldwide, attracting tourists and captivating numerous artists with their beauty (Hudson 2000, Hudson 2013). Waterfalls are often located in remote areas, making it an ideal location for ecotourism. It is crucial as a resource in many countries (Hudson 1998). Some famous waterfalls in Sikkim include Naga, Seven sisters, Bhim Nala, Phamrong, Changey, Bakthang, Ban Jhakri, and

Kyongnosla. In this study, less than 5 km from the waterfall is categorised as very highly suitable, between 5 km to 10 km as highly suitable, 10 km to 15 km as moderately suitable, and above 15 km as unsuitable (Fig. 2k). In Sikkim, the location of the waterfalls is along the southern part of Teesta and Rangeet river following the higher slope angles.

Rainfall

Rainfall is a vital factor in tourism as it provides the necessities to all living creatures. For the study of ecotourism potentiality in Sikkim, places with rainfall ranging less than 3000 mm are considered very highly suitable, 3000 to 3300 mm as highly suitable, 3300 to 3600 mm as moderately suitable, and more than 3600 mm is unsuitable (Fig. 2l). Heavy rainfall in the mountainous state would lead to landslides and flash flood which causes hindrance for practicing tourism. The southwestern part of the state experiences relatively lower rainfall than the southeastern part.

Proximity to international boundaries

Security concerns related to international borders can impose constraints on ecotourism, even in regions that would otherwise be ideal ecotourism destinations. The study area shares the international boundary with Nepal, China, and Bhutan and the national boundary with the state of West Bengal. The famous Nathu la pass is the border between China and India, which can be fascinating for the conventional tourist, but practicing ecotourism is not considered appropriate. Places beyond 25 km from the international boundaries are considered very highly suitable for ecotourism, between 15 to 25 km as highly suitable, between 10 to 15 km as moderately suitable, and places less than 10 km to the international boundaries as unsuitable (Fig. 2m). The famous Nathula pass is the border between China and India can be fascinating for the conventional tourist but practicing ecotourism is not considered appropriate.

Ecotourism potentiality of Sikkim using integrated multicriteria decision analysis

After reclassifying the thematic layers for the thirteen factors used to identify ecotourism potential in Sikkim, these layers were combined on a GIS platform to produce a comprehensive map. Weighted Overlay Analysis, a technique that overlays multiple layers to create a composite raster layer, was employed (KianiSadr et al. 2019). Each factor was assigned a weight based on calculations using the AHP and DEMATEL methods to determine the weights for this analysis.

In determining the weights for the weighted overlay analysis, each factor was subjected to thorough calculations employing the Analytic Hierarchy Process (AHP) and the Decision Making Trial and Evaluation Laboratory (DEMATEL) methods. Subsequently, the average score extracted from each factor's calculated AHP and DEMATEL values was utilized to assign weightage to the 13 factors involved in the analysis (Table 7). This comprehensive approach ensured that the resulting weights accurately reflected the significance of each factor in the overall analysis.

Based on thirteen factors, ecotourism potential is categorized into four categories that are high, moderate, low, and unsuitable. Sikkim's high and moderate ecotourism potential results from low elevation, high reflectance of NDVI, favorable temperature, protected areas, rainfall, and suitable

Table 7. Weightage of the factors using AHP & DEMATEL

Factors	AHP	DEMATEL	Average of both
1	0.177	0.190	0.1835
2	0.159	0.120	0.1395
3	0.154	0.100	0.127
4	0.137	0.090	0.1135
5	0.107	0.090	0.0985
6	0.088	0.080	0.084
7	0.051	0.070	0.0605
8	0.032	0.070	0.051
9	0.027	0.050	0.0385
10	0.02	0.050	0.035
11	0.017	0.050	0.0335
12	0.016	0.030	0.023
13	0.015	0.030	0.0225

Factors: 1=Elevation, 2=NDVI, 3=Protected areas, 4=Slope, 5=Temperature, 6=Proximity to cultural heritage sites, 7=Proximity to roads, 8=Proximity to urban areas, 9=Proximity to lakes, 10=Proximity to rivers, 11=Proximity to waterfalls, 12=Rainfall, 13= Proximity to international boundaries

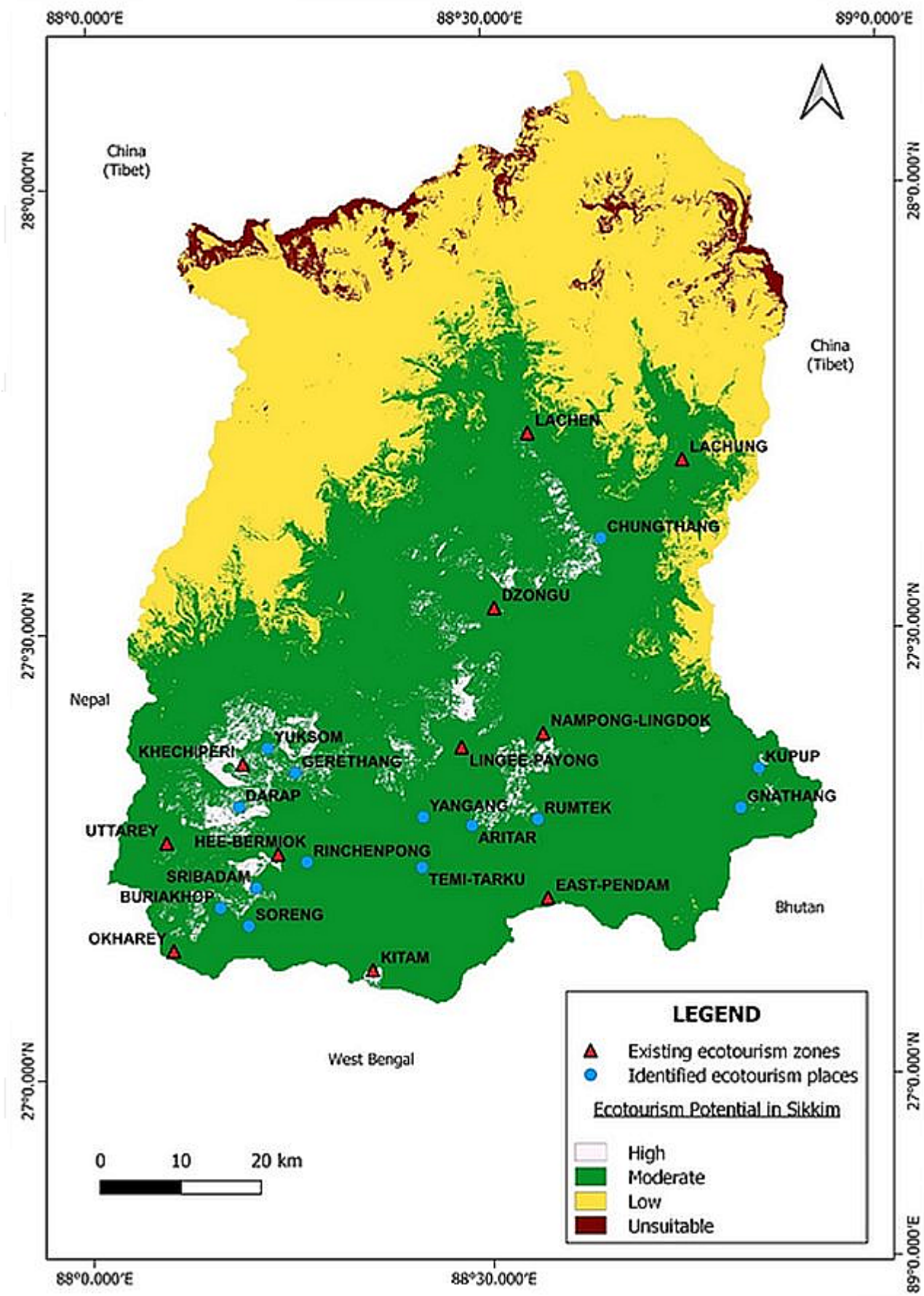

Figure 3. Ecotourism potentiality in Sikkim

proximity to urban areas, roads, cultural heritage sites, waterfalls, and international boundaries. Low ecotourism potential places are near rivers and protected areas, and unsuitable places are located in geographically inaccessible areas with favourable slopes.

The resultant map of the potentiality of ecotourism in Sikkim is classified into four categories: "high," "moderate", "low", and "unsuitable" (Fig. 3). The highly suitable and moderately suitable zones encompass the most significant areas, accounting for 62% (6% and 56%). Conversely, the "low" and "unsuitable" zone constitutes 38% (33% and 5%) of the total area. High ecotourism potentiality in Sikkim is spread up to 426 km^2, mostly concentrated in the southwestern part and the south-central part of the state; some specific limitations and guidelines need to be considered and adhered to when utilizing these attractions for ecotourism purposes; these could include visiting limits, dedicated trails or observation areas, waste disposal and pollution control policies, wildlife behaviour guidelines, and initiatives to involve the community in decision-making. Ecotourism zones falling under this category are Uttarey, Khecheperi, Hee-Bermiok, Okharey, Kitam, Nampong-Lingdok, and Lachen. The moderate potentiality of ecotourism in Sikkim is extended up to 3970 km^2. Dzongu, Lachung, Lingee, and East Pendam are included in this category and spread all across the southern part of the state. The low potentiality of ecotourism is spread up to 2350 km^2 over the northern part, whereas only 350 km^2 is categorized as unsuitable, concentrated in the northernmost part of Sikkim. No ecotourism zones come under the low and unsuitable category (Table 8).

Table 8. Categorised potential ecotourism in Sikkim

Sl. No.	Category	Total area	
		(in km^2)	(in %)
1	High	426	6
2	Moderate	3970	56
3	Low	2350	33
4	Unsuitable	350	5

Identified new horizons for ecotourism development in Sikkim

The researchers have also identified 14 new locations with significant ecotourism potential (Table 9). These areas offer opportunities for expanding ecotourism activities, which could positively impact the natural and cultural environment. The high-potential sites identified are Chungthang, Kupup, Gnathang, Rumtek, Aritar, Temi-Tarku, Yangang, Rinchenpong, Soreng, Sribadam, Buriakhop, Yuksom, Gerethang, and Darap, each with its unique significance. Moreover, developing ecotourism in these areas

Table 9. New places identified for ecotourism development in Sikkim

Places	Significance
Chungthang	Gurudwara Nanak Lama, Naga waterfalls, proximity to Lachen and Lachung.
Kupup	Elephant lake, proximity to Nathu la and Jalep la.
Gnathang	Yak herders, migratory birds, view of mount Kanchenjunga, Sunrise view point
Rumtek	Rumtek monastery, proximity to Paruhang Sapten Mangkhim, Paragliding.
Aritar	Aritar lake, boating, birdwatching, trekking and adventure sports.
Temi-Tarku	Temi tea garden, cherry blossoms.
Yangang	Mainam Hill, Buddhist monasteries.
Rinchenpong	Resum monastery, Jhandi dara trek, view of Kanchenjunga.
Soreng	One of the three gateways to Barsey Rhododendron sanctuary.
Sribadam	Palyul Dechen Gaweling monastery, rainbow trout farming, hiking and trekking.
Buriakhop	Organic farming and proximity to Barsey Rhododenron sanctuary.
Yuksom	Coronation throne, Kathog lake, Kanchenjunga National Park.
Gerethang	Proximity to the adjoining tourist places.
Darap	Srijunga Tuma Manghim, Rani Dhunga, Limboo Musuem, Sukpabong Lingbit, Rimbi Waterfalls, Neytham andSingdrong.

could boost the local economy and help alleviate unemployment.

Validation of the potential ecotourism in Sikkim through ROC

The Receiver Operating Characteristic (ROC) curve is a crucial tool for assessing the validity of any model. The ROC curve visually represents the True Positive Rate (TPR), also known as Sensitivity against the False Positive Rate at different classification thresholds. The area under the ROC curve is known as the area Under the Curve (AUC). The AUC serves as a performance measure for the model, with its maximum value being 1. An AUC of 0.5 indicates a test with no discriminating ability, while an AUC of 1 represents perfect class discrimination (Hoo et al. 2017). The AUC values range between 0 and 1, wherein 0 indicates that the model is less than random and 1 indicates that it has absolute discrimination. The AUC value obtained in this study is 0.803 or 80%, which is considered reliable (Fig. 4).

CONCLUSIONS

Sikkim is one of India's most visited tourist destinations, with new tourist attractions being introduced frequently. The influx of domestic and international tourists consistently shows positive growth each year. Ecotourism is a sustainable way of practicing tourism which reduces the adverse effects on the environment and the local people. The study identifies the potential for ecotourism in Sikkim by considering critical factors related to ecotourism operations using two integrated MCDA techniques: AHP and DEMATEL. As a result, the findings were categorized into four groups: high, moderate, low, and unsuitable. The high and moderate ecotourism potentiality encompasses 62% of the total geographical area where the 11 existing ecotourism zones are located in Sikkim. However, by enhancing accessibility to the moderate ecotourism potentiality, this category can merge with the ecotourism zone with high potential. The unsuitable potential ecotourism zone in Sikkim is minimal and situated in high-elevation areas with sparse vegetation and low temperatures. There are 14 new locations identified for ecotourism development with a high potential for ecotourism practices in Sikkim. This study lays the groundwork for devising ecotourism development in Sikkim. Given the nascent stage of ecotourism in the area, development initiatives should prioritize sustainability. Prioritizing sustainability will help maintain the region's ecological integrity while promoting economic growth and social well-being.

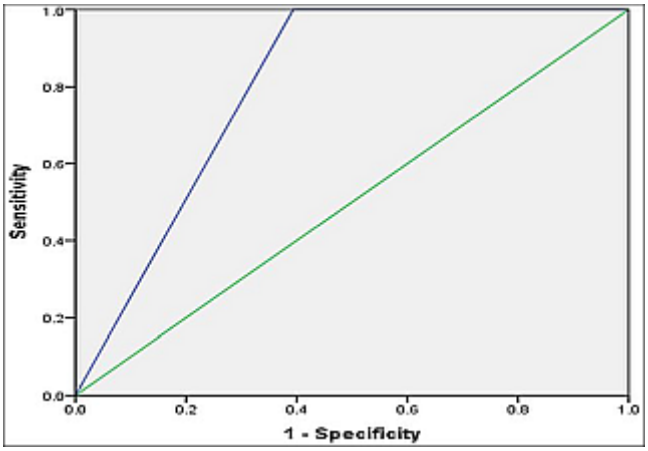

Figure 4. Receiver Operating Characteristic (ROC) curve model

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Tourism & Civil Aviation and Directorate of Ecotourism, Government of Sikkim for the relevant data and information on tourism and ecotourism. The scholar is grateful to the Ministry of Social Justice & Empowerment, Govt. of India, New Delhi for providing the JRF.

Authors' contributions: All authors contributed equally.

Conflict of interest: All the authors declare that there has been no conflict of interest.

REFERENCES

Abrehe, S., Girma, A. and Nigusse, A.G. 2021. Potential ecotourism site suitability evaluation for sustainable natural resource management in Kafta Sheraro National Park (KSNP), north-western Tigray, Ethiopia. Journal of Ecotourism, 20(4), 341-370. https://doi.org/10.1080/14724049.2021.1897599

Acharya, C. and Dokham, A.S.G. 1998. Sikkim: The Hidden

Land and Its Sacred Lakes. Bulletin of Tibetology, 1998(3), 10-15. https://api.repository.cam.ac.uk/server/api/core/bitstreams/e178b04d-9403-4ad8-9867-a93a07c191bc/content

Adom, D. 2019. The place and voice of local people, culture, and traditions: A catalyst for ecotourism development in rural communities in Ghana. Scientific African, 6, Article e00184. https://doi.org/10.1016/j.sciaf.2019.e00184

Ahmadi, M., Faraji Darabkhani, M. and Ghanavati, E. 2015. A GIS-based multi-criteria decision-making approach to identify site attraction for ecotourism development in Ilam Province, Iran. Tourism Planning & Development, 12(2), 176-189. https://doi.org/10.1080/21568316.2014.913676

Anonymous. 2011. District Census Handbook of Sikkim. ORGI-SIKKIM English – (10-2011) Data Product No. 11-009-2011-Cen-Book (E).

Ariff, H., Salit, M.S., Ishmail, N. and Nukman, Y. 2008. Use of analytical hierarchy process (AHP) for selecting the best design concept. Jurnal Teknologi, 49(A), 1-18. https://doi.org/10.11113/jt.v49.188

Bayazit, O. 2005. Use of AHP in decision making for flexible manufacturing systems. Journal of Manufacturing Technology Management, 16(7), 808-819. https://doi.org/10.1108/17410380510626204

Das, B. and Pal, S.C. 2020. Assessment of groundwater vulnerability to over-exploitation using MCDA, AHP, fuzzy logic and novel ensemble models: a case study of Goghat-I and II blocks of West Bengal, India. Environmental Earth Sciences, 79(5), 104. https://doi.org/10.1007/s12665-020-8843-6

Das, M. and Chatterjee, B. 2015. Ecotourism: A panacea or a predicament? Tourism Management Perspectives, 14, 3-16. https://doi.org/10.1016/j.tmp.2015.01.002

Fung, T. and Wong, F.K. 2007. Ecotourism planning using multiple criteria evaluation with GIS. Geocarto International, 22(2), 87-105. https://doi.org/10.1080/10106040701207332

Garrod, B. 2003. Local participation in the planning and management of ecotourism: A revised model approach. Journal of Ecotourism, 2(1), 33-53. https://doi.org/10.1080/14724040308668132

Goharipour, H. and Hajiluie, M.M. 2016. A study on river ecotourism development: Case study: Karaj River. International Journal of Geography and Geology, 5(4), 73-85. https://typeset.io/papers/a-study-on-river-ecotourism-development-case-study-karaj-2p293snjpp

Goodwin, H. 1996. In pursuit of ecotourism. Biodiversity & Conservation, 5, 277-291. https://doi.org/10.1007/BF00051774

Hazra, P. and Krishna, A.P. 2019. Spatio-temporal and surface elevation change assessment of glaciers of Sikkim Himalaya (India) across different size classes using geospatial techniques. Environmental Earth Sciences, 78, 1-20. https://doi.org/10.1007/s12665-019-8390-1

Hoo, Z.H., Candlish, J. and Teare, D. 2017. What is an ROC curve? Emergency Medicine Journal, 34(6), 357-359. https://emj.bmj.com/content/emermed/34/6/357.full.pdf

Hudson, B.J. 1998. Waterfalls resources for tourism. Annals of Tourism Research, 25(4), 958-973. https://doi.org/10.1016/S0160-7383(98)00043-7

Hudson, B.J. 2000. The experience of waterfalls. Australian Geographical Studies, 38(1), 71-84. https://doi.org/10.1111/1467-8470.00101

Hudson, B.J. 2013. Waterfalls, science and aesthetics. Journal of Cultural Geography, 30(3), 356-379. https://doi.org/10.1080/08873631.2013.828482

Jain, A., Singh, H.B., Rai, S.C. and Sharma, E. 2004. Folklores of sacred Khecheopalri Lake in the Sikkim Himalaya of India: a plea for conservation. Asian Folklore Studies, 63(2), 291-302. https://www.jstor.org/stable/30030339

KianiSadr, M., Melhosseini Darani, K. and Golkarian, H. 2019. Quantitative zoning of ecotourism potential in Oshtorankouh protected area using Delphi method, analytic hierarchy process, and weighted overlay methods. Ecopersia, 7(2), 115-123. https://www.magiran.com p1953776

Pathmanandakumar, V., Goh, H.C. and Chenoli, S.N. 2023. Identifying potential zones for ecotourism development in Batticaloa District of Sri Lanka using the GIS-based AHP spatial analysis. GeoJournal of Tourism and Geosites, 46(1), 252-261. https://doi.org/10.30892/gtg.46128-1022

Podhorodecka, K. and Dudek, A. 2019. Disadvantages connected with the development of tourism in the contemporary world and the concept of sustainable tourism. Problemy Ekorozwoju, 14(2), 45-55. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-2da72a27-4542-48ec-9751-e809f497ff81

Ronizi, S.R.A., Mokarram, M. and Negahban, S. 2020. Utilizing multi-criteria decision to determine the best location for the ecotourism in the east and central of Fars province, Iran. Land Use Policy, 99, 105095. https://doi.org/10.1016/j.landusepol.2020.105095

Saaty, T.L. 2008. Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1), 83-98. https://doi.org/10.1504/IJSSci.2008.01759

Saaty, T.L. 1984. The analytic hierarchy process: Decision making in complex environments. pp. 285-308. In: Avenhaus, R. and Huber, R.K. (Eds.). Quantitative Assessment in Arms Control: Mathematical Modeling and Simulation in the Analysis of Arms Control Problems. Springer, Boston, MA, US. https://doi.org/10.1007/978-1-4613-2805-6_12

Sahani, N. 2019. Assessment of ecotourism potentiality in GHNPCA, Himachal Pradesh, India, using remote sensing, GIS and MCDA techniques. Asia-Pacific Journal of Regional Science, 3(2), 623-646. https://doi.org/10.1007/s41685-019-00116-9

Sahani, N. 2020. Application of analytical hierarchy process and GIS for ecotourism potentiality mapping in Kullu District, Himachal Pradesh, India. Environment, Development and Sustainability, 22(7), 6187-6211. https://doi.org/10.1007/s10668-019-00470-w

Sattar, S. 2020. Culture, Creativity and Tourism: A Study of Sikkim. pp. 289-302. In: Sattar, S. (Ed.). The Cultural

Heritage of Sikkim. Routledge, London.
Scheyvens, R. 1999. Ecotourism and the empowerment of local communities. Tourism Management, 20(2), 245-249. https://doi.org/10.1016/S0261-5177(98)00069-7
Singha, R.K.P.G. and Chakma, J.B. 2013. Eco-tourism in Sikkim: A study on its prospects and problems. Traditional Knowledge, ??, 362-372.
Sorupia, E. 2005. Rethinking the role of transportation in tourism. In: Satoh, K. (Ed.) Proceedings of the Eastern Asia Society for Transportation Studies, 5(11), 1767-1777. https://www.easts.info/on-line/proceedings_05/1767.pdf
Sunlu, U. 2003. Environmental impacts of tourism. Pp. 263-270. In: Camarda, D. and Grassini, L. (Eds.) Local Resources and Global Trades: Environments and Agriculture in the Mediterranean Region. CIHEM, retrieved from http://om.ciheam.org/article.php?IDPDF=4001977
Tzeng, G.H., Chiang, C.H. and Li, C.W. 2007. Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. Expert Systems with Applications, 32(4), 1028-1044. https://doi.org/10.1016/j.eswa.2006.02.004
Wood, M. 2002. Ecotourism: Principles, Practices and Policies for Sustainability. UNEP, Paris. 59 pages. https://wedocs.unep.org/20.500.11822/9045
Wu, W., Zhang, X., Yang, Z., Qin, W., Wang, F. and Wang, C. 2015. Ecotourism Suitability and Zoning from the Tourist Perspective: a Nature Reserve Case Study. Polish Journal of Environmental Studies, 24(6), 2683-2697. https://doi.org/10.15244/pjoes/59422
Weaver, D.B. and Lawton, L.J. 2007. Twenty years on: The state of contemporary ecotourism research. Tourism Management, 28(5), 1168-1179. https://doi.org/10.1016/j.tourman.2007.03.004

Received:13th August 2024
Accepted:2nd October 2024