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Research article

# An ecotourism suitability index for a world heritage city using GIS-multi criteria decision analysis techniques

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A B S T R A C T

The concept of ecotourism has experienced a significant surge in popularity over the past two decades, primarily driven by the multitude of adverse impacts associated with mass tourism. The objective of the study was to develop a comprehensive ecotourism suitability index to guide policymakers in implementing tourism development policies. Given the considerable appeal of the study area to both local and international tourists, it is essential to conduct a systematic evaluation to pinpoint suitable areas for ecotourism development. This necessity arises from the study area's placement within a fragile ecosystem and its proximity to a UNESCO World Heritage site. We employed a Geographic Information Systems (GIS) integrated environment coupled with a fuzzy Multi-Criteria Decision Analysis (MCDA) methodology. The GIS-MCDA integrated framework leverages the Analytic Hierarchy Process (AHP) and a weighted linear combination that seeks to amalgamate many features and criteria to assess ecotourism potential by integrating 20 criteria into six separate categories: landscape, topography, accessibility, climate, forest and wildlife, and negative factors. Weights were allocated to each criterion and factor based on the expert's opinions of their impact on the development of ecotourism. The final ecotourism suitability index comprised five unique classes: very high, high, moderate, less, and not suitable. Results reveal that out of the total areas, 45.4 % (259 $km^2$) are within the high and very high suitable classes. The sensitivity analysis suggested that ecotourism potentials are more favorable to forest and accessibility variables. The generated index can be utilized as a road map since validation verified a 64 % accuracy. Given the dearth of earlier research, this study provides vital support for the development of sustainable ecotourism projects in the study area.

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## 1. Introduction

Despite the potential negative repercussions on society and the environment, tourism remains a multidimensional phenomenon that contributes to socio-economic development in various countries and regions [1,2]. Ecotourism offers a potential alternative to mass tourism by simultaneously stimulating the economy and conserving natural and cultural assets [2–6]. The term ecotourism has been subject to conflicting definitions. One of the initial characterizations described it as a model focused on the sustainable utilization of natural resources, while also emphasizing learning from the natural environment [6,7]. Recent data indicate that Costa Rica, Norway, Kenya, India, and Iceland are esteemed as the foremost countries for ecotourism, exerting a significant positive influence on the gross domestic product compared to other economic activities [1,8–10].

Sri Lanka, as an island nation, boasts a wealth of tourism opportunities, thanks to its captivating cultural and natural attractions that draw tourists in. Since 2010, the country's tourism sector has experienced significant growth, marked by a notable increase in international tourist arrivals [6,11]. Between 2012 and 2018, there was a remarkable rise in the number of international tourists visiting Sri Lanka, surpassing 2 million individuals and generating a total of 4380 million US dollars, establishing tourism as the third largest source of export revenue [12,13]. As a burgeoning sector within the Sri Lankan tourism industry, ecotourism currently plays a pivotal role. By prioritizing environmental conservation, there is an enhanced potential for tourists to engage in a diverse range of attractions, including mountains, landscapes, cultural and religious heritage sites, flora and wildlife, and a variety of climatic conditions [14].

Historically, scientific inquiries into ecotourism have predominantly centered on the contributions of tourism to rural development, as well as its impacts on the environment and society. Previous research on the prospects of ecotourism has primarily focused on conventional approaches [5]. Recently, there has been a notable increase in the utilization of geospatial tools and approaches in the field of ecotourism site planning and management. The integration of Remote Sensing (RS) with Geographic Information Systems has been demonstrated to enhance the effectiveness of data processing, analysis, and visualization [5,15,16]. The integration of fuzzy decision-making and MCDA within a GIS framework, supported by the application of the Analytic Hierarchy Process , enables the comprehensive and holistic evaluation of decision-making issues [5,17–20].

Simple human judgments typically carry less weight, but intricate ones often lead to more severe consequences. Real-world problem-solving involves balancing numerous opposing interests and making rational judgments based on priority [21–23]. The MCDA is employed to analyze and compare various variables that often conflict with each other to achieve the optimal solution. It is known by several names in the academic world, including multi-attribute decision-making, multi-objective decision-making, and multi-criteria decision-aiding [21,23,24]. MCDA approaches originated from two primary schools: the American and European operational research schools. The AHP, TOPSIS, and MAUT are among the most frequently used MCDA approaches developed by American schools. On the other hand, ELECTRE, PROMETHEE, and NAIADE are prominent MCDA techniques established by European schools [21,23]. The Fuzzy weighted method and the fuzzy decision score method are also widely recognized approaches in decision science research, which take into account decision alternatives and geographical dimensions [25–30]. Researchers frequently employ AHP to aid decision-making in environmental and spatial planning, natural resource management, resource allocation, and location suitability analysis [29,31,32]. When ecotourism is poorly planned, it can lead to negative socio-environmental repercussions. Most studies prioritize various parameters that emphasize the importance of safeguarding the environment and culture, rather than exploiting the resources of a particular area, when developing ecotourism initiatives [33]. Past studies have utilized a variety of MCDA techniques, including those that integrate AHP [34], Delphi [3,35], ELECTRE [36], FDEMATEL [37,38], Fuzzy AHP [39], Fuzzy ANP [40], OWA [1], TOPSIS [41,42], WLC [37,40], and the updated Simos procedure [33].

The study area possesses remarkable allure for both domestic and international tourists. Hence, it is imperative to conduct a systematic assessment to identify suitable areas for the development of ecotourism, given that the location is situated in a delicate ecosystem and near to UNESCO World Heritage site. Nevertheless, a notable limitation exists in the current body of research, as prior studies in this field are lacking. Therefore, systematically and comprehensively identifying suitable ecotourism locations would prove advantageous in promoting the ecotourism industry in the study area. Thus, the objective of the study was to develop a comprehensive ecotourism suitability index to guide policymakers to implement of tourism development policies. Furthermore, the study facilitates further in-depth investigation into uncovering ecotourism potential in areas with similar physical and socioeconomic characteristics. This was achieved through the aggregation of intricate criteria and factors. The study aims to address two research questions.

I. Are dispersed forest areas in the vicinity of Anuradhapura City suitable for ecotourism development?
II. What are the most influential factors/criteria for ecotourism development in the study area?

The resulting suitability index will offer enhanced insights into sustainable ecotourism management. Additionally, the research addresses existing research gaps in the study area while also opening up new avenues for research by integrating more complex criteria and procedures. The paper was structured into seven sections as outlined below. Section 1 provided an overview of the research background, while Section 2 was dedicated to the literature review. Section 3 outlined the study area, while Section 4 described the materials and techniques utilized. Results, along with the sensitivity analysis, were presented in Section 5. In Section 6 Discussion , important findings are compared with those of other similar research efforts to validate the GIS-MCDA ecotourism suitability index, emphasizing the real-world implications for forest-based ecotourism development in the study area. Finally, Section 7 presents the conclusion.

## 2. Literature review

AHP receives greater attention in ecotourism potential analysis due to its flexibility and practical applicability compared to other methods. Consequently, many researchers have utilized AHP to identify suitable ecotourism sites across various spatial contexts [43–47]. Previous researchers have employed a variety of criteria in their studies to identify suitable ecotourism areas. For instance, Kumari et al. (2010) utilized criteria such as wildlife presence, ecological value, ecotourism attractiveness, and environmental resilience to determine prospective ecotourism sites in Sikkim [48]. Bunruamkaew and Murayama (2012) incorporated criteria such as scenery, wildlife, topography, accessibility, and community features in their study [1]. Similarly, Ghous and Siddiqui (2022) utilized landscape, fauna, topography, accessibility, and settlement factors in their research [49]. Dhami et al. (2014) took into account tourist preferences in their study on ecotourism potential [50]. Similarly, Pathmanandakumar et al. (2023) utilized criteria such as landscape, protected area status, topography, accessibility, and community characteristics in their ecotourism suitability evaluation [6]. Fernando and Shariff (2017) employed six criteria for assessing ecotourism site suitability, including biodiversity, water resources, terrain, land use, road network, and settlements [51].

Chaudhary et al., in 2022 [52], employed an AHP-integrated GIS to identify potential ecotourism sites. Quinta-Nova and Ferreira, in 2022 [53], analyzed ecotourism suitability in the Beira Baixa region using a spatial decision support system based on GIS-MCDA. Samanta and Baitalik, in 2015 [54], identified potentially suitable sites for ecotourism in the surroundings of Bankura, West Bengal, primarily focusing on the natural components of ecotourism using GIS and remote sensing. Acharya et al., in 2022 [55], analyzed ecotourism site suitability using AHP and GIS for sustainable and resilient tourism planning in West Bengal, India. Kaymaz et al., in 2021 [5], employed the GIS-Fuzzy DEMATEL MCDA model to assess areas for ecotourism development in Uzundere, Erzurum, Turkey. Aneseyee et al., in 2022 [56], utilized the GIS Fuzzy WLC technique to identify suitable sites for community-based ecotourism in Abijata-Shalla Lakes National Park, Ethiopia. Sobhani et al., in 2023 [57], evaluated suitable zones for ecotourism in Lar National Park and Kavdeh Wildlife Refuge, Iran, by combining MCDA, a fuzzy set-theoretic approach, ANP, and WLC. Some researchers, such as Ahmadi et al. (2015) and Ohadi et al. (2013), have applied GIS overlay techniques in their studies. However, the majority of researchers have utilized GIS in conjunction with any of the MCDA methods when zoning ecotourism areas [49,50]. Among the MCDA techniques, AHP is the most widely utilized in combination with GIS [48,50].

No previous research was found in the GIS domain, and only one study was identified as having used the same approach utilizing

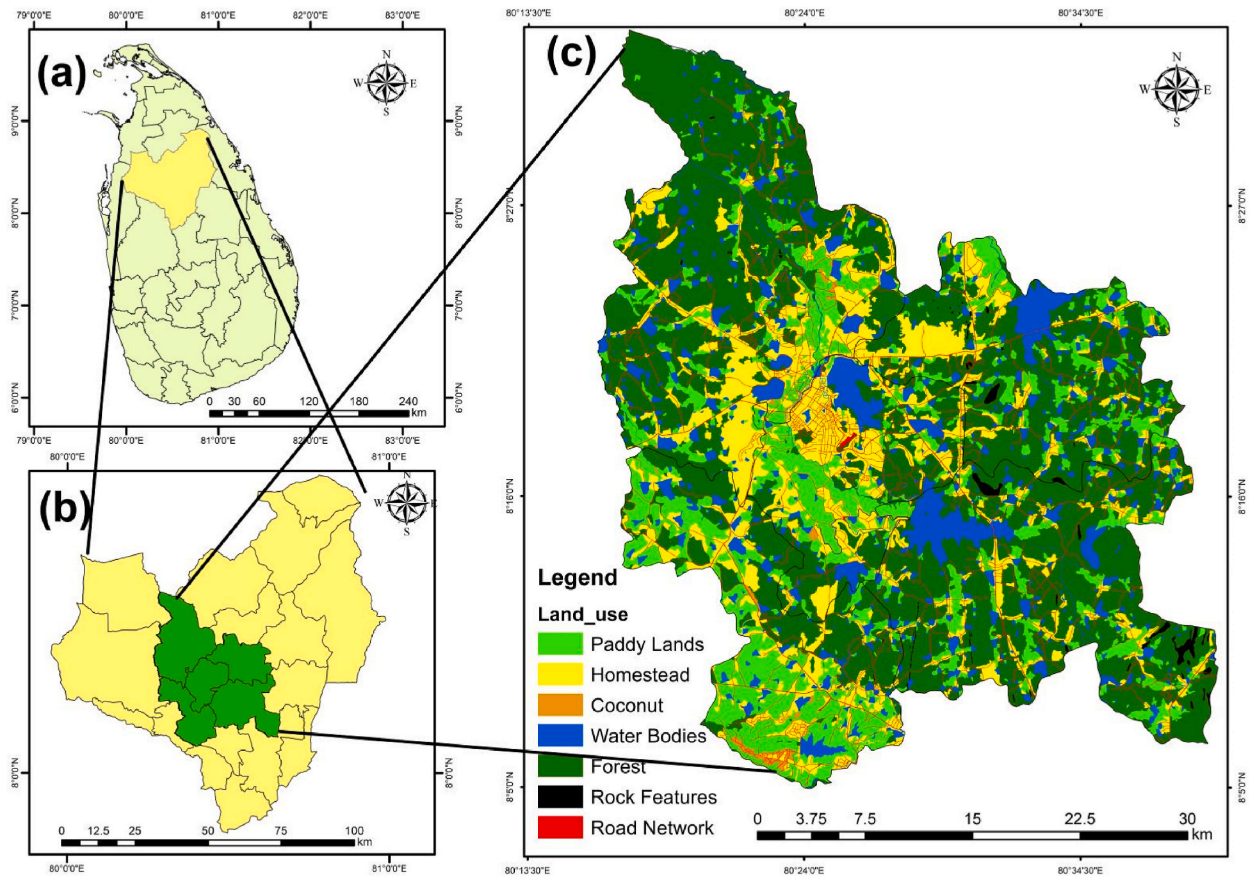


**Fig. 1.** Location (a) Sri Lanka; (b) study area; and (c) land use of study area.

GIS-MCDA by Pathmanandakumar et al. (2023) in the Batticaloa district, Sri Lanka [6]. The study represents the first attempt to apply geospatial tools in determining ecotourism suitability in five Divisional Secretariat Divisions (DSD) in the Anuradhapura district. The fuzzy GIS-MCDA technique was utilized to integrate 20 homogeneous criteria to derive the suitability index. Fuzzy AHP was chosen as the most commonly used technique to address various spatial issues within competing interests. Previous researchers [51] did not validate the findings of their studies using both the ROC curve and sensitivity analysis. Therefore, this study can serve as a reliable reference for conducting more realistic GIS-MCDA-based research in any field in the future.

## 3. Description of the study area

The kingdom of Anuradhapura, established in the fourth century B.C. according to the texts of Mahanama Thero, swiftly rose to prominence as the capital of Ceylon and a revered center of Buddhism. It retained its status as the political and religious heart of Ceylon until the 10th century B.C., except for a brief period during the invasion by Tamil monarchs at the beginning of the 2nd century B.C. During the seventh century B.C., the sacred city of Anuradhapura had a significant influence on the evolution of architecture. One of its main Buddhist sanctuaries is situated within the city [58]. For approximately 1400 years, Anuradhapura served as the capital of Sri Lanka, and over 120 monarchs utilized it as their administrative center to govern the island [59].

Sri Lanka lies comfortably within the tropical zone, positioned between 5° 55″N to 9° 51″N, and 79° 41″E to 81° 53" E (Fig. 1a) covering an extent of 65,610 $km^2$. As one of the world heritage cities in Sri Lanka, Anuradhapura is a more popular destination among domestic and foreign tourists due to its cultural and historical value with a huge number of heritage monuments in and around the

**Table 1**
Data sources and their relevance to the study.

| Factor | Criteria | Geo processing | Relevance | Reference |
|---|---|---|---|---|
| Landscape (F1) | Visibility (C1) | Raster surface analysis | Attractive and diverse landscapes with high visibility have a high potential for ecotourism | [1,37,55] |
| | Aspect (C2) | Raster surface analysis | Aspect influences the sunlight and microclimate | [35,56,57] |
| | Land use (C3) | Reclassify | LULC refers to the occupancy of land for a certain use in an area. The best locations for ecotourism are forests where there is little human influence. | [1,6,38,48] |
| Topography (F2) | Elevation (C4) | Raster surface analysis | The influence of the vertical relief change on the panoramic atmosphere, relief mosaic, and air quality is evident. | [1,6,38,56,61] |
| | Slope (C5) | Raster surface analysis | complexity and percentage of the slope affect accessibility, thus flat land is more suitable for ecotourism | [1,35,38,50, 57] |
| Accessibility (F3) | Proximity to roads (C6) | Euclidean distance | Road networks affect the accessibility of the ecotourism areas. Good interconnection between roads and tourist sites increases the value of tourist destinations. | [6,35,38,50, 51,55,56,62] |
| | Proximity to settlements (C7) | Euclidean distance | The distance from human settlements has a positive impact on ecotourism since it reduces noise and increases privacy | [6,38,50,51, 56,57] |
| | Settlement density(C8) | Reclassify | | |
| | Proximity to rivers/streams (C9) | Euclidean distance | Rivers provide the space for recreational activities and enhance the scenic beauty of an area. | [6,56,63] |
| | Proximity to tanks (C10) | Euclidean distance | The tanks in various scales play a crucial role in ecotourism since they are rich and sensitive ecosystems and also provide space for recreation functions. | [6,35,38,64] |
| | Proximity to accommodation facilities (C11) | Euclidean distance | Accommodation is a basic facility for a tourist in an area that provides shelter, food, and safety | [42,61] |
| | Proximity to cultural sites (C12) | Euclidean distance | Religious, and archaeological sites enhance the value of ecotourism areas and increase tourist attractions. | [1,6,55] |
| Climate (F4) | Temperature (C13) | IDW Kriging | Normal temperature has an impact on how pleasant the environment is, and how long tourists can enjoy the outside tourism activities | [35,56,57] |
| | Rainfall (C14) | IDW Kriging | The duration of stay, the kind of vegetation, as well as the itinerary and route of tourists, are all impacted by the spatial changes in rainfall in a region. | [35,56] |
| Forest & Wildlife (F5) | Proximity to forest/nature reserves (C15) | Euclidean distance | Protected areas and nature reserves have a significant potential for ecotourism because of their natural beauty and preservation of the environment. | [1,38,55] |
| | Forest/wilderness area size (C16) | Reclassify | With the increase the size of forest flora and fauna diversity also increase. The areas with rich biodiversity have more tourist attraction | [38,55] |
| | Vegetation type (C18) | Reclassify | Flora and fauna diversity is greatly influenced by vegetation type. | [56] |
| | Proximity to elephant occurrences (C17) | Euclidean distance | The potential for ecotourism is significantly impacted by vegetation type. While barren land and scrubs lands have little value for the development of ecotourism dense forest areas have the highest value. | [35,56,57] |
| Negative factor (F6) | Distance from towns (C19) | Euclidean distance | Proximity to city noise and congestion hurts ecotourism | [55,56,65] |
| | Distance from industries, mining, and landfill sites (C20) | Euclidean distance | Industrial locations, mining sites, and landfills have a detrimental impact on ecotourism, which lowers the tourist appeal. | [50,55,56] |

sacred city. Due to its individuality and cultural value, the great diversity of Buddhist shrines and historical sites have raised visitors attention. In addition, the surrounding area of the sacred city which houses varied natural landscapes which include old tank cascades, wilderness areas, and the rural lifestyle also offers potential grounds for ecotourism. The study area encompassed five Divisional Secretariat Divisions (DSD) in the Anuradhapura district, including Nuwaragampalatha East, Thalalwa, Mihintale, Nuwaragampalatha Central, and Thirappane (Fig. 1b). These divisions are situated around the sacred city of Anuradhapura, approximately 225 km away from Colombo, the commercial capital of Sri Lanka. These Divisional Secretariat (DS) divisions were chosen due to their proximity to the Anuradhapura World Heritage Site, which is a highly popular tourist destination both locally and internationally. The area covers a total of 1315 km$^2$ and includes 193 Grama Niladhari Divisions (GNDs).The study area belongs to the arid zone, the average annual rainfall in the study area is around 1300 mm with a mean annual temperature of 21°–32 °C. The research area typically experiences dry and warm climate conditions, although there are slight variations depending on the season. On average, there are around 99 days with rain, with the majority of rainy days occurring between October and January. Generally, lower temperatures are observed from November through March [60]. The area is characterized by thousands of tanks organized into tank cascades, which provide water for paddy and other field crops(Fig. 1c). These cascades support a variety of ecologically rich ecosystems with aquatic flora and fauna.

The peak influx of tourists occurs during the period from November to March, coinciding with the winter season in the northern hemisphere. During this time, weather is pleasant, the average temperature is lower, which provides a favourable conditions to visitors [51]. Consequently, both foreign and domestic tourists visit the sacred city of Anuradhapura during this period. The total population in the research region is 278,335 persons, with the majority depending on agriculture [59,60]. Rain-fed and irrigated paddy cultivation, cash crops, and *chena* (slash and burn) agriculture are significant farming practices in the research area. The major land use classes in the area are forest, agriculture, and homesteads. Approximately 43 % of the area is covered by forests, while 33 % is allocated for rain-fed and irrigated paddy fields and other field crop agriculture. Homesteads account for roughly 14 % of land use, and approximately 10 % of the area is covered by water bodies [59].

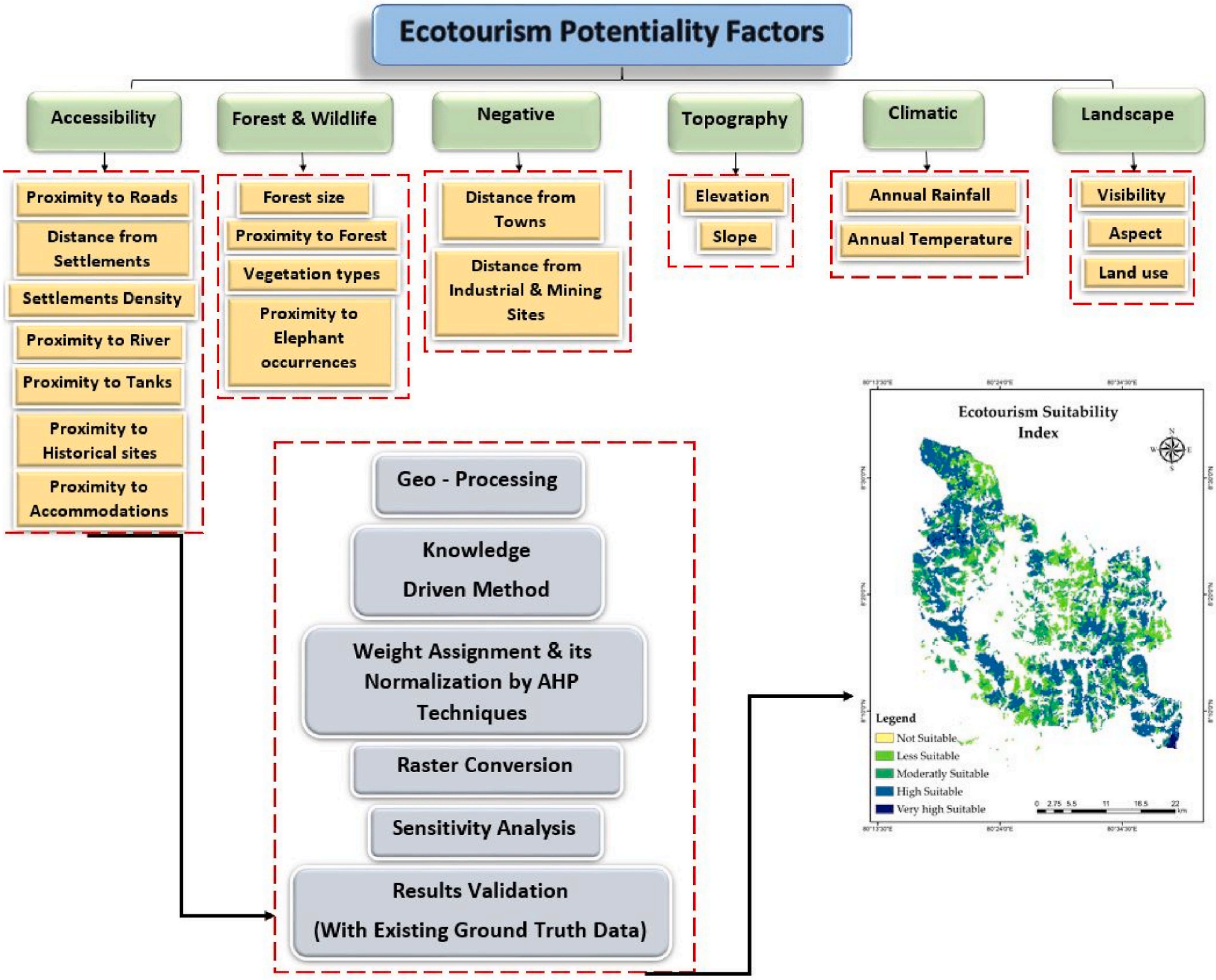


**Fig. 2.** Methodological flowchart of the study.

## 4. Materials and methods

### 4.1. Datasets and sources

Based on informal interviews with experts, previous studies, and the characteristics of the area, 20 criteria (Table 1) were selected. These criteria were then grouped into six factors: landscape, topography, accessibility, climate, forest & wildlife, and negative factors. These factors are deemed crucial for zoning and evaluating ecotourism suitability in the area. All of these criteria were integrated with the Fuzzy -AHP utilizing a distinct methodological flow consisting of six steps, as elaborated in section 4.2.

To obtain spatial data layers of elevation, slope, visibility, and aspect, a 30-m spatial resolution ASTER DEM was utilized. For calculating the visibility layer, eight reference points were employed, including two highest hills in the study area named Ritigala and Mihintale. The land use, vegetation type, vegetation size, forest, roads, tanks, and rivers/streams data layers were derived from the Sri Lankan Survey Department's digital data layer at a scale of 1:50,000. The settlement density layer was obtained from the Global Human Settlement Layer prepared by the European Commission (https://ghsl.jrc.ec.europa.eu/s1_2017.php). Rainfall and temperature distribution layers were generated using the annual average temperature and rainfall data for the year 2022 obtained from the Department of Meteorology Sri Lanka. This data was collected from six rainfall and temperature gauge stations sparsely located in the research area. The vector files of the locations of hotels and guesthouses, historical sites, towns, industries, mining areas, and dumping sites were created using Global Positioning System (GPS)location data gathered from CTDroid Sri Lanka mobile GPS version 4.5, developed by C. Alahakoon (2023) (https://play.google.com/store/apps/details?id=msc.research.ctdroid&hl=en&gl=US).The AHP weight, consistency index, and consistency ratio were computed using GNU Octave 8.4.0 software (https://octave.org/download). GIS Spatial analysis was conducted using Arc GIS 10.8, developed by ESRI (2019).

### 4.2. Methods

This study proposes the utilization of a GIS-coupled fuzzy Analytic Hierarchy Process (F-AHP) to assess the ecotourism potential in Anuradhapura City. Given that human decisions involve various considerations, multi-criteria decision-making encounters challenges such as incompleteness, subjectivity, and ambiguity. However, fuzzy MCDA offers the most effective and efficient judgment by mitigating these challenges. Thus, the Fuzzy MCDA method was also used for this study. Methodological flow includes six main steps: (i) identifying and constructing suitable criteria, (ii) standardizing criteria (iii) weight assignment and criterion scoring, (iv) consistency checking, (v) aggregation of final eco-tourism suitability index and sensitivity analysis, and (vi) validation. The entire research flow is presented in Fig. 2. Each stage is discussed in the sub-sections below.

#### 4.2.1. Selecting and structuring criteria

The identification of criteria is a crucial step in evaluating land suitability [37]. Accordingly, "suitability factors" relevant to an ecotourism suitability index were identified through informal interviews with 15 experts. These experts included 3 university academicians 4 planning directors, 3 tourism development officials, 2 GIS experts, and 3 land use policy planning directors. The selection of experts was based solely on their academic qualifications and professional backgrounds. The interview process addressed subjects such as the requirements of ecotourism development, land features, and other environmental factors. Through this process, 20 criteria were selected and categorized into six elements. Structuring involved identifying the main objective, sub-goals, and formulating criteria for evaluating them. In this study, the main goal is the evaluation of land suitability for ecotourism development. The sub-goals and criteria are organized under a decision tree.

#### 4.2.2. The criteria standardization

One of the most commonly used methods for this purpose is MCDA, which provides superior solutions among various relevant options within complex issue domains [5]. AHP is a frequently used method in MCDA and was introduced by Saaty [66]. AHP utilizes a fundamental scale of absolute numbers to represent individual preferences. This scale consists of a 1–9 scale (Table S1). The comparison between the two criteria was conducted using the relative importance scale for two alternatives as recommended by Saaty (1980), as it is the most commonly used in the AHP [66]. The attribute ranges of each factor were also ranked using a grading system supported by expert opinion, spanning from 1 to 5 (1 = not suitable, 2 = less suitable, 3 = moderate, 4 = highly suitable, and 5 = very highly suitable), as shown in Table S2.

#### 4.2.3. Weight assignment and criteria scoring

According to Satty's 1–9 scale, experts were tasked with ranking the factors and criteria for assessing ecotourism suitability. The GNU Octave 8.4.0 software is utilized to compute the criteria and factors, as well as to determine the AHP weight, consistency index, and consistency ratio. Weights were established using the arithmetic mean method after normalizing each value by dividing the actual value by the sum of the column values in a pairwise comparison matrix. A pairwise analysis of factors was conducted for the definition of possible ecotourism sites. The matrix format in pairwise comparisons defines $A = [C_{ij}]_{nxn}$ as equation (1) [62];

$$\begin{bmatrix} C_{11} & C_{12} & C_{1n} \\ C_{21} & C_{22} & C_{2n} \\ C_{1n} & C_{2n} & C_{nn} \end{bmatrix} \tag{1}$$

After normalizing each value in the pairwise comparison matrix by dividing it by the sum of the column values (Table S3) [67].

#### 4.2.4. Check the consistency

According to Saaty's model, it is important to check the consistency of pair-wise matrices. The Consistency Ratio (CR) is derived using equation (2) [62,67];

$$CR = \frac{CI}{RI} \tag{2}$$

where CI indicates consistency index, RI means random index whose value depends on the matrix order. The consistency index can be expressed as equation (3) [62];

$$CI = \frac{\lambda_{\max\ n}}{(n-1)} \tag{3}$$

here, if the CR > 0.10, then some pair-wise values require to be checked, and if the CR < 0.01, then the value is acceptable. Where $\lambda_{\max}$ is the largest eigenvalue of the matrix, and $n$ indicates the order of the matrix [66]. The RI was estimated according to the random inconsistency table presented by Satty that ranges values from 0.00 to 1.49 (Table S4) Accordingly CI for key variables was reported as 0.53772 and RI was 0.43364 (Table S5).

#### 4.2.5. Ecotourism suitability evaluation

The overlay method was implemented based on the concept of Weighted Linear Combination (WLC). Factors and criteria were integrated using WLC [68] with the derived weights (Table 2). The WLC approach involves normalizing the suitability maps, assigning them relative weights, and then combining these weights with the standardized suitability maps to obtain an overall suitability score [69]. After producing all pairwise comparison matrices (Table S6), the vector of weights, w $\{w_1, w_2, \ldots w_n\}$ is calculated according to Saaty's eigenvector method. This is followed by two steps to calculate weights; first, normalizing the pairwise comparison matrix $A = [C_{ij}]_{nxn}$ based on the following equation (4) [62];

$$C_{ij} = \frac{C_{ij}}{\sum_{j=1}^{n} C_{ij}} \tag{4}$$

Second, the weight for each criterion is computed by the following equation (5) [62];

$$W_{ij} = \frac{\sum_{j=1}^{n} C_{ij}}{n} \tag{5}$$

In the process of evaluating ecotourism suitability, a composite suitability map is developed by aggregating six factors, including landscape, topography, accessibility, climate, forest and wildlife, and negative factors. All thematic layers were converted into raster format and then reclassified into standardized suitability scales assigned for different attribute values (Table S2) for each criterion. The pixel depth of derived rasterized layers was 8bit and 30x30 cell size. The mapping of ecotourism suitability utilizes a dimensionless metric termed the Ecotourism Suitability Index (ESI). The index is calculated after normalizing and reclassifying all criterion layers following the weights and score rankings. ESI is computed using equation (6) [68,69];

**Table 2**
Factor and criterion weights.

| Factor | Weights | Criteria | Weights |
|---|---|---|---|
| Landscape (F1) | 0.0844 | Visibility (C1) | 0.4806 |
| | | Aspect (C2) | 0.4053 |
| | | Land use (C3) | 0.1139 |
| Topography (F2) | 0.1601 | Elevation (C4) | 0.4999 |
| | | Slope (C5) | 0.4999 |
| Accessibility (F3) | 0.1861 | Roads (C6) | 0.0653 |
| | | Settlements distance (C7) | 0.0289 |
| | | Settlements density (C8) | 0.0309 |
| | | Proximity to river (C9) | 0.2349 |
| | | Proximity to tanks (C10) | 0.1830 |
| | | Proximity to accommodations(C11) | 0.1476 |
| | | Proximity to historical sites (C12) | 0.3090 |
| Climate (F4) | 0.0847 | Temperature (C13) | 0.2591 |
| | | Rainfall (C14) | 0.7499 |
| Forest & Wildlife (F5) | 0.3723 | Forest distance (C15) | 0.4567 |
| | | Forest size (C16) | 0.2127 |
| | | Forest type (C17) | 0.1479 |
| | | Proximity to elephant occurrences (C18) | 0.1825 |
| Negative factors (F6) | 0.1122 | Distance from towns (C19) | 0.2591 |
| | | Distance from industry and mining sites (C20) | 0.7499 |

$$ESI = \sum_{i}^{n} W_i X_i \tag{6}$$

where *ESI* stands for ecotourism suitability index, '$W_i$' indicates the multiplication of all related weights in the hierarchy of '*i*th' factor given for a particular class of the '*i*th' factor found on the evaluated land unit. In most MCDA methodologies, sensitivity analysis is suggested to assess the influence of decision-maker biases on the reliability of the generated results [37]. By adjusting the cluster weights (Table S7) for six scenarios according to the study's parameters, sensitivity analysis was conducted to validate the reliability of the outcomes.

## 5. Results

### 5.1. Eco tourism suitability

Following the assignment of weights and score values to the results of the experts' questionnaire survey, varying weights and scores were allocated for each criterion and attribute range. The spatial coverage of suitability classes for each criterion and factor is entirely contingent upon the assigned weights and scores. The ecotourism suitability of each criterion was generated (Fig. 3) based on score

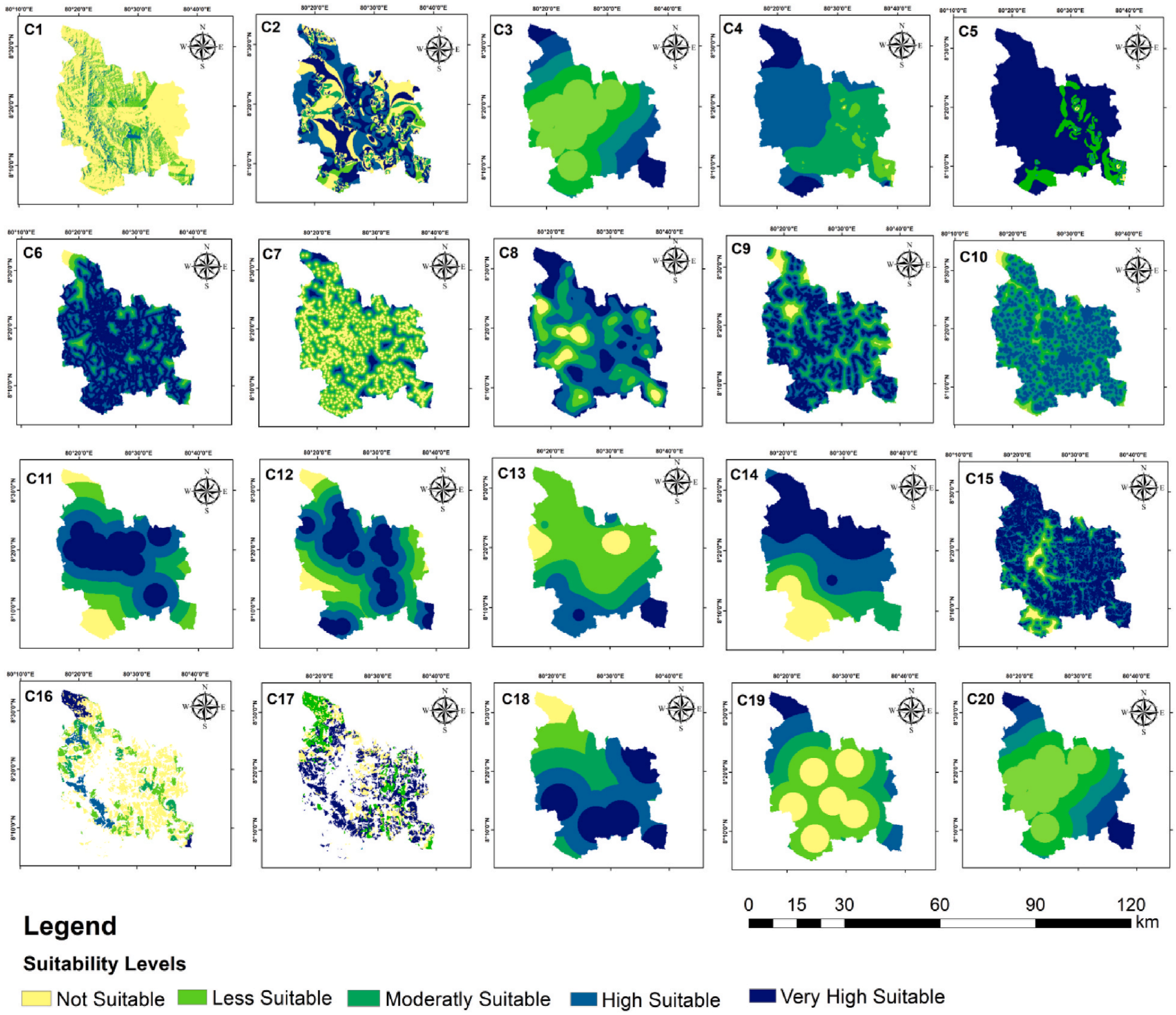


**Fig. 3.** Ecotourism suitability; (C1) visibility, (C2) aspect,(C3) land use, (C4) elevation, (C5) slope, (C6) proximity to roads, (C7) distance from settlements, (C8) settlement density, (C9) proximity to river, (C10) proximity to tanks,(C11) proximity to accommodations, (C12) proximity to historical sites,(C13) temperature,(C14) rainfall,(C15) proximity to forest, (C16) forest size, (C17) forest type, (C18) proximity to elephant occurrences, (C19) distance from towns, (C20) distance from industries & mining sites.

values utilized for different attribute ranges. When allocated the weights for reclassified thematic layers rainfall and distance from industrial and mining sites have received high weight (0.7499) as an individual criterion, whilst settlement distance and settlement density have received low weight as 0.0289,0.0309 respectively. After reclassification, the most highly suitable area reported for slope

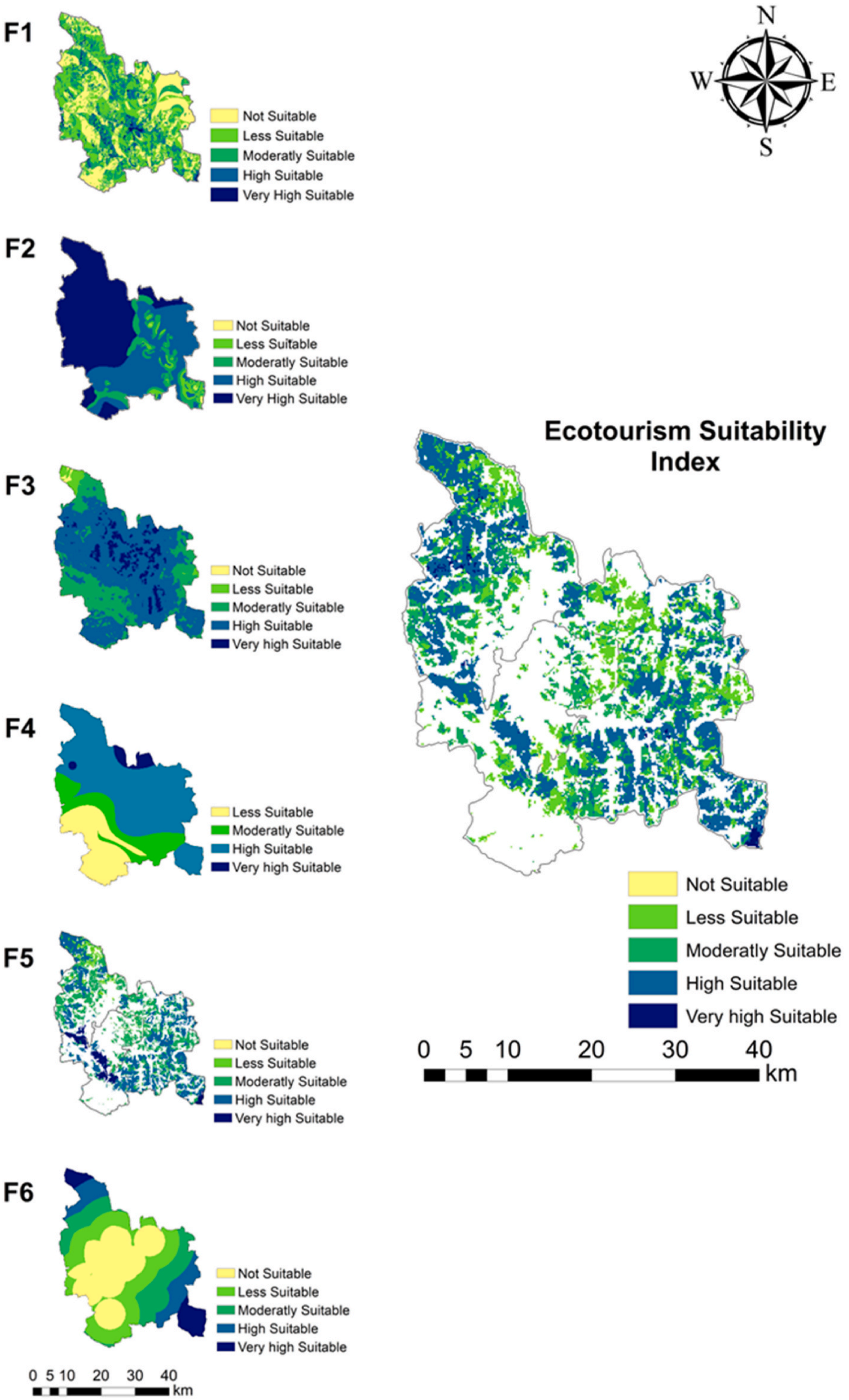


**Fig. 4.** Ecotourism suitability for (F1) landscape factor, (F2) topography factor, (F3) accessibility factor, (F4) climate factor, (F5) forest & wildlife factors, (F6) negative factors, and overall ecotourism suitability index.

(C5) is 1093 km$^2$, while the lowest highly suitable area reported is 2.5 km$^2$ for visibility (C1). The forest and wildlife factor obtained the highest weight in the suitability evaluation (0.3723), while the landscape factor was considered to have the lowest weight among the six factors. According to the generated suitability map (Fig. 4) for the landscape factor, 72.1 km$^2$ (5.4 %) of the area was classified as very highly suitable, while 26.4 % of the areas were deemed not suitable for ecotourism (Table S8).

Since the study area is on level terrain, the topography factor was identified as having the highest very high suitability area (668.5 km$^2$) among all other criteria. Hence, the majority of Nuwaragampalatha's central DSD is highly suitable based on topography factors. Additionally, 934.8 km$^2$ (71 %) of the area around the city, connected to road networks across flat terrain, falls into the high and very highly suitable categories for the accessibility factor. This includes the majority of lodging facilities, historical monuments, and other ecotourism attractions.

Rainfall and warm temperature also create favorable conditions for tourists. Therefore, 62.8 % of the areas fall into the high and very highly suitable categories for ecotourism. However, due to the proximity to small towns and Anuradhapura City, about 413 km$^2$ (31.4 %) of the study area is not suitable due to negative factors. Consequently, only Ritigala strict nature reserve and dispersed forests in the northern boundary of Nuwaragampalatha central DSD can be considered as very highly suitable for ecotourism. Except for forests, all other land use classes totaling roughly 745 km$^2$ are excluded from suitability assessments under the forest and wildlife factor. Thus, only 43.4 km$^2$ can be considered as very highly suitable under this factor. However, the study region is typically rich in dry monsoon forests, with approximately 41 % of the area being highly suitable for ecotourism. Due to the significant weight assigned to the forest and wildlife factor in the overall suitability evaluation, all other areas are omitted from the final suitability assessment. Although only 11.8 km$^2$ (2 %) falls into the very highly suitable category, 43.4 % of the area is classified as highly suitable for

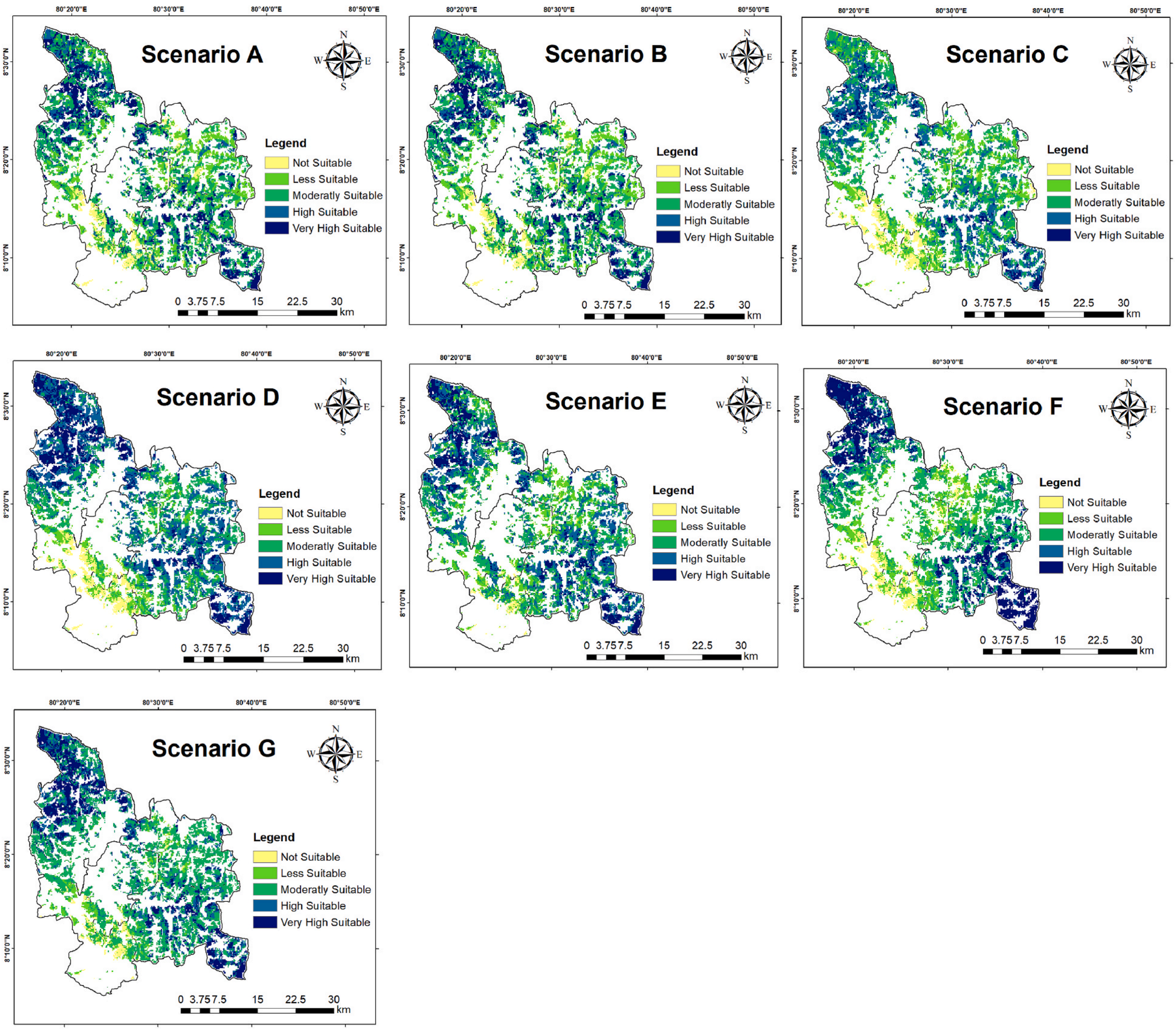


**Fig. 5.** Ecotourism suitability on different sensitivity analyses; (A) landscape scenario, (B) topography scenario, (C) accessibility scenario, (D) climate scenario, (E) forest & wildlife scenario, (F) negative factors scenario, (G) balanced cluster weight scenario.

ecotourism. Only Ritigala strict nature reserve and other small spots surrounding Elayapattuwa are considered to be very highly suitable. Overall, the dispersed forest cover offers significant potential to promote the study area as an ecotourism destination near Anuradhapura World Heritage City. As a result, except for 26.1 % (148.6 $km^2$), all other forest areas are suitable for ecotourism. The most highly suitable areas can be found in Thirappane and Nuwaragampalatha central DSD, while it is impossible to locate very highly suitable areas in the other three DSDs. Not suitable areas are spread in small patches along Mihintale and Nuwaragampalatha east DSDs.

### 5.2. Sensitivity analysis

Ecotourism suitability maps for multiple scenarios were derived by altering cluster weights (Fig. 5 A-G). Table S9 presents the findings of the sensitivity analysis of seven scenarios. The sensitivity analysis revealed that scenarios E-forest and wildlife (Fig. 5 E) and C-accessibility(Fig. 5C) exhibited high spatial consistency when compared with the overall suitability map, whereas scenario A-landscape (Fig. 5 A) showed low consistency. Accordingly, ecotourism development favors and relies more on the attributes of forests, wildlife, and accessibility. In Scenario E, 44.4 $km^2$ is classified as very highly suitable, 216.8 $km^2$ as highly suitable, 184.4 $km^2$ as moderately suitable, 106.7 $km^2$ as less suitable, and 18.5 $km^2$ as not suitable. Conversely, Scenario C demonstrates 62.4 $km^2$, 201.8 $km^2$, 176.4 $km^2$, 105.4 $km^2$, and 22.8 $km^2$ for each respective class.

As fulfill the primary aim of the study, various spatial coverage were documented for each suitability class after processing the ecotourism suitability model. The index reveals that 11.8 $km^2$ of areas are classified as very highly suitable, 247.2 $km^2$ as highly suitable, 161 $km^2$ as moderately suitable, 133.1 $km^2$ as less suitable, and 15.5 $km^2$ as not suitable for ecotourism. Most of these results primarily pertain to Scenario E-forest and wildlife in the sensitivity analysis.

## 6. Discussion

### 6.1. Advantages of GIS-based ecotourism suitability modeling

The GIS-MCDA method efficiently identified distinct suitable zones by overlaying numerous factors and criteria. The proposed approach is deemed more reliable, effective, and cost and time-saving, as it integrates spatial and non-spatial data as well as expert opinion into a common decision hierarchy. Previous studies have also demonstrated that GIS-integrated MCDA analysis techniques are more reliable and cost-effective in selecting suitable areas for ecotourism development [6,35]. Scenario-based prediction and model validation play an essential role in enhancing the reliability of the generated outcomes. The significance of this study is elevated due to the dearth of prior research in Anuradhapura and other regions of Sri Lanka. The application of GIS-MCDA presents valuable opportunities for investigating eco-sensitive areas with substantial tourist attractions. By incorporating more complex factors and criteria, researchers can bolster the reliability of their findings. Additionally, the utilization of sensitivity analysis and model validation techniques, such as Receiver Operating Characteristic (ROC) analysis, can further enhance the credibility and robustness of the study's outcomes. The findings of the suitability index can be leveraged for various purposes by relevant authorities in the North Central Province, including tourism infrastructure planning, visitor flow management, forest and natural resource management, and other strategic initiatives. Given the distinct advantages of the AHP integrated with fuzzy MCDA, such as its capability to handle multiple criteria, ability to integrate both qualitative and quantitative data, low inconsistency, and flexibility in assessment results, this method holds significant potential for application in other research endeavors across diverse spatial contexts. Since Sri Lanka is an island country, the recommended methodology is also highly applicable and fruitful for coastal tourism potential studies.

### 6.2. Forest-based ecotourism development in Anuradhapura area

A comprehensive suitability index for ecotourism potential was developed, comprising five classes: very high, highly suitable, moderately suitable, less suitable, and not suitable. The index indicates that 2 % of areas are categorized as very highly suitable, 43.4 % as highly suitable, 28.3 % as moderately suitable, 23. 6 % as less suitable, and 2.7 % as not suitable for ecotourism. The findings revealed that dry monsoon forests are more inclined towards very high and highly suitable areas for ecotourism development. Near the Ritigala strict nature reserve and other protected forest areas (dispersed forest patches near Wilpattu National Park), some highly suitable spots were identified. Similar results were observed by Pathmanandakumar et al. (2023) in the Batticaloa area, Sri Lanka, and by Chaudhary et al. (2022) in the Himalayan region, India [6,61]. Since the peak season (June–July) is when both domestic and foreign tourists flock to the Anuradhapura Sacred City, it would be more advantageous to encourage rural ecotourism ventures in those areas that have been identified as very high and highly suitable by enhancing the existing amenities and accessibility further. The forest and wildlife elements were found to be more essential in the overall suitability assessment, similar to findings by Pathmanandakumar et al. (2023), Gigović et al. (2016), and Chaudhary et al. (2022) [6,37,61].

Given that the study area is situated within a sensitive environment, ecotourism development should predominantly focus on the principal findings, incorporating sensitivity analysis results. This approach is crucial for ensuring adherence to sustainable ecotourism principles, which aim to preserve fragile ecosystems and cultural values. Thus, it is vital to focus on strict conservative measures to promote forest-based ecotourism, especially in Ritigala strict nature reserve and neighboring parts of Wilpattu National Park, as such places carry a more sensitive ecological environment. Restricted and forbidden methods for natural resource consumption should be established to protect the sensitive ecological environment. Educational ecotourism activities will be more helpful to both visitors and authorities in the Ritigala forest area. Additionally, there is great potential to promote ecotourism activities in villages adjacent to forests by offering lodging and eco-friendly transit facilities for visitors in Mihintale, Nuwaragampalatha East, and Central DSDs. However, despite 25 % of forest areas being deemed not ideal and less suitable for ecotourism, those areas might still be utilized for tourism infrastructure development, as indicated by Pathmanandakumar et al. (2023) [6].

### 6.3. Validating the suitability index

Validation of the ecotourism model is crucial for ensuring the reliability and scientific significance of the produced results [6,61,70]. While earlier researchers have employed various methods to confirm their findings, the Receiver Operating Characteristic (ROC) curve is the most commonly used strategy, illustrating the correlation between false positive values (Y-axis) and false negative values (X-axis) [6,61,71]. The Receiver Operating Characteristic (ROC) curve (Fig. 6) was generated using the results obtained from 40 random points collected from the current ecotourism suitability sites and compared with the generated suitability map (Fig. S1). Among the 40 sample points, 27 locations precisely matched the suitability classes obtained (Table S10). The prediction accuracy of the ROC curve is demonstrated by the area under the curve (AUC) that describes the absence and presence of preset events [6,61,71,72]. The prediction accuracy of the ROC is graded into five groups: poor (0.5–0.6); average (0.6–0.7); good (0.7–0.8); very good (0.8–0.9); and excellent (0.9–1) [6]. The random error matrix was created using points and real ground locations and then validated the results and observations [6,72]. The ROC curve illustrates an average AUC value of 0.649, which reflects 64.9 % accuracy of prediction. In summary, the AUC value suggests that while the AHP-based suitability analysis is better than random chance, it requires scrutiny, adjustments, and possibly collaboration with domain experts to enhance its accuracy and reliability for practical decision-making. However, in the absence of prior similar research, the resulting model is credible and may be applied as a road map for ecotourism planning and development in the study area.

### 6.4. Limitations and future research direction

Due to time and resource constraints, this study was undertaken only in a narrow area. However, identifying tourist potential remains a key issue, as it has the potential to significantly benefit the economy of the North-Central province as well as the entire island. Therefore, further in-depth research should be conducted in the future to explore ecotourism potential in locations with comparable physical and socioeconomic characteristics by incorporating complex criteria and components. In future research, it is advisable to address subjectivity constraints such as bias in criteria selection and weight assignment. By overcoming these challenges, the reliability and objectivity of the research outcomes can be significantly improved. Due to geographic and socioeconomic variations in other areas, generalizing the findings of the index across different spatial contexts may pose inherent challenges. Hence, scholars need to prioritize criteria selection while considering the diverse geographic and socioeconomic settings of the study areas.

Additionally, it is recommended that future research explores additional relevant models offered by earlier researchers in other spatial contexts [1], as the carrying capacity model provides a holistic strategy for managing ecotourism resources in the study area. Comparison studies with other well-known MCDA approaches, such as TOPSIS and DELPHI, would be advantageous to provide more realistic findings in the future, in addition to model validation and sensitivity analysis. Since the GIS tool is only a preliminary method

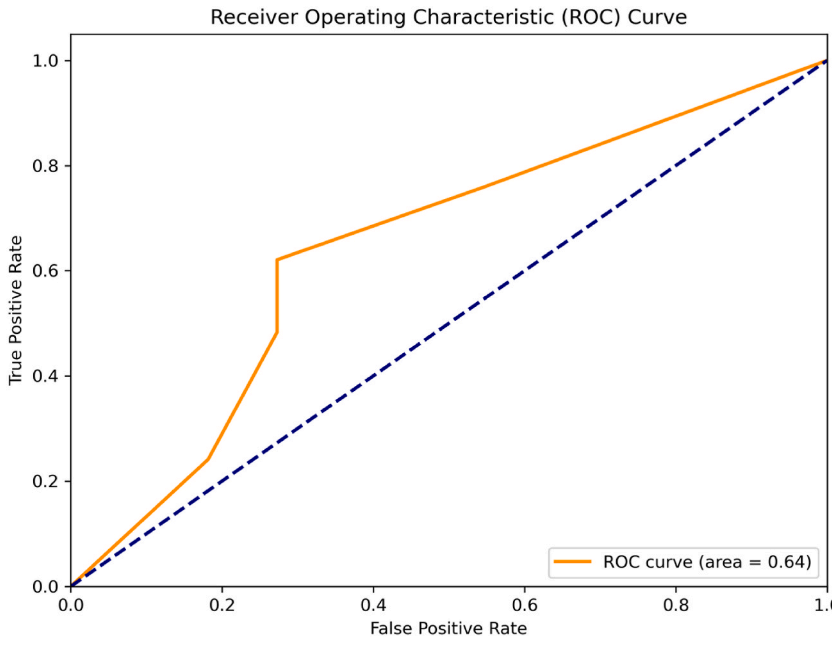


**Fig. 6.** Receiver Operating Characteristic (ROC) curve.

for assessing suitable land areas for ecotourism development, further research can be conducted based on other information sources such as remote sensing and GPS [1]. As land use decisions are not solely determined by GIS-based spatial studies, it is advisable to conduct future research on economic-based evaluations and environmental impact assessments in conjunction with GIS analysis.

## 7. Conclusion

The main objective of our study was to develop a comprehensive ecotourism suitability index for five selected divisional secretariats around the sacred city of Anuradhapura using the GIS-integrated MCDA technique. The following conclusions were drawn from the analysis.

I. 45 % of forest areas in the vicinity of Anuradhapura City are highly suitable for ecotourism.
II. In the suitability evaluation, the forest and wildlife factor obtained the highest weight, whereas the landscape factor was assigned a lower weight.
III. The index suggested that the southeastern boundary and the dispersed protected areas in the northwestern half can be considered very highly suitable for ecotourism development.
IV. Sensitivity analysis revealed that the forest and wildlife, as well as accessibility factors, exhibit high consistency with the overall suitability index.
V. Derived AUC value suggests that the AHP-based suitability analysis is better than random chance.

Sensitivity analysis and validation were crucial in maintaining the scientific reliability of the resulting index. Most of the villages near Anuradhapura -city, with good road connectivity, lodging, and tourist attractions, have substantial potential for ecotourism. However, since the majority of highly suitable sites are situated in dry evergreen forests with high ecological value, it is imperative to implement tourist development strategies that align with restricted and protected measures. Given the substantial benefits of the recommended strategy over previous methods, attributed to its thorough modeling and predictive capacity, it offers a more realistic and efficient approach to tourism planning. Provincial planning bodies engaged in tourism and rural development stand to gain significantly from the suggested suitability index. Moreover, the same strategy, complemented by precise methodologies and data, holds promise for other academics in their future studies on tourism suitability evaluation.

This study was limited to a small area around Anuradhapura city due to time and resource limitations. The absence of freely accessible high-resolution satellite data also posed a challenge during the creation of spatial data layers like houses. This limitation somewhat impacted the quality of the final output layers in GIS-MCDA. Therefore, enhancing the quality can be achieved by utilizing high-resolution remote sensing data in future research. In future research endeavors, it is recommended to address biases in criteria selection and weight assignment to enhance the reliability and objectivity of research outcomes by investigating ecotourism suitability through integrating complex criteria and components. This can be achieved through comparative studies with other established MCDA techniques, such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and DELPHI.

## Ethics approval and consent to participate

**(NA)**

The study primarily focuses on indexing ecotourism suitability in the Anuradhapura world heritage City using GIS- MCDA methodology.The decision not to pursue ethical approval from a committee is grounded in the following considerations.

The study not fall within the scope of medical research or clinical trials involving human beings in a traditional sense. Instead, it concentrates on geographical and spatial analysis to derive a ecotourism suitability index.

The data collection process is internet-based and does not involve direct interaction with participants. Participants were invited to voluntarily fill out a questionnaire, and the information collected was non-sensitive and related to spatial preferences and perceptions.

The participants were explicitly informed that their participation was entirely voluntary and that they could withdraw at any time without facing negative consequences. Additionally, the study ensures anonymity, and no personally identifiable information is collected.

The study utilizes spatial data layers and publicly available information, reducing the potential for privacy concerns or risks associated with sensitive data.

While we acknowledge the significance of ethical considerations in research, we believe that the nature of our study, its' voluntary and non-intrusive aspects, and the transparent communication with participants mitigate the necessity for formal ethical approval.

Given these factors, and in concordance with established practices in internet-based research of a non-intrusive nature, we have concluded that the specific characteristics of our study may exempt it from the formal ethical approval processes typically associated with human subject research.We remain dedicated to transparency, ethical conduct, and the safeguarding of participant rights throughout our research endeavors.

## Consent for publication

(NA)

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## Data availability statement

Data Attached as Supplementary File.

## CRediT authorship contribution statement

**Neel Chaminda Withanage:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dilnu Chanuwan Wijesinghe:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Prabuddh Kumar Mishra:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Kamal Abdelrahman:** Writing – review & editing, Supervision, Software, Resources, Methodology, Conceptualization. **Vishal Mishra:** Writing – review & editing, Visualization, Software, Methodology, Investigation. **Mohammed S. Fnais:** Writing – review & editing, Writing – original draft, Supervision, Software, Investigation, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.


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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31585.

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