Spatial analysis of potential ecological sites in the northeastern parts of Ethiopia using multi-criteria decision-making models

Kiros Tsegay Deribew1 · Yared Mihretu1 · Girmay Abreha1 · Dessalegn Obsi Gemeda2

Abstract
The northeastern part of Ethiopia, particularly Raya area is a pilgrimage site famed for its antique civilization, archaeological sites, and rural landscapes. Despite existing ecotourism potentials, the area has not been utilized for tourism for millennia. While previous work looked at the availability of natural resources, it did not identify and prioritize the resources, so knowledge gaps continue to exist in prioritization of potential ecotourism sites. This study attempted to identify various ecotourism indicators, evaluate and produce maps of suitable ecotourism sites, and prioritize optimum protected areas that are best suited for sustainable ecotourism development of Raya areas. For this analysis, 13 spatial indicators from physical, environmental, archaeological, socio-cultural, and socioeconomic sectors were considered. Analytic Hierarchical Process (AHP) was used to calculate the details of the spatial indicators and class weights. The suitability maps were classified into four classes as Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (N1), and Not Suitable (N2). The results revealed 114.37 Km² (10.33%), 13.36 Km² (1.91%), and 10.39 Km² (1.62%) fall under the highly suitable class in Blocks B, A and C, respectively. AHP weights with ultimate criterion and field observations also ranked lake Ashenge, Hugumburda, and Gratkhassu national forest priority areas as 1st, 2nd, and 3rd optimal zones, respectively. The outcomes of this study are crucial for conservation pioneer work in ecological development, and should be used as an ideal blueprint by ecotourism planners and decision-makers for sustainable ecotourism development strategies.

Keywords AHP · Ecotourism · Multi-criteria decision making · Optimal · Spatial indicators

* Kiros Tsegay Deribew
crossstsegaye@gmail.com

Extended author information available on the last page of the article
Abbreviations

AHP  Analytic hieratical process
CSA  Central statistical authority
MCDM Multi-criteria decision making analysis
WTO  World tourism organization
GIS  Geographic information system
GPS  Global positing system

1 Introduction

The spectrum of ecotourism passes nature-based, natural resources conservation, educational, economic, sociocultural well-being, and sustainable development components (Blamey 1997; Diamantis 1999; Ok 2006; Lee and Xue 2020; Xu et al. 2020; Zabihi et al. 2020; Dowling and Pför 2021; Guo et al. 2022). However, conservation plans and tourist activities may jeopardize the hotspot site if the number of tourists and forms of cultural activities go beyond the carrying capacity; or if it is not managed and monitored under careful plans (Sims 2010; Jennifer et al. 2010; Suryabhagavan et al. 2015; Masih et al. 2018; Mansour et al. 2020; Heshmati et al. 2022). In the environmental dimension, therefore, it is indispensable to lessen the social and physical impacts of human activities via tourism on the environment.

In the recent past, despite the ecosystem and local culture detrimental impacts, ecotourism contributes substantially to economic growth, greater export returns, job opportunities, and foreign investments (Scheyvens 1999; Stronza 2007; Snyman 2017; Omarzadeh et al. 2021). In this regard, owing to economic contributions study highlighted that the ecotourism sector contributes 5–10% of GDP, 35% of the export services, 11.4% of all consumer expenditures, and 4.2% of job opportunities on the planet (WTO 2012). The organization has also highlighted that since the mid of 1980s the sector has raised at an average range of 9–12% per annum though it varies accordingly due to natural and human disturbances. However, the organization in its report in 2021 highlighted that international tourism was up 4% in 2021 but still 72% below pre-pandemic levels. In line with this, the recent surge in COVID-19 cases and the emergence of the Omicron variant could disrupt the recovery of tourism. Nevertheless, Africa saw twice the increase in 2021 due to vaccination distribution compared to 2020, though remained 74% below 2019 levels compared to the Middle East status (UNWTO 2022). In the present day, thus, the idea reflects that ecotourism is one of the most sensitive issues and a key to sustainable tourism development in both developed and developing countries. The existence of natural resources found to be a key contribution to ecotourism development in both high and low-income countries (Lai and Nepal 2006; Lee and Jan 2019). The United Nations World Tourism Organization (UNWTO) in 2022, however, in the recent day, the panacea industry is seen rapidly growing in low-income countries compared to affluent countries. For instance, between the mid-1990s and 2000s, the organization reported that ecotourism has expanded by 9 and 6% in low and high-income countries, respectively (UNWTO 2022). The same organization also reflects...
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that in Africa, the tourism revenue reached US$34.2 billions in 2013, and arrivals are predicted as 134 million by 2030.

Like other tropical regions in Africa, Ethiopia is characterized by potential diverse landscapes and biodiversity, paramount archaeological sites, and socio-cultural diversity. Nevertheless, the countries’ ecotourism is far behind from top seven recipients of tourist arrivals in Africa (Ambecha et al. 2020). It has been dealing with issues such as weak government policy, rapid population growth, pressure on foreign debts, desertification, and lack of capital over the past 6 decades (Abebe et al. 2019; Deribew and Dalacho 2019; Abrehe et al. 2021). The Ethiopia tourism statistics 1995–2022 report highlighted that the tourism receipts for 2018 were a 41.64% increase from 2017, and a nearly three-fold increase from 2016. However, ecotourism is a tool to protect the environment, therefore, economic stimulus is necessary, particularly in remote regions with weak government supervision. Likewise, studies confirmed that ecotourism requires low initial investments to grow at a fast rate to generate income, machine development, cover the debt and protect the environmental conditions in poor income countries (Wunder 2000; Koens et al. 2009; Jeong et al. 2014; Deribew 2019; Omarzadeh et al. 2021).

Geographic Information System (GIS) has accelerated spatial aspects of ecotourism conservation through the identification and prioritization of potential ecotourism sites using the certain criteria for sustainable development at minimum cost and time (Ross and Wall 1999; Ullah and Hafiz, 2014; Deribew 2020). GIS integrates with multi-criteria decision making analysis (MCDMA) using analytic hierarchy process (AHP) based on the pair-wise comparison in ratio scale was found to be a phenomenal method to compare themes supported relative importance for the identifications of potential ecotourism zone (Saaty and Vargas 2001; Kumari et al. 2010; Nino et al. 2017). To evaluate the site’s suitability for ecotourism, GIS and AHP were applied based on environmental and socioeconomic themes in the upper Amazonian forest, and the diversity of large mammals in a land plot that contributes to the development of ecotourism (Salvador et al. 2011; Zabihi et al. 2020). On the contrary, applying the same methods, the presence of slope among used 13 themes contributes to potential ecotourism activities were realized in Kullu district, Himachal Pradesh, India (Sahani 2019). Another study, however, conducted in Andiracha district, Sheka zone in southwestern Ethiopia reported that the existence of the magnificent lake, natural forest, and wetland that contributes to the development of ecotourism (Ambecha et al. 2020). This implies the method is the crux to explore ecotourism development including location, condition of the area, trends and changes, routing to and through the site, and patterns associated with utilization resource.

Thus, identification of potential areas for the development of ecotourism augments economic growth and conservation of natural resources, thereby minimizing pressure on natural resources and, hence assuring sustainable development. Even though natural resources such as ecotourism have been realized the source of sustainable development in several areas, the northeastern Ethiopia (parts of Raya areas) home to natural forests, wetland and grasslands, highland lake, diverse archaeological sites, and socio-cultural sites are entirely dependent on subsistence agriculture and put aggressive pressure on natural resources. The northeastern part
of Ethiopia, particularly Raya area is a pilgrimage site famed for its antique civilization, archaeological sites, and rural landscapes. Despite existing ecotourism potentials, the area has not been utilized for tourism for millennia. While previous work looked at the availability of natural resources, it did not identify and prioritize the resources, so knowledge gaps continue to exist in prioritization of potential ecotourism sites. This study attempted to identify various ecotourism indicators, evaluate and produce maps of suitable ecotourism sites, and prioritize optimum protected areas that are best suited for sustainable ecotourism development in the study area. From this site selection point of view, this paper is crucial for conservation pioneer work in ecological development, and should be used as an ideal blueprint by ecotourism planners and decision-makers for sustainable ecotourism development strategies.

2 Materials and methods

2.1 Description of the study area

The study encompasses parts of selected Raya areas (the former Dobe’a kingdom in medieval of Ethiopia) namely, Raya-Alamata (Block-A), Raya-Ofla (Block-B), and Raya-Maichew or Endamehoni (Block-C) areas are located in the endoreic basin of Afar Triangle of northeastern Ethiopia, which ranged between 12° 12’ and 12° 53’ N latitudes and 39° 03’ to 39° 45’ E longitudes cover area about 2446 Km² (Fig. 1).
In terms of physiographic, the study area is characterized by diverse topographic conditions such as plains, plateaus, valleys, undulating hills, and mountains with elevations ranging from 948 to 3916 m above mean sea level. It is bounded by the Amba Alage mountain range in the north, Girana mountain range in the south, and Zobil mountain range in the southeast. Historically, the selected study sites are parts Raya territories belong to the former Dobe’a kingdom in the medieval Ethiopia; is a pilgrimage site famed for its antique civilization, archaeological sites, and rural landscapes. The area is very rich in biodiversity, and hydrological realm. The study area has about thirteen major magnificent protected areas, six common archaeological and historical areas, and numerous religious and old tribal socio-cultural attraction sites (Table 1a–c). The remnant endemic and threatened flora species such as Juniperus procera, Podocarpus falcatus, Olea europea Subsp, and Cuspidata which belong to the dry Afromontane forest are located in protected areas. These forests had survived millennia of human exploitation and land conversions. Likewise, the formation of lake Ashenge shore (the deepest highland lake in Ethiopia) remains a mystery. Despite diverse natural sites prevailing, the historical and archaeological sites, numerous cultural traits (Rayan’s culture), and religious festivals and annual events happening are still untouched and attract local and foreign tourists. This indicates the study site has tremendous potential to nurture and deed as a catalyst for economic growth and development. Yet, the numbers of tourists have remained few in numbers following poor advertising and infrastructures, poor destination management, regional geopolitical interventions, and weak government supervision (Kidane et al. 2018), as well as global pandemics (COVID-19 and Omicron variant (UNWTO 2022). The key informants during the data collection have also been reflected that the foreign tourist arrival in the study area has been decreased from time to time. As a result, the current status of ecotourism in the study area witnessed urgent instigate through depth reformation to increase the Foreign and national tourist arrival.

The study area receives bimodal rainfall (June–September and March–May) and the mean annual rainfall ranges between 677 and 930 mm (NMA 2017). And the average annual temperature of the study area is 24.89°C. In terms of demography, the study area is inhabited and settled by more than half a million (CSA 2013). The livelihoods of the inhabitants in the study area are entirely dependent on agriculture and natural resources. Furthermore, the shortage of land for cropland, settlement, and pasture areas near and outdoor of the protected areas forced the communities to exploit the remnant resources, and thrash the archeological and historical sites.

2.2 Data type and sources

The data used in this study were collected from different sources as indicated in Table 2. In ecological tourism modeling processes, studies suggested that considering the relevance of topographic indicators (e.g., elevation and slope), climate (rainfall and temperature), demographic factor (population density), soil factor (drainage), accessibility factors (proximity to natural sites, archaeological sites, cultural sites, drainage, urban suitability and distance from road) are decisive to construct
| No | Name of attraction sites                        | Easting | Northing | Block location | Spot attraction remarks                                                                 |
|----|-----------------------------------------------|---------|----------|----------------|-----------------------------------------------------------------------------------------|
| 1  | Tsibet Mountain range                        | 554018  | 142159   | C              | Hiking and beautiful scenery landscapes                                                  |
| 2  | Tserqa’ba mountain range                     | 553850  | 140075   | C              | Indigenous forest, biodiversity and home for medicinal plants, and arc-historical research |
| 3  | Wenberet mountain forest area                 | 556029  | 137609   | B              | Hiking and biodiversity                                                                   |
| 4  | Abune-Aregawi hot spring                     | 577292  | 136093   | A              | Hot spring to cure skin disease                                                           |
| 5  | Bedena Leko bird viewing forest area          | 572445  | 136305   | A              | Mixed indigenous forests, and potential arc-historical research (e.g. antique Manadeley Town of great size) |
| 6  | Gratkhassu national forest area               | 557397  | 137745   | A              | Miracle biodiversity view, home for numerous wildlife (including endemic) and hiking       |
| 7  | Hugumburda forest reserve area                | 558768  | 139123   | B              | Home of avifauna                                                                         |
| 8  | Bala-bird viewing area                        | 568771  | 137239   | A              | Diverse fauna-flora species                                                               |
| 9  | Holla waterfall                               | 558985  | 138291   | B              | Waterfall recreation                                                                      |
| 10 | Sulula Qune wetlands-forest area              | 567010  | 137518   | A              | Home of birds, biodiversity, recreation, and videography                                  |
| 11 | Hayalo forest reserve area                    | 557491  | 137856   | B              | Biodiversity, hiking                                                                     |
| 12 | Waja-Tumuga vast-wet land-forest area         | 565106  | 136054   | A              | Home of birds, recreation, videography                                                   |
| 13 | Ashenge shore lake                            | 55425   | 139001   | B              | Mystery lake, home of birds, endemic aquatic fish, and archaeological research             |
| 1  | Human pillar-stone of wenberet area           | 547198  | 138272   | B              | Mystery stone and mixed Arc-historical research                                           |
| 2  | Adi Golo double massive graves                | 553740  | 138698   | B              | Mixed arc-historical research                                                             |
| 3  | Adeneba battle of Ofla                       | 552454  | 138445   | B              | Mixed arc-historical research                                                             |
| 4  | Mifsas Bahri                                 | 552198  | 139041   | B              | Mixed arc-historical and forest area                                                      |
| 5  | Mado Korem antique historical town           | 558132  | 138351   | B              | Mixed arc-historical area                                                                 |
| 1  | Timkete-Bahir and Epiphany                   | 559936  | 144151   | C              | Annual baptistery place/religious research                                                |
| 2  | Timkete-Bahir and Epiphany                   | 561101  | 137202   | A              | Baptistery place                                                                         |
| No | Name of attraction sites          | Easting  | Northing | Block location | Spot attraction remarks                                                                 |
|----|----------------------------------|----------|----------|----------------|----------------------------------------------------------------------------------------|
| 3  | Timkete Bahir Korem              | 555862   | 1383276  | B              | Baptistery place (Gando sub-district in Korem Town) annual January celebration (January 11 in Ethiopian calendar) |
| 4  | Gereb Odda/Kiliita-Facha Jihan   | 563270   | 1373756  | A              | Common traditional wrestling ground, and for cultural research                          |

Easting and northing refers the x-coordinate (longitude) and y-coordinate (latitude), respectively.
the potential ecological sites (Bunruamakew and Muryama 2011; Mansour et al. 2020; Acharya 2022). In this study, accordingly, to extract drainage networks, elevation, and slope suitability factor maps of the study area ASTER Digital Elevation Model (DEM) at 20 m resolution was obtained from Geospatial Information Agency (GIA). To produce the land cover factor map, a cloud cover free Sentinel-2A image dated 2020 at the spatial resolution of 10 m was accessed free of charge by the European Space Agency (ESA). Spatial enhancement, image filtering, and haze reduction to Sentinel image2-A were applied to obtain an excellent result. Finally, image classification using a maximum likelihood algorithm was applied to generate land use/land cover classes, and an accuracy assessment was conducted in ERDAS image 2014 software (Lelisand et al. 2008). In this regard, points from the historical IKONOS image dated 2020 were exercised to undertake the ground truth of the classified Sentinel image data. Similarly, we used the IKONOS image 2020 to generate a basic road networks factor map. The soil and towns of the study area in polygon and total population in numerical data were collected from Ethiopia Central Statistical Authority (CSA 2013). About 36 years (1984–2020) standardized climate data (temperature and rainfall) were collected from the distinguished seven gauge stations: Alamata, Korem, Chercher; Maichew, Mehoni, Waja, and Kobo (Table 3). IKONOS image 2020, ground survey using handled Garmin Global Positioning System (GPS), and cultural and tourism bureau of the distinguished study area was employed to collect the point data of existing natural protected areas, archaeological areas, historical and cultural sites.

Table 2 Descriptions of ecological tourism data used in the study

| Data type                  | Sources           | Resolution/scale | Purpose                                         |
|----------------------------|-------------------|------------------|-------------------------------------------------|
| Sentinel-2A image          | ESA               | 10 m             | For LULC type suitability analysis              |
| DEM                        | USGS              | 20 m             | For elevation suitability analysis              |
| Slope                      | DEM               | 20 m             | For slope suitability analysis                   |
| Drainage networks          | DEM               | 20 m             | For proximity suitability analysis              |
| Road networks              | IKONOS image      | 1 m              | For proximity suitability analysis              |
| Urban center               | CSA               | 1:50,000         | For proximity suitability analysis              |
| Archeological and          | Survey and interview | 1 m           | For proximity suitability analysis              |
| socio-cultural sites       |                   |                  |                                                  |
| Protected areas            | Survey and ZTO    | 1 m              | For proximity suitability analysis              |
| Climate data               | ENMA              | 20 m             | For climate suitability analysis                |
| Soil                       | ESAR              | 1:50,000         | For soil suitability analysis                    |
| Demography data            | CSA               | Numerical        | For population density suitability analysis      |

ESA is European space agency, USGS is United State of geological survey, DEM is digital elevation model, CSA is central statistical authority, ZTO is zonal tourism office, ENMA is Ethiopia national meteorological agency, and ESAR is Ethiopia soil and agricultural research.
2.3 Methods

In this study, basic procedures, such as spatial analysis and generation ecotourism indicators, standardization, AHP, ecotourism suitability assessment, and prioritization were conducted to produce an optimal site suitability map for ecotourism at minimum investment cost.

In this ecotourism study, six basic procedures: identifying suitable indicators for ecotourism analysis (1), assigning factor priority and rating class weight to the parameters incorporated in the IDR317 software (2), generating land suitability map of ecotourism (3), evaluating ecotourism potential sites (4), selecting very high suitable ecotourism sites using Boolean operation method in ArcGIS10.3 environment (5), prioritizing and ranking land suitability ecotourism sites using ultimate criterion (6), ground substation of optimal ecotourism sites (7) was applied to produce optimal site suitability map for ecotourism at low investment cost as consulted (Nino et al. 2017; Sahani 2019 and Mansour et al. 2020).

2.3.1 Multi-criteria evaluations (MCE) for ecotourism suitability

2.3.1.1 Spatial analysis and identification of indicators The ecotourism site selection is controlled by different elements belonging to physical, socio-cultural, environmental, and socioeconomic factors which vary from place to place and condition to condition (Carver 1991; Malczewski 2004; Fung and Wong 2007; Isik and Demir 2017). In this study, based on the landscape ecosystems and socio-cultural characteristics of the 3 Blocks (A, B and C) about 13 spatial ecotourism indicators such as elevation, land slope, land use–land cover, climate (rainfall and temperature), land visibility, population density, soil, protected natural area proximity, archeological proximity, socio-cultural proximity, urban center suitability, road proximity, and drainage proximity have been taken into consideration (Table 4). All indicators were selected in consultation with the literature reviews, ground survey (Ok 2006; Kumari et al. 2010; Dashti et al. 2013; Jeong et al. 2014), and prior experiences and experts (Malczewski 2004; Eslami and Roshani 2009). Therefore, the spatial data were acquired through high-resolution satellite image data, and survey point data using handle Garmin GPS.
Table 4 Pairwise comparison matrix of the spatial indicators with Eigen weights

| Indicators | Pa | Lc | Rd | Aa | E | S | SC | Uc | Pdn | Dr | Rf | Temp | Rf | Tmp | So | Eigen weight | %influence |
|------------|----|----|----|----|---|---|----|----|-----|----|----|------|----|-----|----|-------------|------------|
| Pa         | 1  | 2  | 3  | 4  | 5 | 6 | 7  | 7  | 8   | 8  | 8  | 8    | 9  | 9   | 9  | 0.25        | 25         |
| Lc         | 1  | 2  | 3  | 4  | 5 | 6 | 7  | 8  | 8   | 9  | 9  | 9    | 9  | 9   | 9  | 0.18        | 18         |
| Rd         | 1  | 2  | 3  | 4  | 5 | 6 | 7  | 7  | 8   | 9  | 9  | 9    | 9  | 9   | 9  | 0.13        | 13         |
| Aa         | 1  | 2  | 3  | 4  | 5 | 6 | 7  | 8  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.10        | 10         |
| E          | 1  | 3  | 4  | 5  | 6 | 7 | 8  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.08        | 8          |
| S          | 1  | 3  | 4  | 5  | 6 | 7 | 8  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.06        | 6          |
| SC         | 1  | 4  | 5  | 6  | 7 | 8 | 9  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.05        | 5          |
| Uc         | 1  | 5  | 6  | 7  | 8 | 9 | 9  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.04        | 4          |
| Pdn        | 1  | 6  | 7  | 8  | 9 | 9 | 9  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.03        | 3          |
| Dr         | 1  | 7  | 8  | 9  | 9 | 9 | 9  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.02        | 2          |
| Rf         | 1  | 8  | 9  | 9  | 9 | 9 | 9  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.02        | 2          |
| Temp       | 1  | 9  | 9  | 9  | 9 | 9 | 9  | 9  | 9   | 9  | 9  | 9    | 9  | 9   | 9  | 0.02        | 2          |
| So         | 1  | 0  | 2  | 2  | 2 | 2 | 2  | 2  | 2   | 2  | 2  | 2    | 2  | 2   | 2  | 1           | 1          |

The value of Consistency ratio (Cr) = 0.03 i.e., acceptable for ecotourism suitability analysis

Pa, proximity to protected areas; Lc, land covers; Rd, distance to road networks; Aa, proximity to archeological area; E, elevation; S, slope; SC, proximity to socio-cultural sites; Uc, proximity to urban center; Pdn, population density; Dr, distance from drainage networks; Rf, rainfall; Temp, temperature; So, soil
based on the information from experts and key informants (specific location ecotourism sites). Finally, the spatial data were organized, corrected, resampled, rectified, analyzed, and displayed in the ArcGIS 10.3 desktop environment, MS EXCEL, ERDAS IMAGINE 2014, and IDRISI SILVA 17 software.

In the first phase, to hold spatial layers (vector and raster data), a spatial database was created. Spatial layers selected for proximity analysis such as protected areas, archaeological sites, socio-cultural sites, roads, drainages, and urban suitability were rasterized and resampled to 20 m spatial resolution. However, to calculate Euclidean distances and buffers the resampled proximity spatial layers were converted to vectors. Likewise, the normalized climate indicators (rainfall and temperature) collected from the distinguished gauge stations were imported to the ArcGIS10.3 environment based on the X, Y, and Z values. The inverse distance weighted (IDW) technique was employed and resampled to the same resolution, accordingly. We applied this method, because it is a point-based tool for interpolation of standardized climate data. It is crucial to create certain climatic indices for big data and along the statistical period of the specific area. Then, the appropriate classification has been done for it and verified with the comparison of real data of the area. From the Sentinel image of 2020, four land cover classes: forest, wetland-grassland, water body were identified and resampled. A maximum likelihood classifier technique was employed, and hence, the land cover map was produced and an accuracy assessment was conducted, and the result had met the minimum requirement. Finally, all classes were classified as suitable and unsuitable for ecotourism activities. In terms of demography, population density (p/sq km) was calculated in the ArcGIS 10.3 desktop by dividing the number of population by total area (Eq. 1). The soil theme extracted from the soil map of the northern region was rasterized and resampled to the same resolution. Moreover, all spatial data collected and used in this study were resampled to 20 m spatial resolutions.

\[ P_{nd} = \frac{P_t}{A_t}, \]  

where \( P_{nd} \) is population density, \( P_t \) and \( A_t \) are the total population and area, respectively.

2.3.1.2 Standardization In this phase, to identify the best suited ecotourism sites all thirteen indicators had to be standardized using multi-criteria decision-making analysis (MCDMA) of the analytic hierarchical process (AHP) method. AHP was employed to create the influential indicators on the hierarchy of selected criteria to determine suitable areas for ecotourism activities (Saaty 1990) and used for decision making in which a problem is divided into different indicators, arranging them in a hierarchal structure making a judgment on the relative importance of pair of elements and synthesizing the result (Malczewski 2004). For this analysis, therefore, is based on different guidelines (Malczewski 2004; Bunruamkaew and Muryama 2011; Tali et al. 2012; WTO 2012; Nino et al. 2017; Sahani 2019; Ambecha et al. 2020; Guo et al. 2022) for potential ecotourism activities 13 ecotourism indicators were reclassified into 4 suitability classes: highly suitable (S1), moderately suitable (S2), mar-
ginal/less suitable (N1), and unsuitable (N2) areas in ArcGIS10.3 environment. The reclassified spatial layers were converted to ASCI formats and exported to IDRISI SILVA17 software, and pair-wise comparisons have been applied after consulting (Saaty 1990).

2.3.1.3 Ecotourism evaluation of weight using AHP In this phase, to determine the criteria weights of the spatial layers AHP method of MCDM analysis was employed based on the proposed 1–9 scientific ratio scale (Saaty 1990). Accordingly, the comparison matrixes of spatial layers were considered as the input, whereas the relative weights of spatial layers were the output. In this regard, to evaluate the ecotourism suitability information that developed from the literature works, experts and local knowledge are indicated in the row matrix realizes the list of features that attract tourists, whereas the column matrix indicates the value of ranks (Eq. 2). As ancillary data, the word ‘local knowledge’ in this study indicates prior experiences of researchers, 16 experts (from NRM, Forestry and Climate Change Adaptation, Tourism Economics, Tourism and Hotel Management, Biodiversity conservation, Ecology and Wildlife Conservation, Ecosystem and Society, Tropical Landscape and Ecology Science, Soil and Integrated Watershed management, Socio-economic development and planning, Population settlement and Demography, Land use planning and management, Survey and Market Value Chain Management, Sociology and Social Anthropology, Law for nature and society, Geopolitical and Conflict Resolution, Tropical Medical Biology etc.), 18 local elders (age +57) that are born, grew up, stay with communities, and working in the study areas; therefore, we have got 2–3 decades of experiences traveling and supporting tourists as a translator, and field surveyor to the existing tourist area. Thus, together with stakeholders and literature review, we build up many experiences, and finally, our works make it easiest for decision-making processes. Hence, priority scores and ranks for the spatial layers were assigned based on the importance and suitability of ecotourism potential. In other words, the final weightings for the spatial layers are the value of the eigenvectors which are related to the highest eigenvalue of the comparison matrix. Before assigning weights of spatial layers, consistency ratio (CR) was calculated to evaluate the reasonability level of consistency or inconsistency in the pair-wise comparison. In other words, the method measures the inconsistency of the decision-makers by calculating the consistency relationship (Eq. 3). In the comparison matrix, CI is a consistency index and RI is a random index. Likewise, CI was calculated using the formula in Eq. 4. If the final result of CR is <0.10, the decision is consistent and fairly acceptable while the value greater than the aforementioned value shows inconsistencies in the evaluation of indicators, hence, recalculation is recommended. The comparison matrices define \( A = [C_{ij}]_{n\times n} \) associated as;

\[
\begin{bmatrix}
C_{11} & C_{12} & \ldots & C_{1n} \\
C_{21} & C_{22} & \ldots & C_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
C_{1n} & C_{2n} & \ldots & C_{nn}
\end{bmatrix}
\]  

(2)
where $\lambda$ is the largest Eigenvalue of the pair-wise comparison matrix and $n$ is the number of ecotourism indicators. In this analysis, the result of CR was obtained as 0.03; hence, it met the minimum threshold.

2.3.1.4 Ecotourism suitability assessment To produce a composites site ecotourism suitability map, the weighting linear combination approach was applied in ArcGIS spatial analyst tool. In this regard, all resampled and reclassified spatial layers were combined and a weighted overlay technique was employed. Accordingly, the weight obtained after pairwise comparison was assigned to each criterion, and the final overlay map with the four suitability classes was produced (Eq. 5). The final overlay map showed the potential areas suitable for ecotourism development.

$$E_{ij} = \sum W_k S_{ijk},$$

where $E_{ij}$ is the composite suitability index for an area in pixel $(ij)$, $W_k$ is the relative importance weight of criteria $k$, $S_{ijk}$ is the grading values of area $i$ under criterion $j$. Finally, suitable sites and unsuitable potential ecotourism areas were identified and maps were produced.

2.3.1.5 Prioritization of very high suitable ecotourism sites The prioritization technique was carried out to compare the very high suitable sites (candidates) based on the ultimate criteria at low investment cost and time (Fung and Wong 2007; Holden 2009; Bunruakaew and Muryama 2011). Hence, five ultimate indicators (purposively selected) were identified and compared based on their accessibilities to protected areas, roads, archeological sites, urban centers, and land use/land cover. The ultimate indicators were selected in consultation with literature review, ground survey, local knowledge, and experts (Bunruakaew and Muryama 2011). Accordingly, the Boolean operation technique was applied to select very high suitable ecotourism sites. In this regard, about nine protected areas were found right within the very high suitable sites. AHP method of series pair-wise comparison matrices was applied for ranking the indicators based on the hierarchy of selected criteria to determine suitable areas for ecotourism sites at minimum cost investments. Finally, optimum ecotourism sites were prioritized and ranked for sustainable ecotourism development. In this regard, the response from experts and local elders (ten selected key informants) supported by literature reviews and concise field surveys have made the output of the objectives significant.

2.3.1.6 Ground substantiation GIS may be a tool; in this way, it is not free from error. Hence, to play down brought about mistakes physically going by the field of think about (nearby older folks, specialists, and analysts) as a way of sealing and
approving the computerized information whether it fits the real marvel on the ground was found to be significant. Subsequently, the arrange of the ideal candidates (very high suitable ecological sites) collected by means of GPS versatile computer program was sealed to the ground and found to be the best suited ecotourism destinations for feasible ecotourism development.

Fig. 2  a Spatial layers indicator maps for ecological tourism suitability analysis (b)
3 Results and discussion

Figure 2a, b presents the fact that the potential areas for ecotourism site development were unevenly distributed due to differentiation in environmental, sociocultural, socioeconomic, and archeological attributes in different parts of the blocks and also within protected areas. In this study, based on their attractiveness the resampled spatial layers (20 m resolution) were reclassified into four classes, and new values of S1, S2, N1, and N2 to represent highly suitable, moderately suitable, marginally/less suitable, and unsuitable were given to each class, respectively. Table 4 shows the pairwise comparison for the appropriately selected parameters of ecotourism development. The pair-wise comparisons associated with the AHP factors were used to weigh the relative importance of factors involved using the technique developed by (Saaty 1990) and the method was known to be used in the scientific study of decision problems. Accordingly, the result of the AHP model in the IDRSI SILVA17 indicated that the consistency ratio \((CR)\) was 0.03, which is < 0.1 and the judgments were acceptable. In other words, the calculated \(CR\), in Table 3, suggests that the weight values of the AHP matrix are consistent and the method presents meaningful outputs. Therefore, Eigenvector weight was generated and analyzed to evaluate the potential ecotourism site. Consequently, proximity to protected areas, land use/land cover, distance from the road, and proximity to archaeological sites share a value of 0.25, 0.18, 0.13, and 0.1 Eigenvector weight, respectively. Accordingly, the AHP result of the Eigen weights for ecological tourism indicators revealed that the degree of influences of protected areas (Pa), land cover (Lc), and road (Rd) were 25, 18, and 13%, respectively, whereas the weights for climate, drainage and soil together had a low degree of influence i.e. 6%.

3.1 Ecotourism suitability indicators

The ecotourism indicators were categorized as topographic (elevation and slope), accessibilities (proximity from road, drainage, urban suitability, protected areas, socio-cultural sites, and archaeological sites), demography (population density), and climate (rainfall and temperature), land use–land cover, and soil.

Topography Elevation, and slope of the landscape have mammoth importance to identify ecotourism potential sites (Bahaire and Elliott-White 1999; Karanth et al. 2008; Bunruamkaew and Murayam 2011; Sahani 2019; Mansour et al. 2020; Xu et al. 2020; Heshmati et al. 2022). The elevation is a key indicator for ecotourism site selection following its effect on the distribution of fauna and flora. Hence, ecotourism potentiality increases with the elevation of the land. The elevation value of the study area ranges from 1167 to 39616 m suggesting the existence of diverse biodiversity and awesome condition for human existence.

The high elevation of the land surface indicates higher possibilities to develop ecotourism sites and the low elevation of the land is less suitable for ecotourism site development. Accordingly, (S1), moderate (S2), marginal (N1), and unsuitable (N2). Based on elevation indicators, the entire block has been classified as S1 (above 2500 m), S2 (2000–2500 m), N1 (1500–2000 m), and N2 (1167–1500 m) and they
Table 5  Spatial layers for the ecological tourism site suitability analysis

| Major indicators                  | Factor map    | Unit        | Level of suitability   |
|-----------------------------------|---------------|-------------|------------------------|
|                                   |               |             | S1  | S2  | N1  | N3  |
| Topography/landscapes             | Elevation     | m           | > 2500 | 2000–2500 | 1500–2000 | 1167–1500 |
| Area (Km²)                        | 808.6         | 935.82      | 442.48 | 259.1      |
| Area (%)                          | 33.06         | 38.26       | 18.09  | 10.59      |
| Slope (deg)                       | < 5           | 5–10        | 10–15  | > 15       |
| Area (ha)                         | 527.66        | 320.25      | 538.95 | 1059.21    |
| Area (%)                          | 21.57         | 13.09       | 22.03  | 43.3       |
| LULC class                         | Wb,F,GWl – – Ors | – – – | 2311.57 |
| Area (ha)                         | 134.43        | – –         | –      | 94.5       |
| Area (%)                          | 5.5           | – –         |        |            |
| Accessibility                      | Proximity to natural sites Km | < 3 | 3–6 | 6–9 | > 9 |
| Area (ha)                         | 968.86        | 380.04      | 663.03 | 434.15     |
| Area (%)                          | 39.61         | 15.54       | 27.11  | 17.75      |
| Distance from major roads Km      | < 3           | 3–4         | 4–5    | > 5        |
| Area (ha)                         | 846.17        | 215.47      | 178.61 | 1205.81    |
| Area (%)                          | 34.59         | 8.81        | 7.3    | 49.3       |
| Proximity to arc sites Km         | < 6           | 6–12        | 12–18  | > 18       |
| Area (ha)                         | 345.47        | 522.84      | 592.55 | 985.22     |
| Area (%)                          | 14.12         | 21.37       | 24.22  | 40.28      |
| Proximity to Religious and cultural sites Km | < 6 | 6–12 | 12–18 | > 18 |
| Area (ha)                         | 439           | 577.16      | 548.60 | 881.31     |
| Area (%)                          | 17.95         | 23.6        | 22.43  | 36.03      |
| Proximity to drainage networks Km | < 0.8         | 0.8–1.6     | 1.6–2.4 | > 2.4     |
| Area (ha)                         | 1113.84       | 797.23      | 378.46 | 156.55     |
| Area (%)                          | 45.54         | 32.59       | 15.47  | 6.4        |
| Proximity to urban suit Km        | 8–16          | 16–24       | 24–32  | > 32; < 8  |
| Area (ha)                         | 766.84        | 549.62      | 435.24 | 694.34     |
| Area (%)                          | 31.35         | 22.47       | 17.79  | 28.3       |
| Climate                           | Rainfall mm   | > 850       | 750–800 | 750–800 | 650–750 |
| Area (ha)                         | 151.35        | 410.26      | 1502.65 | 381.81     |
| Area (%)                          | 6.19          | 16.77       | 61.43  | 15.61      |
| Temperature °C                    | 19–22.5       | 22.5–25     | 25–27.5 | > 27.5    |
| Area (ha)                         | 228.64        | 1640.46     | 467.14 | 109.83     |
| Area (%)                          | 9.35          | 67.07       | 19.1   | 4.49       |
| Socioeconomic                     | Population density P/sqha | > 0.014 | 0.008–0.014 | 0.002–0.008 | < 0.002 |
| Area (ha)                         | 103.99        | 191.03      | 271.55 | 1879.50    |
| Area (%)                          | 4.25          | 7.81        | 11.1   | 76.84      |
cover 808.6 Km² (33.06%), 935.82 Km² (38.26%), 442.48 Km² (18.09%), and 259.1 Km² (10.59%) areas, respectively (Fig. 2a, Table 5). The northern, southern, and southeastern parts of these protected areas in the Blocks B and C are creating a significant landscape matrix. This indicates they belong to high ecotourism potential zones while the lower altitudinal region of the entire Block-A and western part of Block-B is dominated by less biodiversity and harsh climate condition falls under moderate to unsuitable ecotourism potential zones. In Block-B, five protected areas were falls under very high suitable ecotourism sites, whereas two and one protected site are registered in Blocks C and A, respectively. Except for areas conducted in very high mountain ranges such as Great Himalayan region where Oxygen and human existence are limited (Sahani 2019), the majority of studies have also been confirmed that high altitude areas experience good climatic conditions both for tourists and biodiversity (Nyssen et al. 2005; Fung and Wong 2007; Pareta 2013; Ambecha et al. 2020).

The slope of the area is a significant indicator to identify ecotourism potential sites (Phua and Minowa 2005; Dashhi et al. 2013). Studies suggest that the construction of potential ecotourism sites desires a low slope of the land and increasing the slope decreases possibility to develop ecotourism sites (Bunruamkaew and Murayama 2011). The slope of the study area falls within the range of 0–77.6° indicating the complex feature of the landmass. The slope was resampled and reclassified into four suitability classes as S1 (below 5°), S2 (5–10°), N1 (10–15°), and N2 (above 20°) and they cover 527.66 Km² (21.57%), 320.25 Km² (13.09%), 538.95 Km² (22.03%), and 1059.21 Km² (43.3%) areas, respectively (Fig. 2a, Table 5). The southern and southeastern parts of Block-A, and central-eastern and a few portions of western parts of Blocks- B and C feel right to high ecotourism potential zones, while the others were relative falls under within moderate to unsuitable. Accordingly, the eight most suitable sites namely, Abune-Aregawi hot spring holly water site, Balla and Bedena Leko bird viewing forest areas, Waja-Tumuga and Sulula Qune wetlands in Block-A, and Lake Ashenge and Holla waterfall and their environs in the Block-B, and Mekhan wetland in the Block-C are fall under flat and gentle slope land, implies ideal location for ecotourism potential development. Similarly, the study suggests slope is a safety indicator; so, the gentler the sloping land or flat landform, the higher the safety and vice versa (Bunruamkaew and Murayama 2011).

| Major indicators | Factor map | Unit | Level of suitability |
|------------------|------------|------|----------------------|
|                  |            |      | S1     | S2     | N1     | N3     |
| Soil pedological type | Soil Type | Area (ha) | 1108.89 | 47.84 | 454.47 | 834.88 |
|                  |            | Area (%)  | 45.33  | 1.96  | 18.58  | 34.13  |

The total area for all suitability classes for each spatial layer indicators gives 2446 ha (100%). Raster is resolution
On contrary, the study argued that areas located in a steep slope range are rich in a cliff and hanging wall landscape that creates scenic beauty (Ambecha et al. 2020). Others also justified that low weighting given to low-lying areas is aggravated flood risk (Pareta 2013). However, in our study area, the steep slope areas are degraded and composed of fragile poor sedimentary rock which may be difficult in hiking and safe for tourists.

Land use–land cover The proportion of LULC class is a highly important criterion for ecotourism development (Ok 2006; Nino et al. 2017; Abrehe et al. 2021; Heshmati et al. 2022). In this study, four major LULC classes: forest, waterbody, wetland–grassland, and others, were identified, resampled, classified, and later reclassified into suitable and unsuitable classes. The classification result of the 2020 Sentinel-2A image revealed that other LULC classes (settlement, cropland, and degraded land) constituted the largest proportion of land in the study area with a value of 94.5%, followed by forest which accounts for 4.1%, while the smallest land was occupied by 0.56% of water body, and 0.84% of wetland–grassland. Forest, wetland–grassland, and water-body are rich in biodiversity and wildlife, implies essential for research, education, heritage, and recreation (Enright and Newton 2004; Connell et al. 2017). For this analysis, water-body, forest, wetland-grassland which altogether cover 134.43 Km² (5.5%) area falls under S1 zones, whereas the other LULC classes cover 2311.57 Km² (94.5%) of the total were considered as N2 for ecotourism potential zone (Fig. 2a, Table 5). In contrast to this study, however, bare areas (desert) attraction followed by forest and nature reserves had the highest priority for the AHP model, whereas the lowest priorities recorded for water attractions were highlighted in Jordan (Maakah et al. 2021). However, other study argued that in recent years the therapeutic benefits of forest bathing have entered a more mainstream consciousness thereby improving the tourism industry, such as the Japanese practice of shinrin-yoku, or forest bathing has been highlighted (Farkic et al. 2021).

In this study, Blocks B and C are pleasant areas and homes for wildlife, that people expect to visit, and hence they can be the potential tourist destination sites. Moreover, the historical formation of lake Ashenge in Block-B is the remaining mystery and the availability of an archaeological site (antique town) in the nearby lake makes the formation complex. Despite its formations, the area and its environs are rich in endemic and threatened fish, bird, and fauna species, and the spatial patterns that may hold higher scenic values for visitors. The lake is situated at flat landforms at high elevation and close to roads, streams, and protected areas indicating phenomena for ecotourism development.

Soil Soil is an essential parameter during the selection of potential ecotourism development sites (Kumari et al. 2010). It provides a suitable physical environment for root growth that can meet the demands for water, nutrients, and anchorage. In this study, six soil classes: leptosols, eutric regosols, chromic vertisols, eutric cambisols, xerosols, and eutric nitosols were identified, rasterized, resampled, and reclassified according to their relative importance. Soils characterized by good structure and physio-chemical properties are preferable for ecotourism development compared to sticky and degraded soils. Accordingly, eutric cambisols, covers 1108.89 km² (45.33%) area falls under S1 ecotourism zone and eutric nitosols, leptosols, and others such as regosols, xerosols and vertisols cover 47.84 Km² (1.96%), 454.47 Km²
(18.58%), and 834.88 Km² (34.13%) were categorized as S2, N1, and N2 potential zones, respectively (Fig. 2a, Table 5). The result indicates out of the geographical area of the study area, about 50% of the land falls under high suitable ecotourism zone in the study area. Similarly, about 81.5% of the territory has categorized as high to very high potential following an expressive results from soil and other topographic features in a Brazilian municipality (Guerrero et al. 2020). The majority of the land in the western parts of the Blocks A and B, and eastern parts of Block-C fall under the high ecotourism potential zone, whereas massive land in the eastern part of the Block-B reflects unsuitable potentiality for ecotourism sites.

**Accessibilities** Areas proximity to natural sites: zoos, national parks, forest reserves, and communal protected places are phenomena for ecotourism development (Phua and Minowa 2005; Stoll-Kleemann 2010; Zhang 2012; Boley and Green 2015; Oldekop et al. 2016; Omarzadeh et al. 2021). The areas near protected sites realize high suitability for ecotourism potentiality and possibilities decrease with increasing distances. Thus, areas near yards to ideal natural sites allow the area to create a healthy environment and invite visitors to get access easily (Jeong et al. 2014). Accordingly, to identify the suitability of protected natural sites, four buffer zones of less than 3, 3–6, 6–9, and above 9 km have been reflected as S1, S2, N1, and N2 zones and they cover 968.86 Km² (39.61%), 380.04 Km² (15.54%), 663.03 Km² (27.11%) and 434.15 Km² (17.75%), respectively (Fig. 2a, Table 5). Within the high suitability zone, a total of 13 protected natural sites have been identified as potential ecotourism sites, of which six, five, and two sites are situated within Blocks A, B and C, respectively. The majority of areas in the southern and southeastern parts, and a portion of the northern part of the protected blocks fall under the high suitability potentiality zone, whereas the western part of these blocks remained marginal and or unsuitable due to a dearth of protected natural sites. Hence, areas far away from protected areas usually affect the development of potential ecotourism (Nelson 1994; Obua 1997; Abrehe et al. 2021).

Besides protected natural areas, ecotourism can also take place in and near archaeological, historical, and socio-cultural areas (Nahuelhual et al. 2013; Suryabhagavan et al. 2015). This is because ecotourism is also interested in conserving the archaeological and Religious and socio-cultural heritages of the communities. Existing archaeological and socio-cultural sites are heritages of the community that protect the identity and present the history of the area and its inhabitants to future generations. Hence, considering the proximity to existing archaeological and socio-cultural sites during ecotourism site selection analysis is prudent for ecotourism development (Pareta, 2013). The areas nearby archaeological and socio-cultural sites are preferable following time–cost wise and patronage of the tourist resort. As per the result, 345.47 Km² (14.12%), 522.84 Km² (21.37%), 592.55 Km² (24.22%), 985.22 Km² (40.28%) areas located at a radius of below 6, 12, 18, and above 18 km were marked as S1, S2, N1 and N2 potential zones for ecotourism development (Fig. 2a, Table 5). About six fascinating archaeological sites were identified through depth interviews with local elders, cowboy youths, and deadwood collectors in the remote areas of Block-B. In this regard, the history behind Mado Korem antique town near lake Ashenge shore, human pillar-stone within Wenberet area, Mifsas
Bahri and Adi Golo double mass graves near to Korem town within Block-B is unreachable and remained mystery following null documentation.

Similarly, the areas close to the socio-cultural and Religious baptistery (Timkete Bahir) sites have been given priority during the selection of ecotourism and suitability decreases with increasing distance. Accordingly, socio-cultural sites were reclassified into four suitability zones such as S1 (below 6 km), S2 (6–12 km), N1 (12–18 km), and N2 (above 18 km) and they cover 439 Km² (17.95%), 577.16 Km² (23.6%), 548.60 Km² (22.43%), and 881.31Km² (36.03%) areas, respectively (Fig. 2a, Table 5). Ecotourism supports the conservation of the culture of the local community (Plieninger et al. 2013). Similarly, the inhabitants of the study area belong to mixed Afar-Agew-Tigre-Rayas communities where experience unique Rayan identity and cultural characteristics with colorful traditional values such as dressing, language, religion, custom, etc. Likewise, common traditional Ethiopian wrestling (Heshey/Tigel) and Chiguraf games are among the peculiar Rayans cultural festivity that attracts the heart of national and international tourists in the study area, particularly in Blocks A and B. Yet, these games are common from August to the late mid of September. In addition, the Epiphany (Timikete Bahir) annual religious memorabilia ceremony is among registered heritage in UNESCO, and several hundreds of tourists are flowing to follow and enjoy the festivity, and this can enhance the ecotourism development. In this regard, all the stated blocks have fixed ground for celebrating Epiphany.

Accessibility to transportation (road) affects the development of ecotourism (Carver 1991; Holden 2009). Hence, as a distance is close to potential sites, tourists can relax at a minimum cost in a short period and prolong their time stay (Connell et al. 2017). Accordingly, for this analysis, the nearest areas located at low buffer distance were assigned as highly suitable, and the remote area from road access was reflected as not suitable for ecotourism development. For the identification of potential ecotourism zones, five buffer zones below 3, 3–4, 4–5, and above 5 km from the existing major road network have been created which cover 846.17 Km² (34.59%), 215.47 Km² (8.81%), 178.61 Km² (7.3%) and 1205.81 Km² (49.3%) area fall under S1, S2, N1, and N2, respectively (Fig. 2a, Table 5). The road suitability in this study indicates that half of the study area has suffered from the road network effect; thus, lessens to make a sound decision regarding ecotourism development. For this analysis, the potential fate of ecotourism activities in the Tsibet mountain range, Tserqa’ba, and Wenberet (historical and home of the biota) depends on road infrastructures. Even though Block-B is very rich in biodiversity and archeological-socio-cultural sites, it is hostile to ecotourism development following inadequate road infrastructures. The northern and western parts of all blocks have suffered from road effects, respectively.

Water bodies such as lakes, rivers, streams, waterfalls, springs, and ponds are astonishing features where eco-tourists and peoples prefer to spend their leisure time and vacation (Hudson 1998; Tsaura et al. 2006; Ullah and Hafiz 2014). The zone close to the drainage network reflects high suitability for ecotourism development and possibilities decrease with increasing distance. Accordingly, the analyzed result revealed 1113.84 Km² (45.54%) of the total area was located at a radius of 0.8 km distance from the drainage network, indicates the area is rich in biodiversity and has
high ecotourism potential. Yet, 797.23 Km$^2$ (32.59%), 378.46 Km$^2$ (15.47%), and 156.55 Km$^2$ (6.4%) of total area with the buffer distance of 1.6, 2.4, and > 2.4 km from the drainages have been represented as S2, N1, and N2 for ecotourism development, respectively (Fig. 2a, Table 5). The target area belongs to various perennial and seasonal watersheds such as Ashenge, Hara, Agew, and Ettu, only to mention a few. Likewise, Holla waterfall and cave near Korem town (Block-B) and Hera mercy holly water (Block-A) are among very few fascinating drainage resources found in the study area.

The built of the human–environment consists of high population density and colossal infrastructural developments affect ecotourism development (Ross and Wall 1999; Lai and Nepal 2006). Sites far away from urban areas are preferable for ecotourism activities to avoid urban noise and pollution. Accordingly, the values were reclassified into four suitability classes such as S1 (766.84 Km$^2$), S2 (549.62 Km$^2$), N1 (435.24 Km$^2$), and N2 (694.34 Km$^2$) based on literature reviews, experts view and local elders experiences to serene ecotourism environment the area, respectively. Areas that fall within 8–16 km cover 31.35% of the total was found to be highly suitable for ecotourism site selection, whereas 22.47 and 17.79% of the total area found within the radius of 24 and 32 km distances from the urban center have been fallen under moderate to marginal suitable zones (Fig. 2b, Table 5). The western and eastern edges of towns in Blocks A and B, and the southern and eastern edges of town Maichew in Block-C fall under phenomena ecotourism potential zones. Yet, the Balla bird viewing area and Bedena Leko forest area, Waja-Tunuga and Sulula Qune wetlands in Block-A, and parts of protected sites such as Gratkhassu and Holla waterfall in Block-B has been suffered from noise from urban edge effects.

Demography The density of the population determines the development plan of ecotourism (Nelson 1994; Bunruamkaew and Murayama 2011). Ecotourism development in terms of employment, availability of hotels, and development of town thereby high population density is meaningful. There exists a positive relationship between population distribution and ecotourism. Thus, densely populated land indicates higher possibilities of developing ecotourism sites following infrastructural services and employment opportunities, and sparsely distributed land is unsuitable land for ecotourism site development. Accordingly, for this analysis, during the reclassification phases, the highest rank was given for the densely populated area and the lowest rank was given for the sparsely populated areas. In this study, the result revealed areas > 0.014p/sqha categorized as highly suitable for ecotourism cover an area of 4.25%, 0.008–0.014p/sqha categorized as moderately suitable cover an area of 7.81%, 0.002–0.008p/sqha categorized as marginally suitable covers an area of 11.1%, and less than 0.002/sqha categorized as not suitable for ecotourism potential development covers 76.84% (Fig. 2b, Table 5). A similar study has also been observed in Surat Thani province, Thailand, where densely populated areas were selected as highly suitable for potential ecotourism development while unsuitable rank was given to sparsely populated areas (Bunruamkaew and Murayama 2012). Even though the population density of our study area looked sparse outside the town the existing dense population suitability for potential ecotourism site development was located along with the protected areas, waterbody, near proximity, and decent
climate. In this regard, 3/4th of sites (natural and socio-cultural, and archeological) were located in Blocks-A and B were among the most densely populated.

Climate—Precipitation (rainfall) modifies the state of weather conditions of a given area (Dube and Nhamo 2018; Alemu and Dioha 2020). Studies revealed area which receives a high amount of rainfall is considered highly suitable for ecotourism compared to areas that receive a low amount of rainfall (Kumari et al. 2010; Salvador et al. 2011). Our study area receives bimodal rainfall (June–September and March–May) and the mean annual rainfall ranges between 677 and 930 mm. Increasing rainfalls indicate an increased in Oxygen, biota, and human existences; thus, higher possibilities for ecotourism site construction. Hence, rain-showered areas experience good climatic conditions and experience diverse biodiversity. In this study, therefore, areas with high rainfall were categorized as highly suitable and areas with a low amount of rainfall are ranked as not suitable. Thus, the mean annual rainfall ranges from 850 to 930 mm categorized as S1 for ecotourism covers an area of 151.35 Km² (6.19%); 800–850 mm categorized as S2 covers an area of 410.26 Km² (16.77%). Whereas areas that receive a low amount of rainfall covering 1502.65 Km² (61.43%) and 381.81 Km² (15.61%) were considered as marginally and unsuitable for ecotourism potential site development, respectively (Fig. 2b, Table 5). In this regard, Blocks B and C, receives 80% of persistent rainfall as compared to Block-A. This implies, Blocks B and C, have higher possibilities for the construction of ecotourism due to the presence of biodiversity and healthy climate conditions.

Climate as a factor, the temperature is priceless in the development of ecotourism sites and the increasing temperature has a negative relation to ecotourism construction (Tali et al. 2012). The lower temperature reflects higher possibilities for ecotourism site selection and vice versa. The mean annual temperature of the study area is 24.89°c. The average temperature of the area ranges from 19.65°c in the wet season to 30.43°c in the dry season. In this study, hence, areas that experience low/moderate temperature are ranked as highly suitable for potential ecotourism compared to areas that experience a high amount of temperature. The analyzed result showed that the study area covers 228.64 Km² (9.35%), 1640.46 Km² (67.07), 467.14 Km² (19.1), and 109.83 Km² (4.49%) of the total area with the buffer temperature ranges 19–22.5, 22.5–25, 25–27.5, and > 27.50c were ranked as S1, S2, N1, and N2, respectively (Fig. 2b, Table 5). This implies that 75% of the total study

| Table 6  Ecological tourism suitability area |
|------------------------------------------------|
| Blocks | Level of suitability | Total |
|--------|----------------------|-------|
|        | Area (Km²) | S1   | S2   | N1  | N2  |
| A      | 13.36      | 117.23| 73.91| 494.22 | 698.72 |
| %      | 1.91       | 16.78 | 10.58| 70.73 |
| B      | 114.37     | 214.91| 182.31| 595.70 | 1107.29 |
| %      | 10.33      | 19.41 | 16.46| 53.80 |
| C      | 10.39      | 210.45| 78.8 | 340.38 | 640.04 |
| %      | 1.62       | 32.88 | 12.31| 53.18 |
area temperature is potentially suitable for ecotourism site selection. Yet, the potential tourist sites that experience such temperatures in the same country in different regions were not found to be suitable following high cloud cover and snow for extended months (Ambecha et al. 2020).

### 3.2 Ecotourism suitability assessment

Table 6 and Fig. 3a show the overall suitability analysis ranging from very highly suitable (S1) to moderately suitable (S2), marginally suitable (N1), and unsuitable (N2). The result indicated that suitable zones in Block-A, 13.36 Km² (1.91%) falls under S1 zones, whereas 117.23 Km² (16.78%), 73.91Km² (10.58%), and 494.22 Km² (70.73%) areas, respectively, fall under the S2, N1, and N2 suitability zones. The eastern and northwestern of this block encompasses protected natural sites such
as Sulula Qune wetland, Balla bird viewing area, and parts of Gratkhassu forest priority belongs to the S1 ecotourism potential zone, whereas the lower altitudinal region and remote from archaeological-socio-cultural sites of Abune Aregawi hot spring and Bedena Leko forest areas fall under moderate ecotourism construction. Yet, protected areas that fall under highly suitability zones of this block have been selected to prioritize optimum ecotourism sites considering land use/land cover, proximity to the road, conserved areas, and archaeological sites. In the Block-B, S1, S2, N1 and N2 zones embrace 114.37 Km² (10.33%), 214.91Km² (19.41%), 182.31 Km² (16.46%), 595.70 Km² (53.80%) areas, respectively. The northeastern and southeastern edge of the block incorporates paradise protected natural sites (e.g. lake Ashenge, Hugumburda, Wenberet, Hayalo, parts of Gratkhassu, Tserqa’ba, and Holla waterfall areas, etc.) and miracle archaeological and historical sites (e.g., Human pillar stone, Mado Korem, Mifsas Bahri, Adi Golo, and Adeneba) characterized by ideal location for ecotourism construction. The protected natural sites in Block-B fall under high suitability zones and are nominated to prioritize ecotourism optimum sites. In this regard, the key informants in this zone has also been suggested that ideal climate combined with diverse natural, and ancient attractive archaeological resources has created job opportunities for young peoples, and engine of economic growth in the zone. In Block-C, 10.39 Km² (1.62%), 210.45 Km² (32.88%), 78.8 Km² (12.31%), and 340.38 Km² (53.18%) area are fall under the S1, S2, N1 and N2 zones, respectively. This Block is characterized by high slope land in the northern and southern parts, poor infrastructural developments throughout, and the protected natural sites belong to a low ecotourism potentiality zone whereas areas around Mekhan grassland near to Hugumburda national forest priority forest reserve area in the southeast reflect high potentiality following its diverse biota. Generally, the study area has promised massive potential ecotourism development as indicated in Fig. 3b.

### 3.3 Prioritizing high suitable protected areas

Today, many countries are encouraged to allocate a sizeable amount of investment to the ecotourism sector since the industry continued generating high income and conserves the environment sustainably (Zurick 1992; Xu et al. 2009; Sims 2010; Pareta 2013; Kidane et al. 2018; Sahani 2020; Dowling and Pforr 2021). Table 7 shows

| Ultimate spatial indicators | Pa | Lc | Dr | Aa | Uc | Eigen weight | % influence |
|-----------------------------|----|----|----|----|----|--------------|------------|
| Pa                          | 1  | 2  | 3  | 4  | 5  | 0.29         | 29         |
| Lc                          | 1  | 3  | 4  | 5  |    | 0.22         | 22         |
| Dr                          | 1  | 4  | 5  |    |    | 0.18         | 18         |
| Aa                          | 1  | 5  |    |    |    | 0.16         | 16         |
| Uc                          |    |    |    |    |    | 0.15         | 15         |

Refer Table 3 for full name of ultimate candidates
the comparison of protected natural sites located at high suitable (S1) potentiality of ecotourism zones. Therefore, to start the ecotourism business in a short period at the minimum investment, we preferred the prioritization technique to rank and select some of the very high ecotourism potential (Fig. 3c). In this regard, we consult experts, local elders, literature works and experiences, and, five ultimate ecotourism indicators have been used to construct the best suited ecotourism construction (Table 7). Hence, protected natural site candidates have been evaluated considering land use/land cover, proximity to protected areas, urban center, road, and archaeological indicators. Finally, nine potential ecotourism sites were identified and ranks were provided accordingly. Accordingly, the matrix Eigenvector analysis of proximity to protected areas, land cover, distance from the drainage, proximity to archaeological sites, and distance from the urban center has been weighted 0.29, 0.22, 0.18, 0.16, and 0.15.

The availability of lakes, indigenous forests, varieties of medicinal plants, various streams, biota, and eye-catching landscape in the study area can operate the ecotourism business (Xu et al. 2020; Farkic et al. 2021). Accordingly, based on the ultimate spatial layers of matrices, very high suitability sites in Raya areas such as lake Ashenge, Hugumburda forest reserve, Gratkhassu national forest, Hayalo forest reserve, Wenberet forest area, Holla waterfall, Ball bird viewing area, Sulula Qune wetland-forest area, and Tserqa’ba area were selected and ranked (Table 8 and Fig. 4). In line with this, validation technique through field-survey was conducted. Accordingly, AHP weights with ultimate criterion and field observations also ranked lake Ashenge, Hugumburda, and Gratkhassu national forest priority areas as 1st, 2nd, and 3rd optimal zones in the study area, respectively. In this regard, the former of the two optimal and largest parts of the later zones fall under Block-B, and the southern and southeastern parts of the later zone fall under Block-A. Yet, some portion of the Hugumburda national forest priority area belongs to Block-C.

Table 8 Final status of optimal ecological tourism sites in terms of certain selected criterion

| SCW | Pea | Lc | dR | Pas | dUs | Eigen weight | Overall influence | Rank |
|-----|-----|----|----|-----|-----|--------------|------------------|------|
| Hb  | 0.16| 0.15| 0.2 | 0.08| 0.11| 0.1447      | 14.47            | 3rd  |
| Hf  | 0.14| 0.12| 0.13| 0.08| 0.13| 0.1227      | 12.27            | 4th  |
| Ta  | 0.12| 0.1 | 0.03| 0.15| 0.09| 0.0997      | 9.97             | 5th  |
| Hl  | 0.1 | 0.25| 0.16| 0.17| 0.18| 0.167       | 16.7             | 1st  |
| Wf  | 0.09| 0.09| 0.06| 0.09| 0.1 | 0.0861      | 8.61             | 6th  |
| Bb  | 0.08| 0.04| 0.11| 0.11| 0.05| 0.0769      | 7.69             | 7th  |
| Ho  | 0.07| 0.03| 0.04| 0.09| 0.16| 0.0725      | 7.25             | 9th  |
| Sk  | 0.06| 0.05| 0.09| 0.1 | 0.08| 0.0726      | 7.26             | 8th  |
| Total| 1   |     |     |     |     |             |                  |      |

The value of Consistency ratio (Cr)=0.03 i.e., acceptable. SCW is the sub-criteria weight and values in each left-columns ultimate criterion are each candidate ecotourism very high suitable sits relative weight. The shaded candidates are the optimal suitable ecotourism candidates for the study area.
These top three optimal sites are very rich in biodiversity, hydrology streams, shares a convenient landscape, and healthy climate, and are located at nearby distances from protected areas, and road (<3 km), archaeological sites (<6 km), and urban center (8–16 km). However, the remaining six high suitable sites were either they are located remotely from protected sites, roads, archaeological sites or covered with another land cover, or situated very close to the urban center/source of the noise.

Therefore, continuous ecotourism tourism investment in the nominated top three optimal sites and their environs could boost the ecotourism industry thereby generating high income and conserving the wildlife resources sustainably. For instance, lake Ashenge serves as a habitat for varieties of migratory birds and endemic fish species (*Serinus nigriceps*, *Columba albitorques*, *Onychognathus albirostris*, and *Corvus crassirostris*). Similarly, the remaining two potential sites: Hugumburda and Gratkhassu national forest area, are home of varieties fauna and consists of diverse medicinal plants and dense indigenous forest species (*Juniperus procera*, *Olea europaea cuspidate*, *Podocarpus falcatus*, *Milletia ferruginea*, *Croton macrostachyus*, *Celtis Africana*, *Ekebergia capensis*, *Prunus Africana*, *Cordia Africana*, and *Ficus spp.* ) could satisfy the drought of ecotourism revenue in the study area. However, the remaining eight other potential sites could be transformed into suitable if the infrastructures such as roads, hotels, reforestation, zoos, sanctuaries, and museums are well established, expanded, and improved.
4 Conclusion and implications

This study gives insight into the identification of optimal ecotourism potential zones in the parts of Raya area of northeastern Ethiopia using a multi-criteria-based holistic assessment. Hence, the novelty of this research falls on the fact that it considers multiple physical, archaeological, socio-cultural, climate, soil, land use–land cover, environmental, and infrastructural spatial layers for ecotourism potentiality analysis in three Blocks.

The results have shown that there have been significant eco-tourism potential sites in the study area. However, despite the massive existing ecotourism potential, the area is not employed for commercial ecotourism business following unequal distribution of infrastructures, advertisement, and demographic effects. The result of this study also indicates massive moderate ecotourism potentiality in Blocks A and C, suggesting deprived infrastructural expansions and underprivileged media communications and advertisements because of sensitive geopolitics. Yet, most of these sites are situated close to protected zones, indicating ideal for ecotourism advancements. The analyzed ecotourism potential result has a significant positive implication for decision-makers to articulate stratagems for ecotourism infrastructure and sustainable resources management in the minimum investment cost in a short period. Therefore, satellite infrastructural developments, organized media communications, and advertisements about the sensational resources at the national and international levels should be introduced and expanded.

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Authors and Affiliations

Kiros Tsegay Deribew1 · Yared Mihretu1 · Girmay Abreha1 · Dessalegn Obsi Gemeda2

1 Department of Geography and Environmental Studies, Raya University, P.O. Box 92, Maichew, Ethiopia

2 Department of Natural Resource Management, College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia