



Utilizing supply-demand bundles in Nature-based Recreation offers insights into specific strategies for sustainable tourism management

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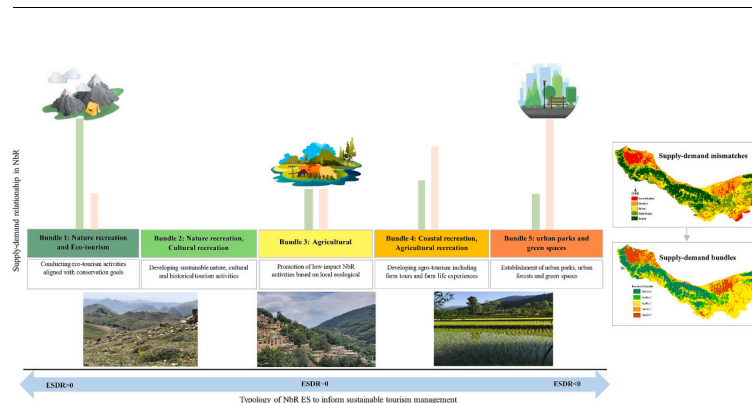
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HIGHLIGHTS

- Nature-based recreation supply and demand are mapped and assessed using a wide range of biophysical and social indicators.
- Spatial supply-demand mismatches in nature-based recreation are provided.
- Nature-based recreation typology based on bundles of spatial socio-ecological units is presented.
- Different recreational opportunities are identified based on the supply-demand characteristics within each bundle.
- Bundles linked to nature-based recreation typology can inform strategies for sustainable tourism management.

GRAPHICAL ABSTRACT



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ABSTRACT

Balancing supply and demand in Nature-based Recreation (Nbr) has the potential to yield co-benefits across multiple Ecosystem Services (ES), helping to make tourism activities more sustainable. However, a comprehensive understanding of supply-demand mismatches in Nbr is challenging due to the complex interaction among various social, economic and ecological factors. This paper investigates mismatches in Nbr supply and demand to provide insights for informing spatial and regional planning to achieve sustainable tourism. To this end, the paper uses a wide range of indicators such as biophysical attributes, accessibility and social indicators to map and assess Nbr supply and demand, followed by the application of spatial statistics to analyse supply-demand mismatches. Cluster analysis was performed based on the supply-demand relationship to identify a typology of Nbr ES across the study area in the north of Iran. The paper proposes an innovative application of recreation ES bundles with potential implications for sustainable tourism in a region marked as a hot spot for tourism. The analysis generated a typology of five bundles of Nbr ES with differing recreational opportunities. Bundles 1 and 2, characterized by a supply surplus and substantial ecological value, are suitable for Nbr activities such as camping, hiking, climbing, and birdwatching. In contrast, bundle 4 and 5 associated with urban centres, experience a supply deficit, making them less suitable for Nbr. Bundle 3, characterized by a mixture of

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natural and productive lands, plays an important role in maintaining a balanced supply-demand state. This region holds potential for diverse forms of tourism, including rural and agricultural recreation such as farm tours and farm life experiences. Based on findings, the paper provides valuable insights for spatial and regional planning by proposing targeted strategies to sustainably manage tourism activities.

1. Introduction

In recent decades, the demand for Nature-based Recreation (Nbr) has increased worldwide due to population growth and the growing awareness of its health benefits (Schirpke et al., 2018; Scholte et al., 2018; Suárez et al., 2020). In particular, rapid urbanization and land development have resulted in an increasing demand for recreational activities in natural and semi-natural environments (Schirpke et al., 2018). However, urbanization adds pressure to the availability of land for the provision of green spaces and natural environments in both urban and peri-urban areas (Chen et al., 2019). Consequently, urban residents may increasingly value and seek opportunities to connect with nature for recreation through urban parks, nearby forests, lakes, or other semi-natural areas as they provide opportunities for maintaining a healthy work-life balance (Willibald et al., 2019).

Nbr is a type of ecosystem service (ES) that enables people to directly experience the various benefits of ecosystems and enhance human-nature relationships, whilst providing conservation opportunities for these ecological systems (Kulczyk et al., 2018; Bing et al., 2021). Hence, landscapes with high Nbr opportunities hold substantial value for a significant number of people (Scholte et al., 2018). This is particularly prominent for regions characterized by a high demand for recreational activities due to the opportunities created by the presence of diverse landscape features such as mountains, forests, coasts and water bodies (Hermes et al., 2021). These include sports activities such as hiking, climbing and running (Oteros-Rozas et al., 2018), through to wildlife or biodiversity experiences such as bird watching and foraging for edible plants (Lee and Hsieh, 2016), and coastal activities such as swimming, diving, or simply unwinding along the shoreline (Chen et al., 2020; Le Corre et al., 2021). However, despite their physical, mental and economic benefits, Nbr has put pressure on ecosystems, leading to environmental degradation (Olson et al., 2017). This issue mostly stems from an imbalanced relationship between the supply of recreation potential offered by ecosystems and the demand for their services (Liu et al., 2021). Therefore, identifying spatial mismatches between the supply and demand of Nbr is critical to inform spatial and regional planning to sustainably manage tourism activities (Lorilla et al., 2019; Peña et al., 2015).

Several studies have emphasized the significance of an ES approach that integrates social and ecological systems to understand the interaction between Nbr supply and demand (Yee et al., 2021; Paracchini et al., 2014). Nbr supply refers to the potential of an ecosystem that is accessible for recreational purposes (Casado-Arzuaga et al., 2014; Peña et al., 2015). Nbr demand includes recreationists and their willingness to participate in Nbr activities (Kulczyk et al., 2018; Schirpke et al., 2018). Mismatches between Nbr supply and demand arise when recreation demand exceeds the available supply, often due to disparities in quality or quantity (Yang and Cao, 2022). Mapping supply-demand mismatches in Nbr is recognized as a crucial tool for integrating the ES approach into policy and decision-making processes promoting sustainable tourism (González-García et al., 2020). Several studies have demonstrated the practical application of this approach. For example, Zhang et al. (2021) assessed supply-demand mismatches in Nbr to inform sustainable land use management. Similarly, Lin and Chang (2022) examined the spatial relationship between recreation ES supply and demand, offering operational insights for policy-making in Taiwan's protected areas. Furthermore, Vallecillo et al. (2019) mapped Nbr potential, demand, and flow in Europe with the aim of quantifying both met and unmet demands to support decision-making for ecosystem

enhancement and its associated benefits.

Mapping Nbr as an ES involves various methods and variables. In particular, the approach and indicators employed in Nbr studies are highly dependent on the context and characteristics of the area (Peña et al., 2015). Mapping and assessing recreation ES thus require the consideration of the area's geographical heterogeneity, which directly influences the provision of recreation ES (Tenerelli et al., 2016). Commonly used indicators in mapping Nbr ES include physical attributes such as land cover, topography, water bodies, proximity to urban areas and accessibility (Paracchini et al., 2014; Inácio et al., 2022; Nahuelhual et al., 2017; Scholte et al., 2018; Schirpke et al., 2018). Other approaches include the application of participatory mapping leading to the production of high-quality spatial data (Kulczyk et al., 2018; De Valck et al., 2016; Kienast et al., 2012). Recent studies (Zhang et al., 2021; Schirpke et al., 2018; Kim et al., 2019) have utilized social media data to not only estimate visitation rates but to also identify spatial patterns of recreational values and preferences. Furthermore, some studies employed a mixed-method approach combining spatial indicators and social media data (Schirpke et al., 2018) as well as the integration of spatial indicators with participatory techniques (Crouzat et al., 2022; Kulczyk et al., 2018) to map and assess recreation ES. Regardless of mapping approach, incorporating both Nbr supply and demand within the ES framework is a critical step toward sustainable tourism management (Schirpke et al., 2018; Peña et al., 2015; Kalinauskas et al., 2021) - a concept that has been applied across different spatial and temporal scales.

Most studies exploring ES related to Nbr have predominantly focused on local and regional scales within the EU, USA and China, with limited studies being conducted in the Middle East (e.g., Ghasemi et al., 2023; Meshram et al., 2022; Koniak et al., 2011). This paper aims to add to this body of knowledge by investigating mismatches in Nbr supply and demand in the north of Iran so as to provide insights for informing spatial and regional planning to sustainably manage tourism activities. To this end, the study applies an ES-based approach to investigate the interactions between Nbr supply and demand to provide bundles in which specific strategies can be linked to supply-demand mismatches. Findings contribute to a comprehensive understanding of how the supply-demand relationship of Nbr ES is bundled and how these bundles represent different types of Nbr across the study area. Based on this, the paper concludes by discussing how a Nbr ES-based perspective can inform spatial and regional planning to sustainably manage tourism activities.

2. Methods

2.1. Study area

The study area is located in the north of Iran, within the South Caspian Basin (see Fig. 1). The territory covers over 35,302 km² and includes the provinces of Gilan and Mazandaran. The study area encompasses diverse natural landscapes such as sea, forests, and mountains, extending from the coastline to the Alborz Mountain ridge making it a major tourist attraction in Iran. The forested area of this territory covers approximately 15,006 km² (42% of the total) and extends from the coastal areas to an elevation of 2,300 m a.s.l. in the Alborz Mountains. High humidity and diverse vegetation contribute to its richness in plant and animal species (Saeidi et al., 2017). The area has around 500 km of coastline length characterized by a moderate climate with very low fluctuation in the whole region. All these attributes make the region

significant from an ecological, economic, and tourism perspective.

Overall, the study area is recognized as a prominent tourist destination within Iran, drawing millions of visitors annually during peak seasons. For example, In the Spring of 2019, over 17 million domestic tourism trips were recorded in the study area (Statistical Center of Iran, 2019). However, high tourism demand in this region could potentially result in pressure on ecosystems due to overcrowding, environmental degradation, and adverse impacts on biodiversity. The unique characteristics of the study area, marked by its diverse natural landscapes along with significant demand for recreational activities, underscore the need for effective spatial and regional planning to ensure their long-term conservation and corresponding provision of high-quality Nbr opportunities.

2.2. Study design

This study aims to investigate mismatches in Nbr supply and demand in the north of Iran to provide insights for informing spatial and regional planning to achieve sustainable tourism. To accomplish this, the study was structured into three parts. Firstly, the supply of Nbr was mapped by integrating recreation potential supply and recreation opportunity (see Fig. 2a). Recreation potential was determined by employing a set of five biophysical attribute indicators based on available literature (e.g., Schirpke et al., 2018; Paracchini et al., 2014; Nahuelhual et al., 2013). These indicators were then spatially combined to identify areas with high Nbr potential. Recreation opportunities were mapped based on distance statistics to assess the level of accessibility across the study area. For Nbr demand, three indicators were used: population data, road network, and visitation numbers (see Fig. 2b). This was followed by a spatial analysis to examine the relationship between recreation supply and demand (see Fig. 2c). Cluster analysis was then employed to identify bundles of recreation production that shared similar characteristics in terms of the supply-demand relationship across

the study area. These bundles were used as spatial units of social-ecological integration to construct a typology of Nbr ES.

All data were converted to raster data with a spatial resolution of 30 × 30 m, ensuring consistency for analysis. Land use/land cover data and Digital Elevation Model (DEM) were derived from Landsat 8 OLI images and Shuttle Radar Topography Mission (SRTM) data respectively, both available at a 30 × 30 m resolution. Maintaining the original resolution avoids information loss and misrepresentation of critical features like topographical variations, hydrological networks, and landscape models (Wu et al., 2008; Roostae and Deng, 2020). Upscaling to a coarser resolution could have compromised the accuracy and reliability of our models. Therefore, a pixel resolution of 30 × 30 m was chosen for quantifying all indicators, allowing us to adequately capture the small-scale landscape elements that contribute to Nbr supply (Lautenbach et al., 2011; Yang and Cao, 2022).

2.3. Mapping recreation supply

2.3.1. Recreation potential supply

Nbr supply of the study area was mapped by combining recreation potential supply (RPS) and recreation opportunity. The evaluated indicators used to calculate the recreation potential supply included Recreation Potential Index (RPI), Tourism Attraction Capacity (TAC), Tourism Use Aptitude (TUA), Scenic Attractiveness (SA), and Landscape Aesthetic Quality (LAQ) (see Table 1). RPI reflects the ecosystem’s potential to provide recreation ES. RPI is measured using three biophysical indicators, namely: the degree of naturalness, presence of protected areas, and water attractiveness (Paracchini et al., 2014; Peña et al., 2015; Schirpke et al., 2018). TAC refers to the unique features and assets of a land area with potential to promote tourism activities. Indicators used to assess TAC encompass the richness and concentration of natural tourist attractions, as well as the availability of tourism services (Nahuelhual et al., 2013). TUA categorizes each land cover based on its

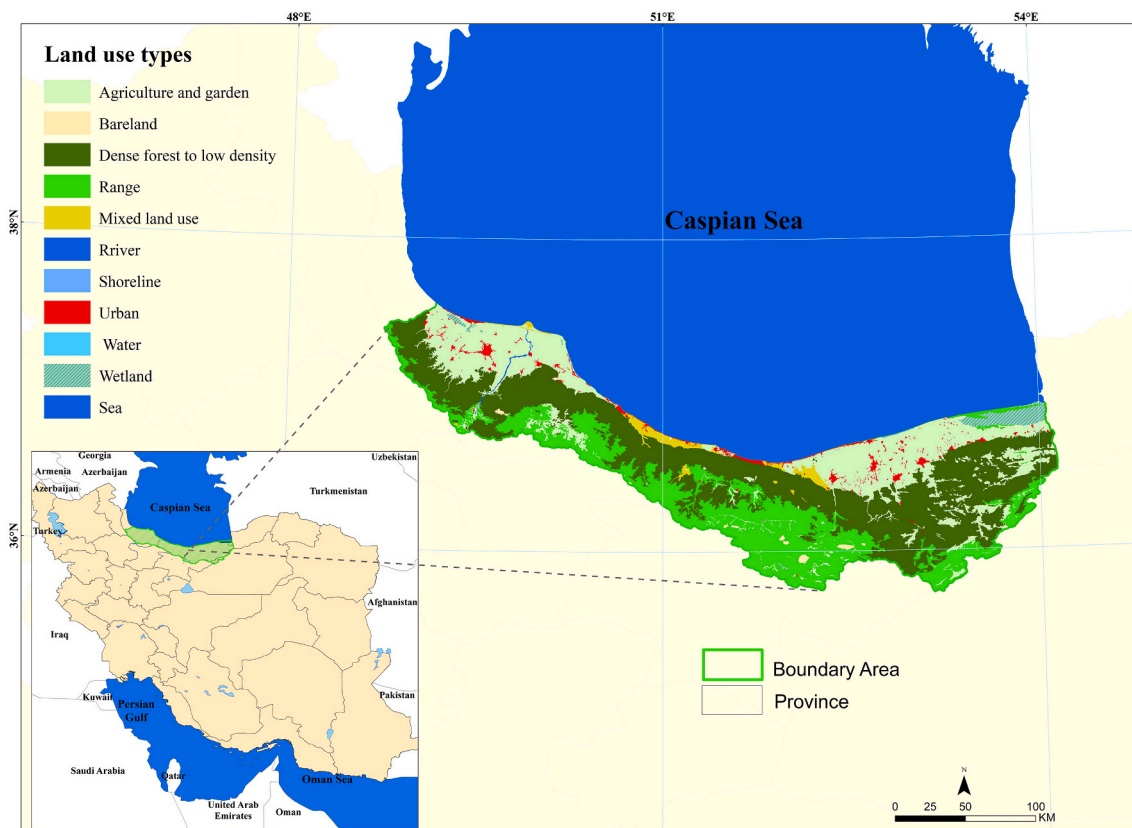


Fig. 1. Geographical location of the study area with land use types.

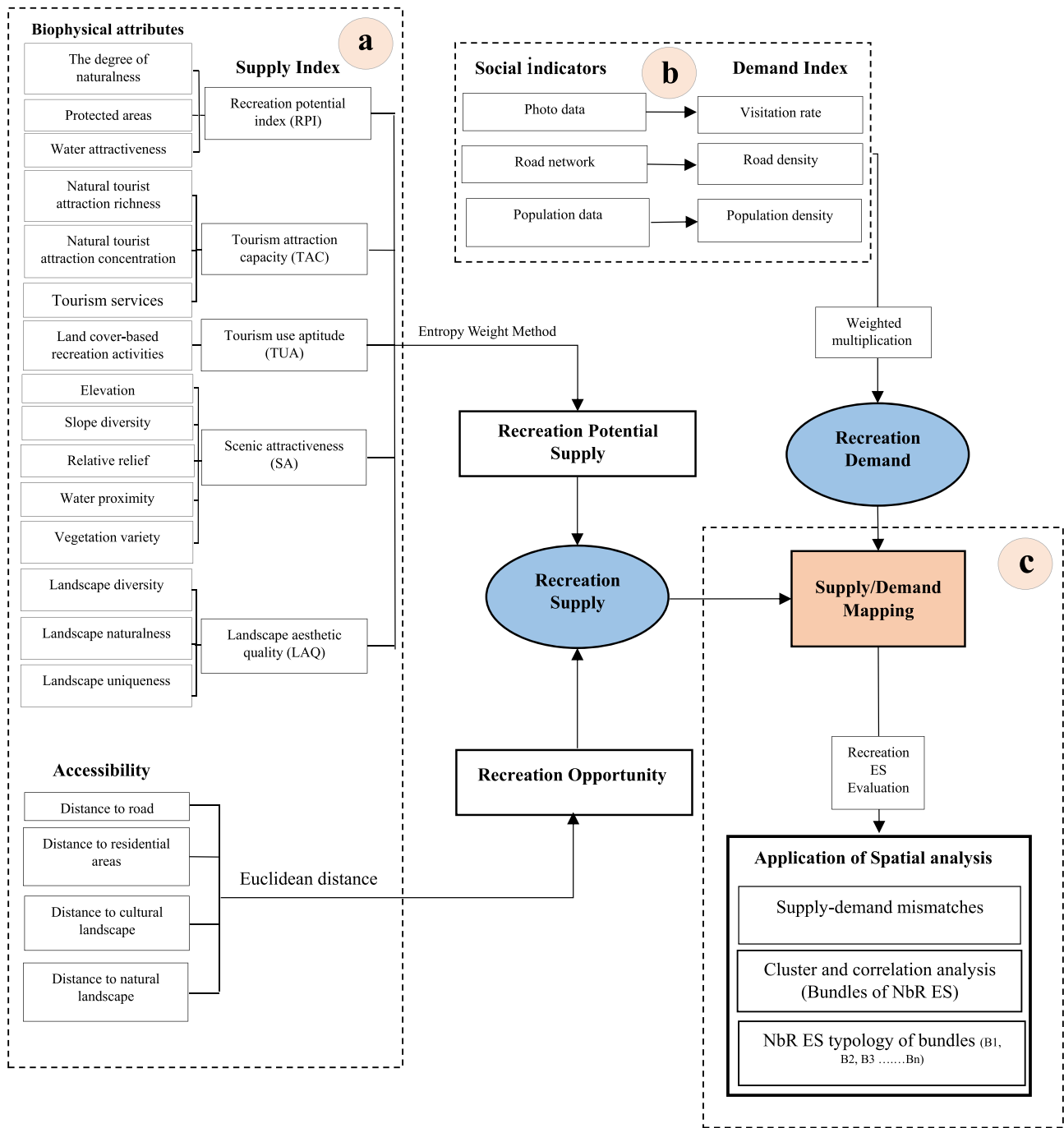


Fig. 2. Methodological framework: (A) Indicators for mapping Nature-based Recreation (NbR) supply, (B) Indicators for mapping NbR demand, (C) Spatial analysis of supply-demand relationship.

potential to support NbR activities, including bird watching, climbing, cycling, trekking, fishing, hunting, horse riding, swimming, and boating. SA refers to the scenic quality of a visible geographical space within its surroundings. This index is quantified using a linear regression model that takes into account landscape biophysical features such as elevation, slope diversity, relative relief, water proximity, and vegetation variety as inputs (Chhetri and Arrowsmith, 2008). LAQ represents the enjoyment people obtain from appreciating the beauty of both natural and cultivated spaces. It includes the features of the landscape that facilitate aesthetic experiences (Hermes et al., 2018; Thiele et al., 2020).

In this study, three sub-indicators, namely: landscape diversity, landscape naturalness, and landscape uniqueness were employed to assess the LAQ of the study area. All spatial indicators were quantified at

a regular grid resolution of 30 × 30 m. Then, recreation potential supply of the study area was calculated as follows (Eq. 1):

$$RPS = RPI w_i + TAC w_i + TUA w_i + SA w_i + LAQ w_i \quad (1)$$

where RPS is recreation potential supply determined through a weighted sum method. The weights of the five indicators are assigned using the Entropy Weighting Method (Liu et al., 2021; Ding et al., 2023).

2.3.2. Recreation opportunity

Recreation opportunity (RO) encompasses the infrastructure that facilitates and guides visitors toward recreational and tourism activities (Casado-Arzuaga et al., 2014). The presence of cultural and natural sites

Table 1
Recreation potential indicators for mapping Nature-based Recreation (NbR) Ecosystem Services (ES).

Indicator	Sub-indicator	Mapping approach	Spatial proxies	Data source	Resolution
Recreation potential index (RPI)	The degree of naturalness	The degree of naturalness is calculated by using naturalness evaluation index indicating the human activities influence on ecosystems and landscapes (Bing et al., 2021; Casado-Arzuaga et al., 2014; Liu et al., 2021; Peña et al., 2015; Schirpke et al., 2018).	0: Artificial ecosystems; 1: Agricultural ecosystems; 2: Semi-natural ecosystems; 3: High natural ecosystems	Land use/land cover (utilizing existing data extracted from Landsat 8 OLI images (Ghasemi et al., 2023)).	30m
	Protected areas	Presence of natural protected areas (Cunha et al., 2018; Nahuelhual et al., 2017; Paracchini et al., 2014; Schirpke et al., 2018; Vallecillo et al., 2019).	1: Presence of protected areas; 0: No protected areas	DOE database of protected areas	1:25000
	Water attractiveness	Attractiveness is calculated by using an impedance function (distance <2000 m from water bodies) with the assumption that attractiveness is halved at mid-distance (Paracchini et al., 2014; Schirpke et al., 2018).	-	Iran Water Resources Management Company	1:25000
Tourism attraction capacity (TAC)	Natural tourist attraction richness	Variety of natural attractions (rivers, beaches, forests, wetlands) (Nahuelhual et al., 2013)	Euclidean distance from attractions (shortest distance indicates the highest richness of attraction)	Land use/land cover	30 m
	Natural tourist attraction concentration	Number of natural attractions (Nahuelhual et al., 2013; Tardieu and Tuffery, 2019).	-	Land use/land cover	-
	Tourism services	Distance to tourism services (hotels, restaurants, and travel-related services) (Nahuelhual et al., 2013).	Euclidean distance from tourism services	Ministry of Cultural, Heritage, Handicrafts and Tourism	1:50000
Tourism use aptitude (TUA)	Land cover-based recreation activities	TUA is calculated by constructing a double entry matrix where the columns show the tourist activities that can be carried out in the study area and the rows represents the land cover types (Nahuelhual et al., 2017; Nahuelhual et al., 2013).	1: possibility of conducting an activity in the land cover; 0: conducting the given activity in the land cover is impossible (lack of aptitude)	Land use/land cover	30 m
Scenic attractiveness (SA)	Elevation	Elevation is considered as mean height above mean sea level.	Extracted from DEM and reclassified in ArcGIS	Digital elevation model (DEM)	30 m
	Slope diversity	Slope steepness is measured in each grid cell as a degree of angle in DEM. Slope diversity is calculated from the slope steepness grid for every cell (Chhetri and Arrowsmith, 2008).	Extracted from DEM and reclassified in ArcGIS	Digital elevation model (DEM)	-
	Relative relief	Relative relief is measured in the range between the maximum and minimum height in the neighbouring areas.	Height difference calculated in ArcGIS	Topography	1:25000
	Water proximity	Water proximity is calculated using a distance function of every cell in the study area to its nearest water bodies.	Euclidean distance from types of water bodies	Iran water resources management company	1:25000
	Vegetation variety	Vegetative variety is determined as the number of vegetation communities in each grid cell.	Derived from vegetation community map and converted to raster layer	Forests, range and watershed management organization	1:25000
Landscape aesthetic quality (LAQ)	Landscape diversity	Landscape diversity is measured by three variables, including land cover diversity, structural diversity, and relief diversity (De Valck et al., 2016; Hermes et al., 2018; Kalinauskas et al., 2021; Morelle et al., 2019; Schirpke et al., 2018; Thiele et al., 2020)	Land cover diversity is calculated by Shannon Diversity Index (SHDI) Structural diversity is measured through edge density index and the density of point elements (e.g., single tree or rock).	Land use/land cover - Topography	30 m 1:25000
	Landscape naturalness	The degree of land cover naturalness refers to landscape naturalness (De Valck et al., 2016; Hermes et al., 2018; Kalinauskas et al., 2021; Thiele et al., 2020)	Relief diversity is measured based on the density of contour lines.	Land use/land cover	30 m
	Landscape uniqueness	Landscape uniqueness is calculated based on the rareness of land cover types, the rareness of landscape types and presence of rare, historical or unique elements (Hermes et al., 2018; Kalinauskas et al., 2021; Thiele et al., 2020).	Landscape naturalness is calculated using naturalness evaluation index. frequency of rare land cover types (Number of elements/area)	Land use/land cover	30 m

serves as a motivating factor for tourists in selecting a destination (Bing et al., 2021; Khazaei Fadafan et al., 2018; Nahuelhual et al., 2017). Hence, to calculate RO the following indicators were used: distance to roads, distance to residential areas, distance to cultural landscapes, and distance to natural landscapes (see Table 2). RO for each grid cell was determined by applying a weighted sum of the Euclidean distance from roads (DR), residential areas (DS), cultural landscapes (DC), and natural landscapes (DN), as shown in the following equation (Eq. 2):

$$RO = DR_{norm} w_i + DS_{norm} w_i + DC_{norm} + DN_{norm} \quad (2)$$

The final recreation supply map was generated by combining the values of recreation potential supply (RPS) and recreation opportunity (RO) in grid cell i (Liu et al., 2021) using the following formula (Eq. 3):

$$Recreation Supply = RPS_i \times RO_i \quad (3)$$

2.3.3. Weighting of spatial indicators

The Entropy Weighting Method was employed in this study to assign weights to recreation supply indicators based on their relative importance. This method substantially mitigates the limitations arising from expert-based weighting and the potential for biased judgments (Yongxiu

Table 2
Recreation opportunity indicators for mapping Nature-based Recreation (Nbr) Ecosystem Services (ES).

Indicator	Mapping approach	Spatial proxies	Data source	Resolution
Recreation opportunity				
Distance to road (DR)	Euclidean distance tool is applied to calculate distance to road (Kienast et al., 2012; Nahuelhual et al., 2017; Peña et al., 2015; Scholte et al., 2018; Ustaoglu and Aydmoglu, 2020; Vallecillo et al., 2019).	Euclidean distance from road	Ministry of Roads and Urban development	1:25000
Distance to residential areas (DS)	Euclidean distance tool is applied to calculate distance to the location of residence (Kienast et al., 2012; Rabe et al., 2018; Schirpke et al., 2018; Vallecillo et al., 2019).	Euclidean distance from residential areas	Ministry of Roads and Urban development- Statistical Centre of Iran	
Distance to cultural landscape (DC)	Distance to cultural landscape (e.g., historical and cultural heritage sites) is calculated by Euclidean distance (Beeco et al., 2014; Bing et al., 2021).	Euclidean distance from cultural landscapes	Ministry of Cultural, Heritage, Handicrafts and Tourism	1:50000
Distance to natural landscape (DN)	Distance to natural landscape (e.g., water bodies, forests, wetlands, coasts) is calculated by Euclidean distance (Beeco et al., 2014; Bing et al., 2021).	Euclidean distance from natural landscapes	Land use/land cover	30 m

et al., 2020; Kuller et al., 2019). The steps for calculating the weighting were: (1) normalizing indicator values to a comparable scale; (2) calculating the relative entropy of each indicator using the entropy formula; and, (3) determining indicator weights by dividing the relative entropy by the sum of all relative entropies (Yongxiu et al., 2020; Sun et al., 2017; Ding et al., 2023). By calculating the entropy of each indicator’s values, it was possible to assign higher weights to indicators of greater significance, recognizing their influential role in the overall assessment of recreation supply.

2.4. Recreation demand

Three indicators were used to map Nbr demand (see Fig. 2b): visitation rate, road density, and population density (see Table 3). Geo-tagged photo data from the Flickr website were utilized to estimate the visit rate in the study area. Social media data are regarded as reliable information for estimating recreational visit rates, particularly on a

Table 3
Recreation demand indicators for mapping Nature-based Recreation (Nbr) Ecosystem Services (ES).

Indicator	Mapping approach	Spatial proxies	Data source	Resolution
Recreation demand				
Visitation rate (VR)	The number of photos uploaded to the Flickr website per grid cell (Bing et al., 2021; Cunha et al., 2018; Langemeyer et al., 2018).	–	InVEST Recreation model	–
Road density (RD)	A kernel density function tool is applied to calculate road density (length/area) by considering distance decay effect (Lorilla et al., 2019; Schägner et al., 2016; Willibald et al., 2019).	–	Ministry of Roads and Urban development	1:25000
Population density (PD)	Average number of people per grid cell (number/area) (Baró et al., 2016; Chen et al., 2019; González-García et al., 2020; Paracchini et al., 2014; Vallecillo et al., 2019).	–	Statistical Center of Iran	–

large spatial scale (Kim et al., 2019; Sinclair et al., 2018), and is recognized for its high spatial accuracy (Tian et al., 2021). The InVEST Recreation model was employed to quantify the visitation rate. All indicators were assigned equal weights and the calculation of recreation demand was carried out using the following formula (Eq. 4):

$$Recreation\ Demand = VR_i \times RD_i \times PD_i \tag{4}$$

where VR is the visitation rate, RD is the density of the road network and PD is the population density in grid cell i. PD directly reflects the potential for recreation demand, as higher population density corresponds to higher demand for recreation (Liu et al., 2021). Another indicator, VR, represents the actual level of recreation demand. Previous studies (Bing et al., 2021; Cunha et al., 2018) have shown a positive correlation between the density of photos uploaded to Flickr and both visitation rate and landscape value.

2.5. Supply-demand match and mismatch analysis

The ES supply-demand ratio (ESDR) links actual supply to human demand to reveal the surplus or shortage of ES supply in a designated area (Chen et al., 2019; Li et al., 2023). ESDR was calculated using the following equation (Eq. 5):

$$ESDR = \frac{S - D}{(S_{max} + D_{max})} \tag{5}$$

where S and D refer to recreation supply and demand, respectively. S_{max} and D_{max} indicate the maximum value of supply and demand in the study area extracted from the related spatial layers. The positive value of ESDR represents ES surplus, the zero value indicates supply-demand balance and the negative value shows that supply cannot meet the existing demand or there is a deficit. ESDR values, according to expert opinions, can be divided into five levels to represent a better distribution of supply-demand relationship (Lorilla et al., 2019).

2.6. Spatial correlation analysis of supply-demand pattern

To measure the spatial pattern of ESDR within the study area, two spatial correlation indexes were utilized. First, Global Moran’s I was used to evaluate whether the spatial pattern was dispersed, clustered or random (Eq. 6). This approach has been widely employed in the literature to reveal the spatial agglomeration patterns and interrelationships of ESDR (e.g., Pan et al., 2021; Wu et al., 2019; Zhai et al., 2020).

$$Moran's I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \tag{6}$$

$$S^2 = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2$$

where n is the number of grid cells, and xi and xj are the ESDR values in grid cell i and j, respectively. Wij is also the spatial weight matrix of grid cells i and j obtained through the rook adjacency matrix. \bar{x} is the average value of ESDR. Moran's I varies between 1 and -1. Positive Moran's I value (> 0) indicates a clustered pattern or positive correlation in the distribution of ESDR. Conversely, a negative Moran's I value (< 0) suggests a dispersed pattern or negative correlation. A Moran's I value of 0 indicates a random spatial distribution, indicating no spatial autocorrelation in the ESDR.

Next, the Local Indicator of Spatial Association (LISA) was applied to help visualize significant local patterns of spatial clustering by comparing ESDR values in each specific area with the values in neighbouring areas (Anselin et al., 2007). Four types of ESDR spatial clustering were identified including High-High clusters (HH), Low-High clusters (LH), Low-Low clusters (LL), and High-Low clusters (HL). For computational efficiency, a regular 1 × 1 km grid was utilized as the spatial unit for spatial relationship analysis. This enabled the detection of the heterogeneity of small units in the study area. Accordingly, recreation supply and demand layers were rescaled to 1 × 1 km grid in ArcGIS 10.8. The values obtained from all grids were then used as input for spatial correlation analysis performed through GeoDa 1.18 (<http://geodacenter.github.io>).

2.7. Cluster analysis and Nbr ES typology

A bivariate mapping technique was employed to identify the spatial distribution of supply-demand relationship (see Fig. 2C). This enabled

the visualization of both supply and demand patterns on a single map, utilizing distinct color schemes for each variable (Liu et al., 2021; Shen et al., 2019). A 3 × 3 color matrix was constructed in which columns represented the demand for Nbr ES, while rows represented the supply. Supply and demand values were classified into low, medium, and high categories using a geometrical interval classification method.

Next, to identify the bundles of the supply-demand relationship, the k-means clustering algorithm was applied. This algorithm minimizes within-group variability, ensuring that the composition of recreation supply and demand is similar within each bundle (He et al., 2019; Schirpke et al., 2019). The optimal number of bundles was determined using silhouette measurements, resulting in four clusters for supply, four clusters for demand, and five clusters for the combination of recreation supply and demand. Bundles 1 to 5 were classified based on z-scores and visualized using GIS methods, representing different supply-demand relationships across the landscapes.

Each bundle represents a unique combination of supply and demand characteristics, enabling the classification of different types of Nbr ES (see Fig. 3). Each bundle was assigned to a specific type of Nbr based on its dominant land use, using the knowledge and insights from scholars and experts in the recreation and tourism sector of the study area as well as relevant literature (Hermes et al., 2021; Ayhan et al., 2020; Tuzon et al., 2014) to create a typology of Nbr ES. This typology captures the diverse recreational uses and activities within each bundle, reflecting the interactions between potential supply and demand.

3. Results

3.1. Spatial patterns of recreation supply and demand

The spatial distribution pattern of recreation potential supply is illustrated in Fig. 4a. Approximately 30.6% of the study area has a high potential for recreation, while only 8.3% exhibits the lowest values. Notably, there is a remarkable spatial variation across the study area, with the highest RPS values concentrated in areas primarily

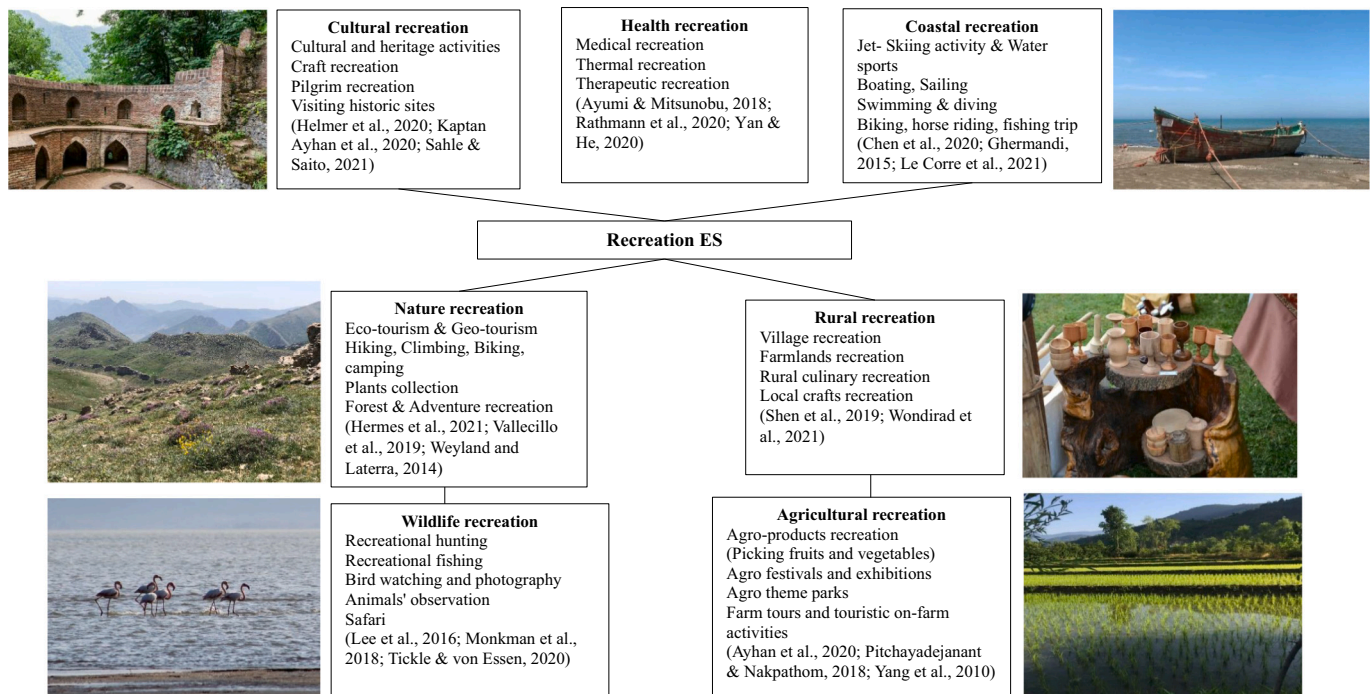


Fig. 3. Different types of Nature-based Recreation (Nbr) Ecosystem Services (ES) within the study area [1] Helmer et al., 2020, [2] Ayhan et al., 2020, [3] Sahle and Saito, 2021, [4] Ayumi and Mitsunobu, 2018, [5] Rathmann et al., 2020, [6] Yan and He, 2020, [7] Chen et al., 2020, [8] Le Corre et al., 2021, [9] Hermes et al., 2021, [10] Vallecillo et al., 2019, [11] Weyland and Lateralra, 2014, [12] Shen et al., 2019, [13] Wondirad et al., 2021, [14] Lee and Hsieh, 2016, [15] Monkman et al., 2018, [16] Tickle and von Essen, 2020, [17] Pitchayadejanant and Nakpathom, 2018, [18] Yang et al., 2010.

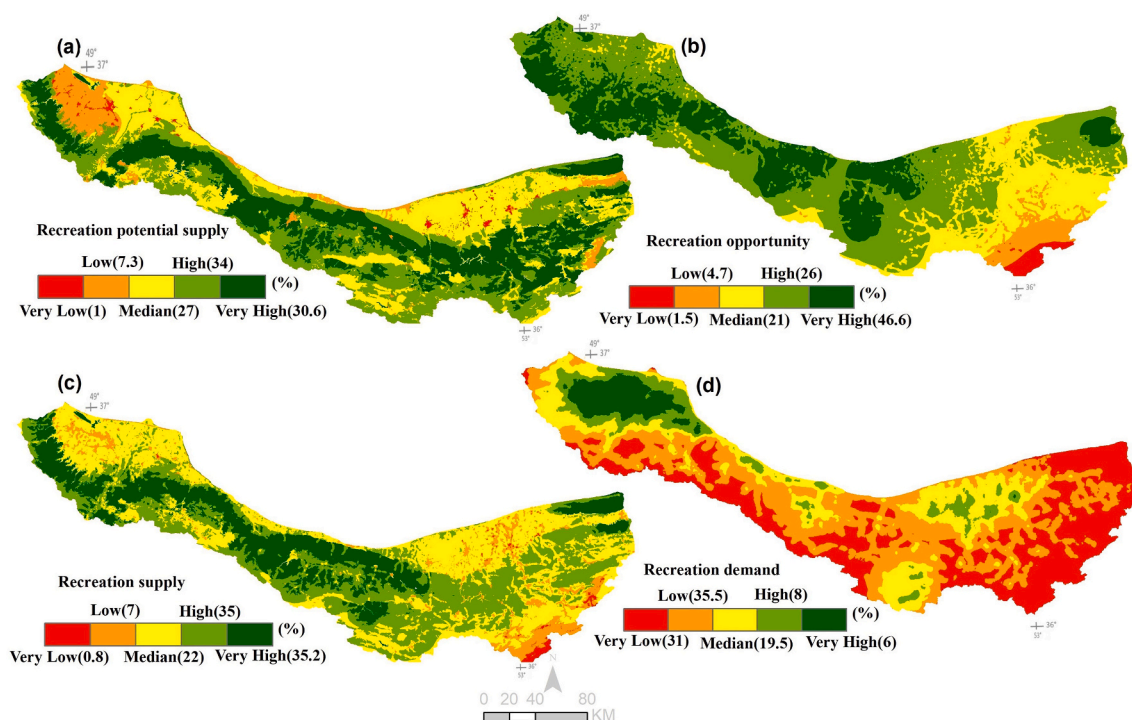


Fig. 4. Spatial pattern of Nature-based Recreation (NbR) supply and demand: (a) recreation potential supply, (b) recreation opportunity (c) recreation supply and (d) recreation demand in the study area.

characterized by forests, rivers, and protected natural areas with diverse and mountainous landscapes. These high-value regions are extended along a strip from the eastern to the western boundaries of the study area. Conversely, the lowest RPS values are concentrated in areas dominated by homogeneous and constructed landscapes, where the level of naturalness is very low.

Comparison of the weighting results between the indicators participating in recreation potential supply reveals that LAQ has the highest weight, indicating its significant impact on the distribution pattern of RPS. Access to roads and residential areas was found to have the highest weight in providing recreation opportunities in the study area (see Table 4). The spatial distribution of RO within the study area exhibits a distinct pattern (see Fig. 4b). Areas with limited recreation opportunities encompass only 6.2% of the area, primarily concentrated in the south-eastern part of the territory, where access to roads and residential areas is minimal. These regions characterized by mountainous terrain predominantly consist of grasslands and rangelands. On the other hand, the highest level of recreation opportunities, accounting for 46.6% of the study area, was concentrated in regions that are accessible through the road network, providing abundant possibilities for recreational activities for tourists.

Fig. 4c illustrates a gradual decline in recreation supply from the

Table 4
Entropy-based weights for evaluation indicators of recreation supply.

Indicator	Weight (w_i)	% of total	Rank
Recreation potential supply			
Landscape aesthetic quality (LAQ)	0.4551	45.5	1
Tourism use aptitude (TUA)	0.3149	31.5	2
Tourism attraction capacity (TAC)	0.1089	10.9	3
Recreation potential index (RPI)	0.1024	10.2	4
Scenic attractiveness (SA)	0.0187	1.9	5
Recreation opportunity			
Distance to road	0.3752	38.13	1
Distance to residential areas	0.2625	25.99	2
Distance to cultural landscape	0.19	18.82	3
Distance to natural landscape	0.1723	17.06	4

central areas toward the periphery. Regions characterized by a very high recreation supply cover 35.2% of the study area, representing abundant natural resources such as dense and semi-dense forests, water bodies, coastlines, cultural attractions, and high level of accessibility. In contrast, 7.8% of the territory exhibits a low recreation supply primarily concentrated in residential areas, agricultural lands impacted by human intervention, and mountainous regions lacking sufficient access despite the presence of remarkable natural landscapes.

The spatial distribution of recreation demand is shown in Fig. 4d. Approximately 14% of the study area exhibits high and very high demand, while 31% displays low values of demand. The areas with high demand are primarily concentrated in specific hotspots, particularly in the northern part of the study area which contains population centers as well as natural, historical, and cultural attractions that are easily accessible to visitors. In contrast, other areas demonstrate significantly lower demand, often characterized by mountainous and highland terrain, dense forests, and intense conservation zones of protected areas. These areas, despite being attractive, are less accessible to tourists. The visitation rate further confirms that tourists have predominantly visited areas that are easily reachable via the road network or in close proximity to their homes.

3.2. Mismatch and spatial correlation analysis of supply-demand pattern

The ESDR index was employed to conduct a match and mismatch analysis between supply and demand. Fig. 5 shows the distribution of index values across the study area. The surplus, slight surplus, and balance patterns occupy the majority of the territory, while the severe overload pattern represents the smallest proportion. Overall, deficit areas (severe overload and overload) with negative ESDR values encompass 28.9% of the study area. These areas primarily concentrate in urban and rural centers, where tourism demand is not fully satisfied, resulting in an unbalanced spatial distribution between recreation supply and demand. On the other hand, surplus areas (slight surplus and surplus) with positive ESDR values cover 46.2% of the study area and are characterized by a high degree of naturalness. Additionally, 24.9%

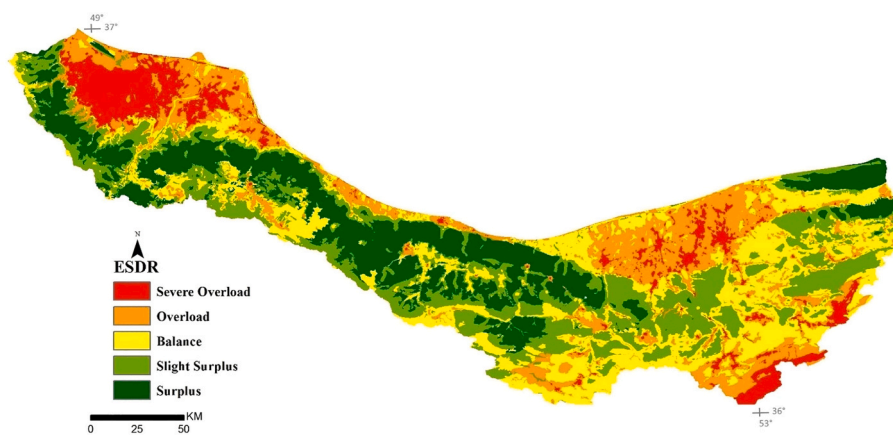


Fig. 5. Spatial distribution of supply-demand ratio of Nature based Recreation (Nbr) Ecosystem Services (ES).

of the study area exhibits a balanced pattern.

The spatial distribution of ESDR exhibits a clustered pattern, as indicated by a global Moran's I value of 0.863. This means that areas with high supply and areas with low supply are geographically clustered together. As shown in Fig. 6a, HH clusters of high recreation supply potential are present in the central part of the study area, whereas LL clusters are concentrated in high-demand areas with developed infrastructure. Approximately 81.5% of the study area demonstrated a supply equal to or greater than demand, while 18.4% experienced a supply lower than demand (see Fig. 6b).

3.3. Recreation ES bundles in the study area

Four distinct bundles (S1-S4) were identified for recreation supply, along with four bundles (D1-D4) for recreation demand (see Fig. 1 in the Supplementary Material). Using a cluster analysis of two components, five types of bundles were identified in the study area. Each bundle was categorized into a specific type of Nbr ES (see Fig. 7 and Fig. 2 in the

Supplementary Material) based on its dominant land use (Fig. 8), location and considering expert opinions along with insights from relevant literature (Hermes et al., 2021; Ayhan et al., 2020; Tuzon et al., 2014).

Bundle 1 encompasses 22.1% of the study area and is primarily concentrated in the central part of the territory, characterized by elevated areas. This bundle is predominantly covered by forest (17.9%), high-quality rangelands (2.5%), and protected wetlands (1.6%). The presence of Hyrcanian mixed forests with a high rate of endemic species and protected wetlands, such as Miankaleh and Anzali, contributes to the remarkable landscape aesthetics and ecological value of this bundle (Aghsaei et al., 2020). This region offers a high potential for Nbr making it a hotspot of eco-tourism involving various activities such as camping, hiking, climbing and birdwatching.

Bundle 2, occupying 12% of the study area, is primarily distributed in highlands and on the outskirts of Bundle 1. This region is predominantly characterized by forests (7.1%) and rangelands (4.6%), with minimal presence of other land uses such as agricultural lands, urban areas, and water bodies (less than 1%). The abundant vegetation

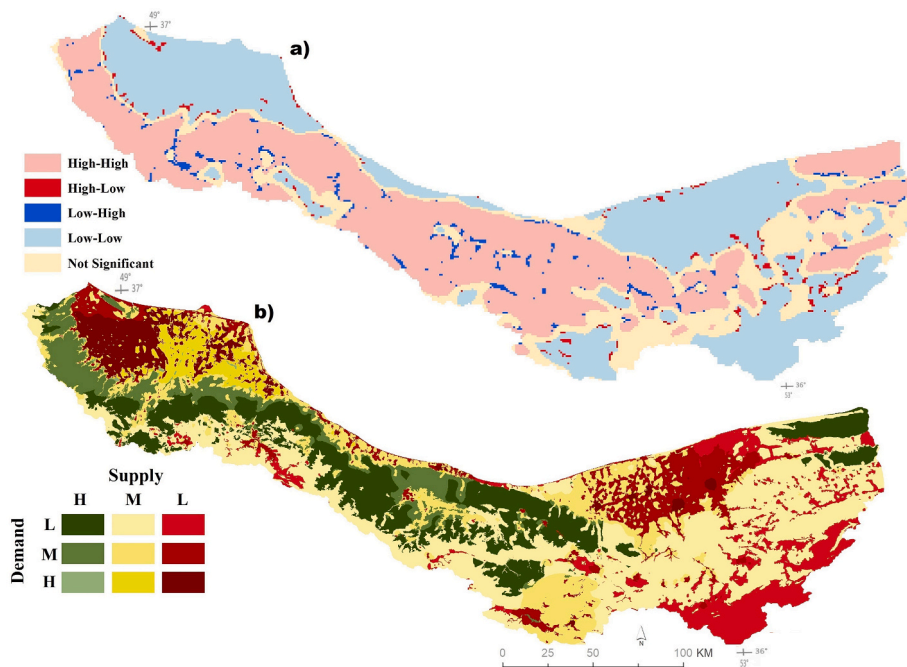


Fig. 6. Spatial distribution of Nature based Recreation (Nbr) supply-demand: (a) Cluster patterns of ESDR based on LISA index in the study area. Not Significant in this figure refers to areas where the ESDR values do not show a statistically significant difference from their neighbouring areas. (b) Bivariate mapping of Nbr supply-demand. This Figure illustrates the overlap of supply and demand at the same geographic areas, providing a better understanding of their relationship. For example, dark red areas indicate High Demand and Low Supply, allowing for a simultaneous visualization of both factors.

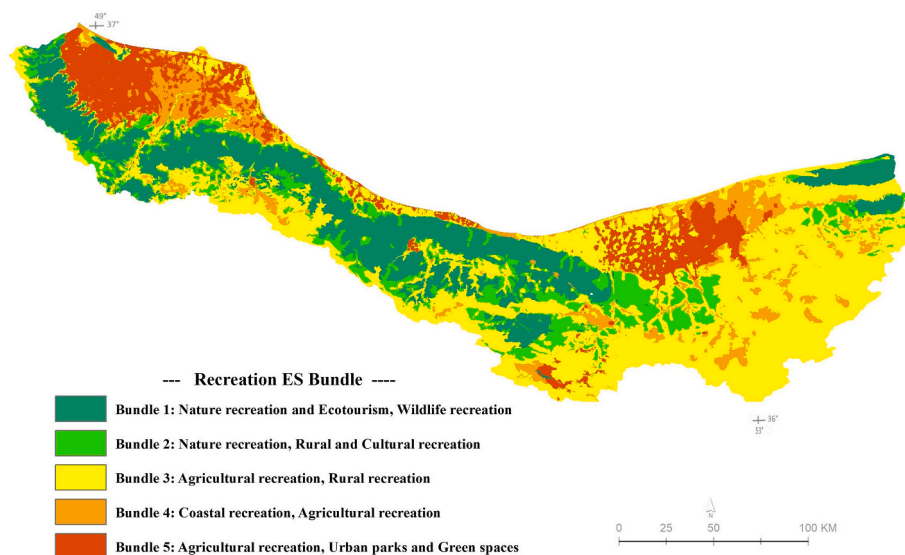


Fig. 7. Spatial distribution of supply-demand bundles representing a typology of Nature based Recreation (Nbr) Ecosystem Services (ES).

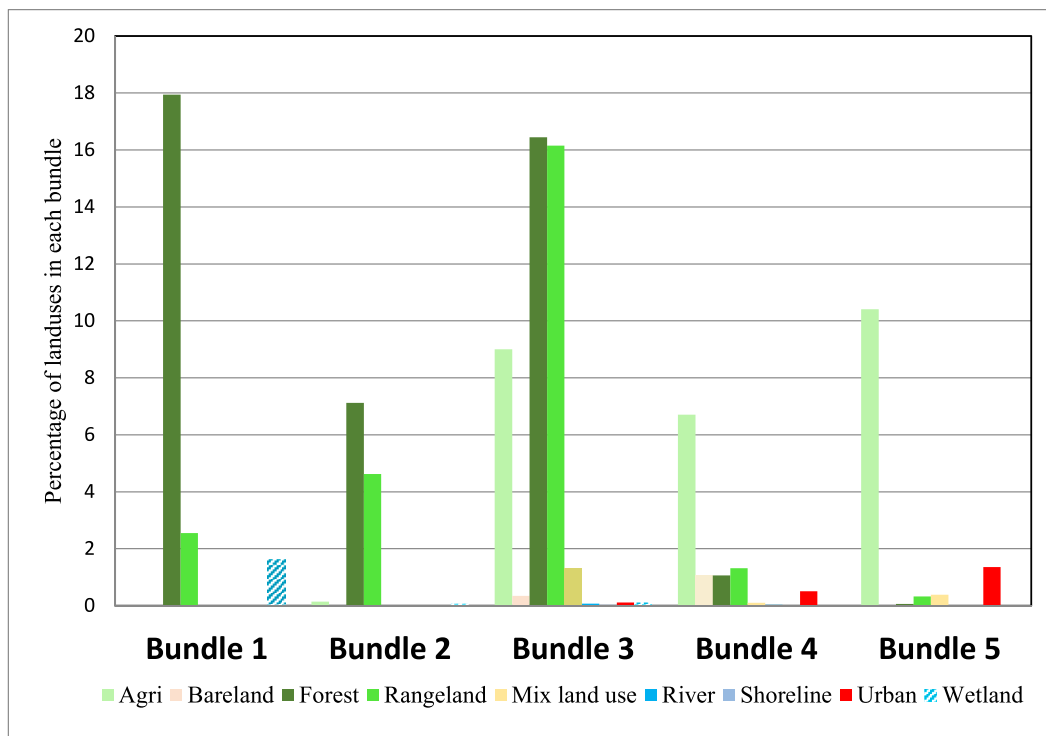


Fig. 8. The percentage of land use/land cover within each Nature based Recreation (Nbr) Ecosystem Services (ES) bundles.

coverage in this bundle contributes to its high recreation production potential, making it highly suitable for the development of Nbr activities that align with the area’s landscape features. Additionally, village recreation and plant collection can be suggested as alternative recreational activities, given the presence of historical villages and quality rangelands that offer abundant opportunities for discovering medicinal and edible plants.

Bundle 3, spanning from lowlands to higher elevations, encompasses the largest portion of the study area, accounting for 43.6%. This bundle exhibits a diverse range of land uses, including forests with a high rate of planted species (16.4%), quality rangelands (16.1%), and agricultural lands (9%). Compared to Bundles 1 and 2, there is a relatively higher proportion of urban areas in this bundle. It is categorized as a

moderately suitable zone for Nbr. However, this region offers potential for other types of tourism, such as agricultural recreation involving agro-product activities, farm tours, and on-farm experiences, as well as rural recreation and outdoor recreation in general.

Bundle 4 comprises 9.7% of the study area and is predominantly located in the northern outskirts, characterized by lowlands. Agricultural lands dominate this region, accounting for 6.7% of the bundle. Forests (1.05%), rangelands (1.3%), and urban areas (0.5%) are present but in smaller proportions. The population density is relatively high in this area due to its proximity to major urban centers and the presence of various villages, resulting in a significant demand for recreation. It is classified as a zone of low suitability for Nbr. However, it offers potential for agricultural and rural recreation, and in certain areas, coastal

recreation due to its proximity to the Caspian Sea.

Bundle 5, primarily located in the lowlands, is characterized by a significant proportion of agricultural land (10.4%), which serves as the main source of livelihood for local communities, and urban areas with a high population density (1.3%). This bundle covers 12.5% of the study area and exhibits a distinct land use distribution compared to Bundle 1. It represents a cold spot in terms of recreation production, mainly due to its low degree of naturalness and the prevalence of built and agricultural lands. The region demonstrates very low suitability for NbR, highlighting the need for effective spatial and regional planning to address the mismatch between supply and demand.

4. Discussion

This study investigated mismatches in NbR supply and demand in the north of Iran to provide insights for spatial and regional planning to sustainably manage tourism activities. To achieve this, a range of indicators was used to map and assess the spatial distribution of NbR supply and demand and corresponding supply-demand relationships. Cluster analysis was performed based on the supply-demand mismatches to create a typology of NbR ES that identifies various types of recreation ES offered by the area. This study proposed a novel application of NbR ES bundles to advance the understanding of supply-demand mismatches and to inform sustainable tourism management.

4.1. Nature-based recreation ES assessment as an integrated approach for mapping NbR supply and demand

Previous studies on NbR evaluation have often focused on single indicators such as the naturalness degree (González-García et al., 2022), or have utilized a limited set of natural variables, including naturalness, protected areas and water bodies (Vallecillo et al., 2019) along with landcover types and type of reliefs (Schirpke et al., 2018; Peña et al., 2015). This study expanded on this by presenting a comprehensive analysis of NbR, incorporating various indicators that combine different natural variables for mapping the supply of recreation potential, as well as employing different distance indices to map recreation opportunities. By integrating different indicators of recreation supply and demand the study helps to increase the understanding of the complexity of NbR which is influenced by the interaction among social, economic and ecological factors (Kulczyk et al., 2018). Furthermore, we consult with experts and scholars to obtain spatially accurate information for identifying various types of NbR ES within the study area (see above Sections 2.7 and 3.3).

The NbR supply of the study area reflects the coexistence of various attributes. These include natural and physical attractions offering recreation potential supply, along with proximity to these attractions, residential areas, and the road network, which help offer recreation opportunities. The most important indicator contributing to recreation potential supply of the study area is LAQ. This indicator considers the diversity, naturalness, and uniqueness of the landscape, highlighting the greater importance of diverse and natural landscapes in the provision of recreation potential compared to homogeneous and constructed landscapes. The significant role of landscape attractiveness to support NbR has been also emphasized in the literature (Walz and Stein, 2018; Komossa et al., 2021). This study found that the most important contributing factors in recreation opportunity are proximity to road network and residential areas in line with the findings from other studies (Peña et al., 2015; Willibald et al., 2019; Scholte et al., 2018).

NbR supply was mapped and assessed by combining recreation potential supply and recreation opportunity. This integrated approach not only facilitated the identification of areas with high recreation production, characterized by a high potential of NbR ES and high levels of accessibility, but also enabled the construction of a NbR ES typology. The combination of different indicators enabled the investigation of a wide range of activities defined within the context of types of recreation

that are accessible to nature-based recreationists in the study area. Each type offers a range of NbR experiences that are influenced by the interaction between the availability of natural settings and the preferences of recreational participants. Identifying these types based on supply-demand relationship can be particularly beneficial for spatial and regional planning conducive to sustainable tourism. In particular, understanding the existing supply-demand mismatches in NbR can inform decisions on where to allocate conservation efforts and infrastructure development, as well as to promote local ecological knowledge and traditional activities linked to NbR (Wu et al., 2022; Vallecillo et al., 2019). This maximizes their benefits whilst mitigating any potential negative impacts such as tramping, erosion, pollution, and habitat degradation.

Most studies that evaluated NbR supply concentrated on a special type of landscape and therefore selected indicators were limited to the characteristics of the dominant landscape in the territory (Schirpke et al., 2018; Kulczyk et al., 2018; Inácio et al., 2022). However, the geographical scope of the present study encompasses diverse landscapes and ecosystems, providing an appropriate basis for constructing a NbR ES typology that identifies various types of recreation ES offered by the area. This study also differs from others (e.g., Paracchini et al., 2014; Crouzat et al., 2022) in the approach employed to evaluate recreation opportunity, or NbR supply. Specifically, recreation opportunity was considered as a separate indicator for mapping NbR supply involving measuring the proximity to all the possibilities that increase the locality's recreation potential. Studies that integrate recreation potential and recreation opportunity for assessing NbR supply are rare in the existing literature (e.g., Vallecillo et al., 2019; Peña et al., 2015).

This study assessed NbR demand by using indicators influencing potential demand (e.g., population density) and those affecting actual demand (e.g., visitation rate). Additionally, road density was considered due to its impact on both potential demand and actual use. While previous research primarily focused on either potential demand (Baró et al., 2016; Chen et al., 2019; Cui et al., 2019; González-García et al., 2020) or actual use (Kulczyk et al., 2018; Peña et al., 2015; Scholte et al., 2018) in mapping NbR demand of an area, this paper integrated both aspects to provide a more comprehensive understanding of demand patterns within the study area. A significant challenge in assessing demand for NbR is the complexity and context-dependency of quantifying demand (Schirpke et al., 2018; Paracchini et al., 2014). In natural landscapes, such as mountains and forests, demand may be most accurately estimated by mapping the level of actual use, whereas in urban areas and their surroundings, it might be better reflected by mapping the local population. Consequently, studies relying solely on one method may not offer an accurate representation of NbR demand. The indicators proposed in this study for mapping recreation demand address this challenge by considering both potential demand and actual use of NbR. This evaluation method not only helps to determine the precise representation of recreational demand in a large-scale study area, but also can provide effective information for NbR supply-demand mismatch analysis.

4.2. Contribution of NbR ES mismatches to inform spatial and regional planning

Mapping and quantifying supply-demand mismatches is a fundamental prerequisite for implementing an ES-based approach and inform spatial planning and decision-making (Li et al., 2023). This study conducted an analysis of supply-demand mismatches in NbR across the case study area based on its spatial diversity to gain deeper insights into the relationship between ES supply and demand. Through this analysis, the extent of supply needed to meet current demand to achieve a balance state between supply and demand was quantified, ultimately identifying areas that should be prioritised in future spatial and regional planning to support sustainable tourism. Achieving and maintaining this balance necessitates both reducing disparities in areas with excess demand and

effectively managing those regions where supply aligns with demand. However, implementing demand reduction strategies may be impractical in densely populated areas. Instead, a comprehensive analysis of existing demand patterns and preferences, including understanding the specific demand for natural landscapes or urban green spaces, can yield actionable insights for planners and decision-makers (Yang and Cao, 2022). Adapting strategies based on these insights becomes crucial for enhancing NbR supply in a way that it aligns with the diverse recreational preferences of residents. Proposed strategies include creating more urban green parks in densely populated areas, restoring or conserving natural landscapes in rural and suburban regions, and improving connectivity between urban and rural areas to facilitate residents' access to different types of NbR. This approach aims to reduce the distances between areas experiencing excess demand and those facing excess supply. Other alternatives include enhancing the accessibility and tourism infrastructure in regions characterized by high supply and low demand for NbR, strengthening tourist attractions. However, it is essential to identify what is the critical supply-demand threshold to avoid trade-offs such as turning low-demand locations into high-demand and low supply (Meng et al., 2020).

The methodology proposed offers a comprehensive representation of both the supply and demand aspects of NbR, considering various potential supply and all demand possibilities, ranging from urban areas to remote natural landscapes that extend beyond residential zones. This approach enables precise identification of areas with deficits and surpluses in supply, enhancing the supply-demand mismatch analysis. Furthermore, this identification enabled the analysis of bundles of supply-demand relationships within the study area, extending beyond administrative boundaries. This adds to previous literature, where such analyses were typically conducted at the administrative division scale (González-García et al., 2020; Liu et al., 2020). This approach has considerable significance, as it holds the potential to promote collaboration and coordination among administrative units to work together toward a shared goal (González-García et al., 2022).

Addressing supply-demand mismatches in NbR has the potential to yield co-benefits across multiple ES, enhancing the sustainability of tourism activities (Yao et al., 2023). By identifying these mismatches, specific strategies can be devised in the study area to rectify under-balanced areas without overloading areas that are well-matched to the current demand. These strategies can include the development of urban parks, green spaces, urban forests and, in rural areas, the preservation of a diverse agricultural landscape facilitating the development of agrotourism activities. This approach not only meets the current demand for NbR but also makes substantial contributions to the provision of various ES, including climate regulation, water retention, carbon sequestration and aesthetic value as a component of cultural ES (Lorilla et al., 2019; Chen et al., 2019; Yao et al., 2023). Meanwhile, within areas where supply and demand are well-matched, effective management strategies are vital in maintaining these balances. This not only safeguards biodiversity conservation and habitat quality but also prevents excessive pressure on these areas. Consequently, addressing supply-demand mismatches in NbR emerges as a pivotal factor in generating co-benefits across multiple ES within the study area, resulting in a positive impact on human health and well-being (Baró et al., 2016). The results of the supply-demand mismatch analysis can guide spatial and regional planning to optimize sustainable tourism management while preserving natural ecosystems.

4.3. Application of recreation ES bundles in spatial planning and decision-making

This study mapped and assessed recreation ES bundles based on the supply-demand relationship to construct a typology of NbR ES across the study area. The study advances the recreation ES bundle approach by providing a comprehensive view of how the supply-demand relationships of NbR ES are bundled and distributed across the study area. Each

bundle represents a shared pattern of its ES states in terms of surplus, balance and deficit. They also share similar geographic conditions, ecological characteristics and human activities (Shen et al., 2023; Schirpke et al., 2018). Hence, the bundles can serve as spatial units of social and ecological integration to help decision-makers in devising spatial and regional plans that enhance the sustainability of social-ecological systems (Shen et al., 2023; Baró et al., 2016; Li et al., 2023). In particular, they could be useful for identifying and prioritizing key locations where supply-demand mismatches exist, rather than focusing on the management of a single ES (Li et al., 2023; Baró et al., 2016).

Applying cluster analysis, this study generated a typology of NbR ES comprising five bundles with differing characteristics. Each bundle has a set of attributes that reflect specific recreational uses and experiences within the study area. Identifying a typology of NbR ES can provide insights for planners to formulate appropriate targeted strategies based on the region's characteristics, fulfilling development or conservation objectives. The characteristics of the five identified bundles reveal that the study area is suitable for different types of NbR. The regions with abundant natural landscapes (bundle 1 and 2) are characterized by a surplus in supply and substantial ecological value. These regions are suitable for NbR and eco-tourism. Conducting these activities in a sustainable manner contribute to local economic development while preventing ecosystems degradation and associated ES. Furthermore, effective tourism management strategies to avoid potential ecological impacts such as unorganized visits, disturbance frequency, frequent fire events and development of facilities in these areas are essential to align recreational activities with conservation goals and mitigate potential ecological impacts, ensuring the overall ES supply. This finding is consistent with previous research conducted by Lorilla et al. (2019), who proposed that nature-based tourism in regions of high naturalness and with a surplus of recreation supply can both help achieving sustainable tourism and safeguard the long-term supply of ES.

Conversely, regions experiencing a supply deficit (bundles 4 and 5) are primarily linked to highly urbanized areas. Therefore, appropriate planning policies can be adopted, particularly in coastal areas with concentrated urban centres and substantial populations, to address the supply-demand mismatch. These include policies that promote the establishment of urban parks, green spaces, agricultural recreation and ecological restoration so as to help meeting the recreational needs of residents. Other studies which addressed supply-demand mismatches also emphasized the importance of adopting land use planning strategies that are conducive to building blue-green infrastructure (Chen et al., 2019), developing green spaces and urban parks (Wang et al., 2019) as well as restoring vegetation in degraded ecosystems (Xu et al., 2021). Moreover, crafting targeted strategies to enhance tourism activities and experiences rooted in local ecological knowledge where applicable (e.g., traditional farming tours, traditional fishing techniques) can yield multiple benefits for local communities as well as support other cultural ES. This knowledge holds substantial potential for promoting sustainable tourism practices and fostering community-based tourism (de Souza Queiroz et al., 2017; Aguado et al., 2018; Chakraborty et al., 2020).

Bundle 3 is characterized by a mixture of natural and productive land uses. The mixed land uses in this region contribute significantly to achieving a balanced state between supply and demand. Given the potential transition from a balanced state to a state with a supply deficit in this intermediate bundle, planning strategies could be adopted to protect and enhance multiple ES while also improving opportunities for NbR within the area. This may include the promotion of tourism activities and experiences that are based on low-impact infrastructure, responsible visitor behaviour, and local ecological knowledge (Kil et al., 2014; Schirpke et al., 2018). This approach not only enhances the provision of ES but also strengthen the resilience of both natural and productive landscapes, ensuring their ability to cope with the impacts of tourism activities.

The identified typology of NbR in this study offers valuable insights into its potential contributions to other ES within the study area. Examining these contributions is crucial for addressing other mismatches between supply and demand of ES. For instance, the development of urban green parks and the promotion of agro-tourism practices can enhance multiple ES, including carbon sequestration, climate regulation and water retention. Furthermore, traditional activities can foster a strong connection between people and the landscape, increasing cultural ES and subsequently influencing spatial and regional planning practices. This analysis highlights the complex role of NbR in supporting sustainable tourism and ES provision.

4.4. Limitations and challenges

This study identified supply-demand mismatches in NbR ES in the north of Iran which can inform spatial and regional planning strategies seeking to support the emergence of more sustainable forms of tourism. However, there are still limitations to be addressed in further research. One common challenge in mapping and modeling is handling data resolution, particularly when dealing with datasets of varying resolutions. Resizing data at different resolutions has been shown to reduce model accuracy (Kalinauskas et al., 2021). However, we believe that we have selected the optimal scale for the spatial indicators, thereby reducing this uncertainty. While this study adopted reliable models to quantify NbR supply and demand, there could be uncertainties related to the evaluation results. For example, LAQ was quantified based on indicators that were calculated by landscape metrics or scored based on the literature (Hermes et al., 2018; Kalinauskas et al., 2021). This approach has limitations because a landscape can be defined as the appearance of the land from a human perspective (Brown and Brabyn, 2012). Similarly, LAQ can be perceived as the pleasure people gain from the aesthetic appreciation of landscapes (Solecka et al., 2022; Hermes et al., 2018). Accordingly, users' perceptions and preferences for different landscape features in the study area could be combined into our models to validate the results and make it more robust. This could be achieved by employing qualitative research methods such as interviews, questionnaires, participatory mapping, or using social media data to examine landscape aesthetics (Hermes et al., 2018).

This study mapped and assessed various types of NbR ES based on the supply-demand relationship across the study area to provide information for spatial and regional planning to achieve sustainable tourism management. However, the effective operationalization of sustainable tourism requires a comprehensive consideration of tourism carrying capacity. This concept considers the maximum number of visitors who can visit a tourist destination simultaneously without causing destruction of the physical, economic, and sociocultural environment (Adrianto et al., 2021; Salerno et al., 2013). Therefore, future research could quantify social and ecological carrying capacity within the study area to support sustainable tourism management and provide a balance between social and ecological systems.

NbR demand was evaluated based on the population density as potential and visit rate for actual demand without considering the influence of socio-cultural and economic factors on the level of demand. However, previous studies (Sun et al., 2024; Guo et al., 2022; Willibald et al., 2019) have highlighted the role of socio-demographic and economic factors in shaping recreational use and preferences in a region. Considering different socio-cultural and economic components in mapping recreation demand could provide a better understanding of the recreation participation pattern over the study area. Furthermore, it is suggested that conservation constraints, particularly those related to habitats and biodiversity conservation, should be incorporated into the process of recreation supply mapping. By doing this, a balance between recreational activities and ecological conservation could be achieved to ensure the sustainability of native land covers and protected areas. Additionally, it is advisable to explore the role of biodiversity in providing NbR ES, particularly in regions with protected areas known

for their rich biodiversity. Such areas contribute to both the provision of recreation ES and the need for conservation efforts.

Another limitation of this study is the creation of bundles of NbR ES based on statistical processes. However, considering administrative units is fundamental for spatial planning, not only for aligning with governance structures and decision-making scales but also to be able to better reconcile interests between different stakeholders (González-García et al., 2022). Therefore, future studies should consider administrative units along with the bundles of social-ecological units to update and facilitate a more integrated spatial planning in the study area. Moreover, a co-production approach that incorporates the perspectives of different actors and stakeholders is essential for spatial and landscape planning (González-García et al., 2023), rather than relying solely on statistical processes to create social-ecological units. Therefore, future studies could adopt a participatory process in the region that includes the views of actors and stakeholders, to conduct a comprehensive spatial planning process based on our data and local knowledge. This approach would facilitate the inclusion of diverse values and perspectives, enhancing our understanding of the interaction between NbR supply and demand. Despite these limitations, the proposed methodology to investigate supply-demand mismatches in NbR through the creation of a typology of NbR ES provides valuable insights for the region, especially considering its abundance natural landscapes and a lack of spatial data.

5. Conclusion

Applying supply-demand bundles to establish a typology of NbR offers valuable insights for crafting specific strategies in sustainable tourism management. This study identified five distinct bundles, each representing a unique type of NbR within the study area. Bundles 1 and 2 have abundant supply and high ecological value, making them ideal for nature-based activities such as camping, hiking, climbing, and bird-watching. In contrast, Bundles 4 and 5, closely linked to urban centres, face supply deficits, making them less suitable for NbR. Bundle 3, characterized by a mixture of natural and productive lands, plays an important role in maintaining a balanced supply-demand state. This region holds potential for diverse forms of tourism, including rural and agricultural recreation such as farm tours and farm life experiences. The findings facilitate the identification of priority areas as seen in Bundle 3, where substantial efforts in improving sustainable NbR practices could have positive cascading effects on other ES.

This paper has proposed a typology of NbR ES based on their supply and demand characteristics, which can inform the design of targeted strategies to balance the provision and use of NbR in tourism destinations. Moreover, the typology of NbR identified in this study provides valuable insights into its potential contributions to other ES within the study area. Exploration of these contributions reveals the importance of understanding these interactions to effectively address mismatches between ES supply and demand. However, this typology also raises the question of how to involve stakeholders in high-demand areas to adapt and implement these strategies through effective spatial and regional planning. Future research could explore how to integrate biodiversity conservation and participatory approaches within administrative boundaries, thus advancing our understanding of how to coordinate tourism management and ecosystem preservation not only in the context of NbR but also in the broader framework of multiple ES. Participatory exercises that involve tourism operators, local communities, and conservation groups can enhance shared understanding and develop sustainable strategies that help to achieve a balance between tourism activities and conservation efforts. This collaborative approach can inform further research exploring trade-offs and synergies between various ES, potentially adapting the NbR typology as a framework for managing these complex interactions within the study area. By utilizing the NbR typology, collaborative initiatives have the potential to transform areas characterized by high supply and low demand, such as protected wetlands or native forests, into sustainable tourism destinations.

Responsible ecotourism, informed by stakeholder participation, generates income while supporting habitat restoration and educating visitors about ecosystem services, biodiversity, and cultural significance. Such collaborations balance economic benefits and ecological protection, ultimately enhancing multiple ES through synergistic management. This adoptable approach demonstrates the effectiveness of the NbR typology in surpassing conventional management of individual ES by harmonizing the relationship between different ES, ultimately optimizing outcomes for sustainable tourism development.

CRedit authorship contribution statement

Mitra Ghasemi: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alberto González-García:** Writing – review & editing, Supervision, Conceptualization. **Zabih Charrahy:** Validation, Resources, Investigation, Data curation, Conceptualization. **Silvia Serrao-Neumann:** Writing – review & editing, Supervision, Conceptualization.

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2024.171185>.

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