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Designing Recreational Trails in the Sarigol National Park and Protected Area, Iran

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ABSTRACT

Aims: Access paths to natural attractions in protected areas must be designed and developed considering environmental impacts. Visitors' movement in areas susceptible to soil erosion may cause destructive impacts on trails, such as widening, increasing susceptibility to erosion, and damaging surrounding vegetation. This research aims to suggest a sustainable trail network (off-road vehicles and hiking trails) in the Sarigol National Park and Protected Area,

Materials & Methods: The study has been conducted based on the least-cost path algorithm and comparing the results with existing recreation trails. The required field information was obtained through the study area, including the width of 431 trails and 15 environmental factors affecting the trail width. Analysis of Covariance has been used for estimating the potential of pathwidth expansion. The model's accuracy was assessed by root mean square error, which is 29cm for hiking trails and 126cm for off-road vehicle trails.

Findings: One optimized off-road vehicle trail and one optimized hiking trail in the study were suggested using a degradation map and least cost patch model. The present study's findings indicated that existing paths are located in areas with high susceptibility to widening because of crowding.

Conclusion: Geology, climate, distance from villages, and distance from the river (as the indicators of human presence) have been considered influential factors on hiking trails in the Sarigol National Park and Protected Area. Constructing new trails in sites with minimum susceptibility to degradation or decreasing crowding impacts on existing trails is recommended.

Keywords: Spatial Optimization; Recreational Trail; Nature Conservation; Least-Cost Path Analysis (LCPA).

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Introduction

Protected areas provide a range of ecosystem services, including biodiversity conservation. They are also essential destinations for various nature-based tourism and recreation activities (1). Trails are considered as a link between visitors and nature (2). They are designed to avoid the uncontrolled dispersal of visitors (3) and provide more infrastructure to access natural areas (4). They are constructed to create a sustainable network for improving the quality of visitor experience and travel services in the natural areas and protect the environmental resources by limiting the dispersion of visitors (5). The protected areas are increasingly becoming popular recreational destinations, which may increase visitors' use pressure on trails. Trails must be carefully located, designed, and managed to minimize negative impacts on the ecological properties of the protected area and provide a satisfactory experience. The adverse ecological impacts of recreational trails on flora, fauna, soil, and water resources, such as vegetation decline, vegetation composition change, trail widening, soil loss, and soil compacting, have been widely reported. (6, 7, 8, 9, 10, 11). Table 1 describes a range of ecological and social impacts of trails. Although considerable research has been devoted to the context of tourism and recreation, little attention has been paid to synthesizing knowledge on spatial optimization of recreational trails and the role of human mobility patterns on the degradation.

The conservation of natural habitats and biodiversity is the primary concern of protected areas. Various recreational opportunities are also provided in these areas (12). The frequent trade-offs between these activities pose challenges for management and require decisions about prioritizing and directing management actions (11). Based on the strategic management plan of protected areas in Iran, sustainable tourism is organized in two zones: intensive nature-based and extensive nature-based. Recreation trails are allowed to be constructed in both zones (13).

Recently, in Iran, the protected areas are facing increasing demands for providing recreation opportunities alongside playing their priority function in nature conservation. This may lead to conflicts of interest. Recreational trails can help to decrease this conflict because they provide access to tourist attractions scattered across protected areas while restricting visitor traffic to prepared routes (11). However, their negative impacts will exceed their benefits if designed and constructed in sites with high susceptibility to degradation. Predicting areas susceptible to trail degradation is valuable for implementing protective measures and reducing trail damage (14). The factors influencing the susceptibility of recreation trails to degradation must be identified and considered in constructing new trail networks and managing existing ones. Recreation ecology studies have described influential environmental and managerial attributes' relationships with trial degradation. Dragovich and Bajpai (2022) considered trail width to indicate visitor impacts on vegetation, soil, water, and, potentially, visitor safety (15). Tomczyk and Ewertowski (2013), in a survey that presented a framework based on geographic information system (GIS) and regression tree analysis of optimized recreational trail location, considered slope (i.e., landform grade), aspect, profile curvature, planar curvature, elevation, landform type (valley, mid-slope, ridge), soil type, bedrock type, type of plant cover, use level, and use type as influential factors on degradation of the trail network (16). Marion (2023) conducted a review of trail science research, and based on his findings, the most influential "non-sustainable" attributes revealed in recent trail science studies include alignments: 1) with steep Trail Grad, 2) that closely approximate the fall line, and 3) that cross flat terrain, particularly with wet and/or organic soils (17). Meadema et al. (2020) considered three core types of trail impact, including trail soil loss, widening, and muddiness, as the most critical trail degradation forms. Their findings confirm the importance of landform grade in determining the susceptibility of trails to degradation and the influence of routing decisions. They found that although local climate, soils, and vegetation influence the rate and severity of trail degradation, designers can minimize the influence of these factors by selecting sustainable trail alignments relative to topography (18). Stevenson et al. (2022) identified that trail degradation increased where there was surface water (19).

This research was planned as quality research is scarce, and more scientific investigation is needed in Iran for recreation trial susceptibility. It aims to:

1) Determine the environmental factors affecting trails and their surrounding degradation in the Sarigol National Park and Protected Areas.

2) Design the best route for trails in the study area to decrease the environmental impacts of trails to the minimum possible level.

1.The study was conducted in the area without considering the zoning plan because two tourism zones cover a tiny portion. On the other hand, due to the need to update the management plan, there was a possibility of changing the boundaries of the mentioned zones.

Materials & Methods

Study area

The Sarigol National Park and Protected Area are in Northern Khorasan Province, NE Iran (Figure 1). It covers an area of 28,000 hectares, including the Sarigol National Park (IUCN category II) of about 6,000 hectares and a protected area (IUCN category IV) of about 22,000 hectares. Almost all of the area

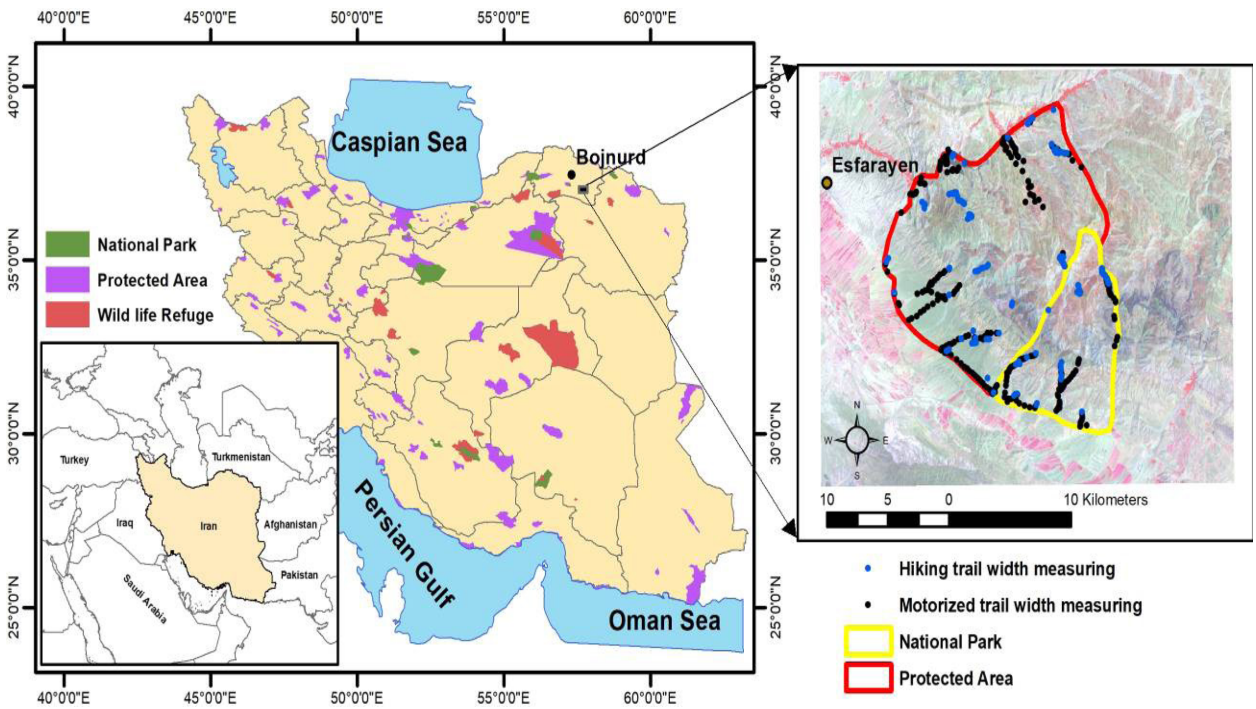

Figure 1) The study area located in the Northeast of Iran.

is covered with mountains, valleys, hilly, and a small area of about 2000 hectares of the plain. Due to the diversity of topography and relatively large amounts of water resources, the area's biodiversity is considered rich. Considering the diverse conditions of the area, it has great potential for research, education, and recreation (20, 21).

Driving factors

This research has been conducted to design trails with the least possible impacts on ecological properties and to determine the environmental and human factors affecting the degradation of trails and their surroundings. Determined influential factors were categorized into two groups based upon degradation reduction, namely (1) biophysical and (2) anthropogenic, including fifteen explanatory variables in the database, while trail width databases from the field campaign can be considered a dependent variable in degradation modeling (Table 2).

Landform characteristics, e.g., slope, aspect, and elevation, are often surveyed to explain trail degradation. Topography is influential on most geomorphologic processes. Aspect is one of the main factors affecting solar radiation energy (3,9). Climate conditions (i.e., temperature, humidity, precipitation, solar radiation, wind) directly impact environmental sensitivity (3,10,22). Trampling resulted in trail widening and soil exposure to erosion (23) and negatively impacted surface soil properties, aboveground plant cover, and height (24). Soil resistance to erosion is significantly based on soil characteristics, including specific gravity, drainage layers, particle size, and organic matter (25,26). Geology is a critical environmental factor affecting other factors, such as topography, soil, and vegetation (27,28). Land use is critical in determining the type of human activity and its presence. It is an essential factor in environmental condition changes (29,30,31). Visitor use has a substantial negative impact on recreation trails. Visitor presence in the areas closer to villages and rivers is more significant than in distant areas (32, 33, 34).

Trail width sampling

Using the Cochran formula, the most suitable sample size was identified based on time, budget, and personnel limitations and needed accuracy (Eq. 1).

$$n = \frac{Nt^2\, pq}{(\mathrm{N}-1)d^2 + t^2\, p.q} \qquad \text{Eq. (1)}$$

where n is the sample size, N is the population size, p is the proportion of unties in the sample, q is 1-p, t is the t table value at the required confidence level, and d is the margin of error (35).

Based on the above formula, the number of needed sample points was calculated at 431. However, it is only possible to measure width for some 431 points due to time and budget limitations in sampling. Therefore, three routes were selected for width sampling: a path south of the national park, the border between the protected area and the national park, and a crowded path north of the protected area. A total of 50 sample points were selected among 431 sample points based on time and budget. The sampling method was random without replacement: observations are chosen randomly and may occur only once in the sample. The selected sample points were surveyed in the field and re-surveyed on Google Earth. Trail width was measured in selected routes in Google Earth. Trail width has been measured in some sample points in the field by tape measure to verify measurements. Trail width sampling was conducted from June to September 2015. In each sampling point, spatial reference has been recorded using GPS (accuracy= ± 4). The points were then transferred to Google Earth software, and their width was obtained on the

Table 1) Different forms of trial impact and their ecological and social effects (3).

Impact Form	Ecological Effects	Social Effects
Soil Erosion	Soil and nutrient loss, water turbidity/ sedimentation, alteration of water runoff, more permanent impacts	Increased travel difficulty, degraded aesthetics, safety, Increased restoration costs
Exposed Roots	Root damage, reduced tree health, intolerance to drought	Degraded aesthetics, safety
Trampling	Vegetation loss exposed soil	Degraded aesthetics
Wet Soil	Prone to soil puddling, increased water runoff	Increased travel difficulty, degraded aesthetics
Running Water	Accelerated erosion rates	Increased travel difficulty
Widening	Vegetation loss, soil exposure	Degraded aesthetics
Visitor-Created Trails	Vegetation loss, wildlife habitat fragmentation	Evidence of human disturbance degraded aesthetics

image, dated in 2011, by the show ruler tool. The correlation coefficient between field data and extracted width data from Google Earth software images was acceptable (R = 0.89). Therefore, other samples were extracted from Google Earth software. Google Earth is an online mapping application that provides users with interactive mapping capabilities. Academic users often use this program as a source for referrals or basic maps, easy access, and a free image information source. Therefore, many individuals and researchers use Google Earth as an accurate and reliable data source for mapping applications (36).

Creating a database in GIS

All independent variables used in this study were resampled into a grid format of 27 m spatial resolution because the highest spatial resolution belongs to DEM data with a pixel size of 27 m (Figure 2). The total size of the spatial matrix for the study area was 843 ×938 (columns and rows), which contained 790734 cells with 27 cell sizes. All needed maps and 431 sample points were imported into the ESRI ArcGIS software ® version (ESRI, Redlands, CA, 2006). The needed information of sample points was then extracted into the attribute table of 431 sample points. The values of independent variables were determined for each point, including slope, direction, elevation, vegetation, climate, minimum and maximum temperature, rainfall, solar radiation, Land use, erosion, soil type, distance from the village, and distance from the river.

The ASTER imagery has effectively generated land use/cover and soil maps (37, 38). This study used one scene of ASTER data dated June 20, 2014, for classifying soil and land-use types. The surface reflectance data was georeferenced to UTM map projection, zone 40, and the datum of WGS84. The training data was then prepared based on the soil and land-use map of the Natural Resources and Watershed Management Organization. The maximum likelihood algorithm selected for the supervised classification is one of the most popular algorithms for classifying remote-sensing image data.

In the next step, the data of dependent and

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Table 2) Variables analyzed in the model, explaining the degradation of trails in the study area. All variables were generated or resampled at a 27 m resolution.

Variable	Data Type	Source	Measurement Method
Trail Width (cm)	shp file	A total of 431 sampling sites were collected from the study area. Point vector format	Fiberglass Measuring Tape, GPSmap 76S
Elevation (m)	Grid file-continues	ASTER GDEM V2	(Tachikawa et al., 2011)
Aspect	Grid file-encoded	Aspect derived from elevation grid.Categorical	Calculated from GDEM, V2, SAGA terrain Analysis/Morphometry module (Conrad et al., 2015)
Slope(○)	Grid file-continues	Slope angle derived from elevation grid (○)	Calculated from GDEM, V2, SAGA terrain Analysis/Morphometry module (Conrad et al., 2015)
Climate Index	Grid file-encoded	Meteorological data	De Martonne Index climatic classification (Koleva et al., 2004)
Minimum and Maximum Temperature (°C)	Grid file-continues	Meteorological data	Linear regression relationship between elevation and temperature. The R2 for minimum and maximum temperatures were 0.65 and 0.78, respectively.
Precipitation(mm)	Grid file-continues	Meteorological data	Linear regression relationship between elevation and precipitation. The R2 for precipitation was 0.93
Solar Radiation (Watt-h.m^{-2})	Grid file-continues	ASTER DEM image	Solar radiation modeling. Solar radiation analysis tools, ArcGIS, and ArcMap 10.3.1
Vegetation (No dimension)	Grid file-continues	ASTER	NDVI Index (Kogan, 2002)
Soil Type	Grid file-encoded	ASTER	Maximum Likelihood Classification method. ENVI 4.5, Kappa coefficient 0.56
Erosion	Grid file-encoded	Collected from Forests, Range and Watershed Management Organization (FRWO), Iran	
Distance to the Village (m)	Grid file-continues	Collected from Saman Engineering Consultants Co., Ltd.	Calculated from digital maps of topographic (The National Cartographic Center of Iran (NCC), Iran, (ArcGIS® 10.0, Esri, Redlands, USA)
Distance to the River (m)			
Geology	Grid file-encoded	Collected from Forests, Range, and Watershed Management Organization	
Land-use	Grid file-encoded	ASTER	Maximum Likelihood Classification method ENVI 4.5, Kappa coefficient 0.82

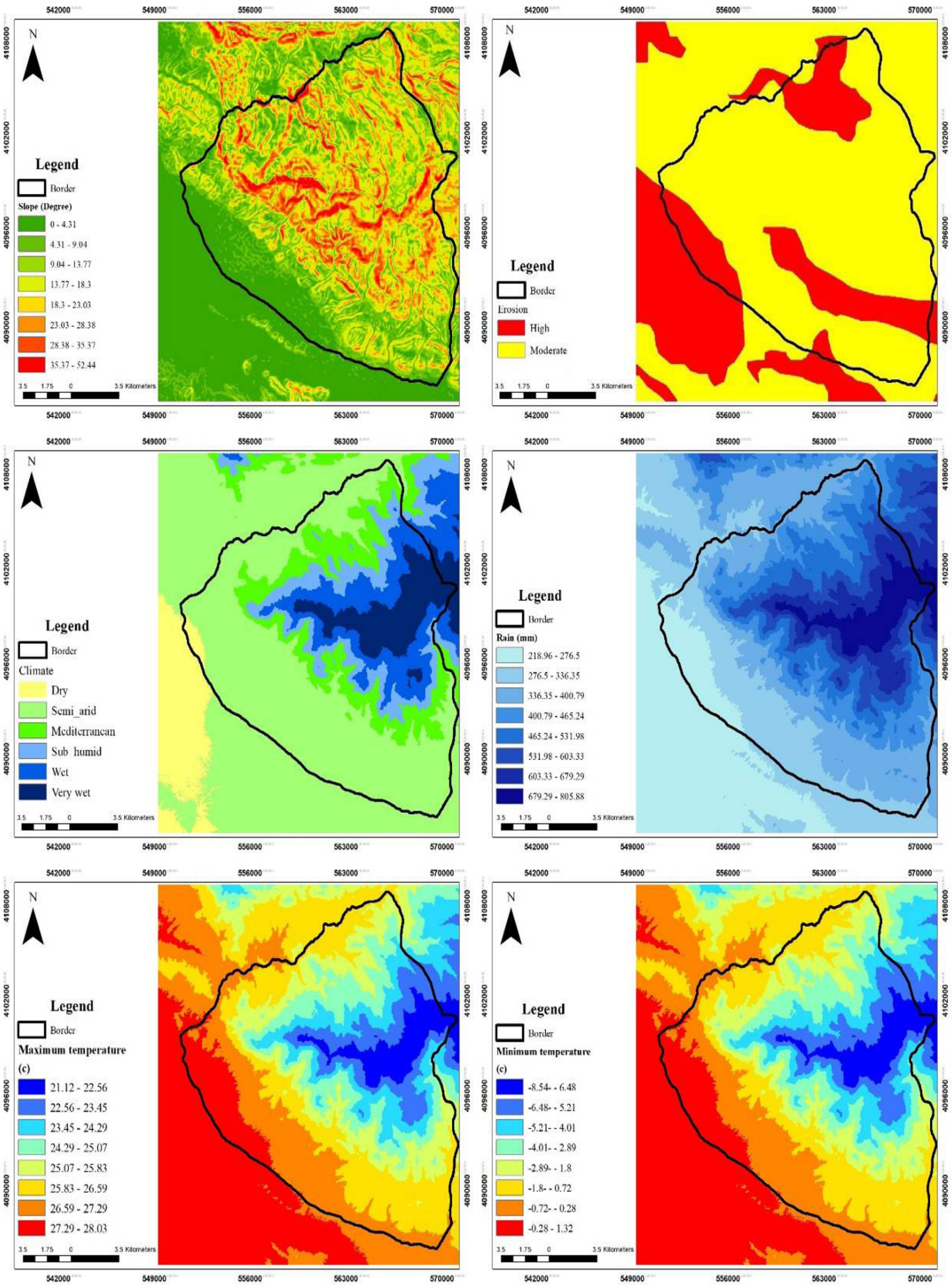

Figure 2) Variables are integrated into the model for assessing environmental sensitivity to recreational trails in the Sarigol National Park and Protected Area.

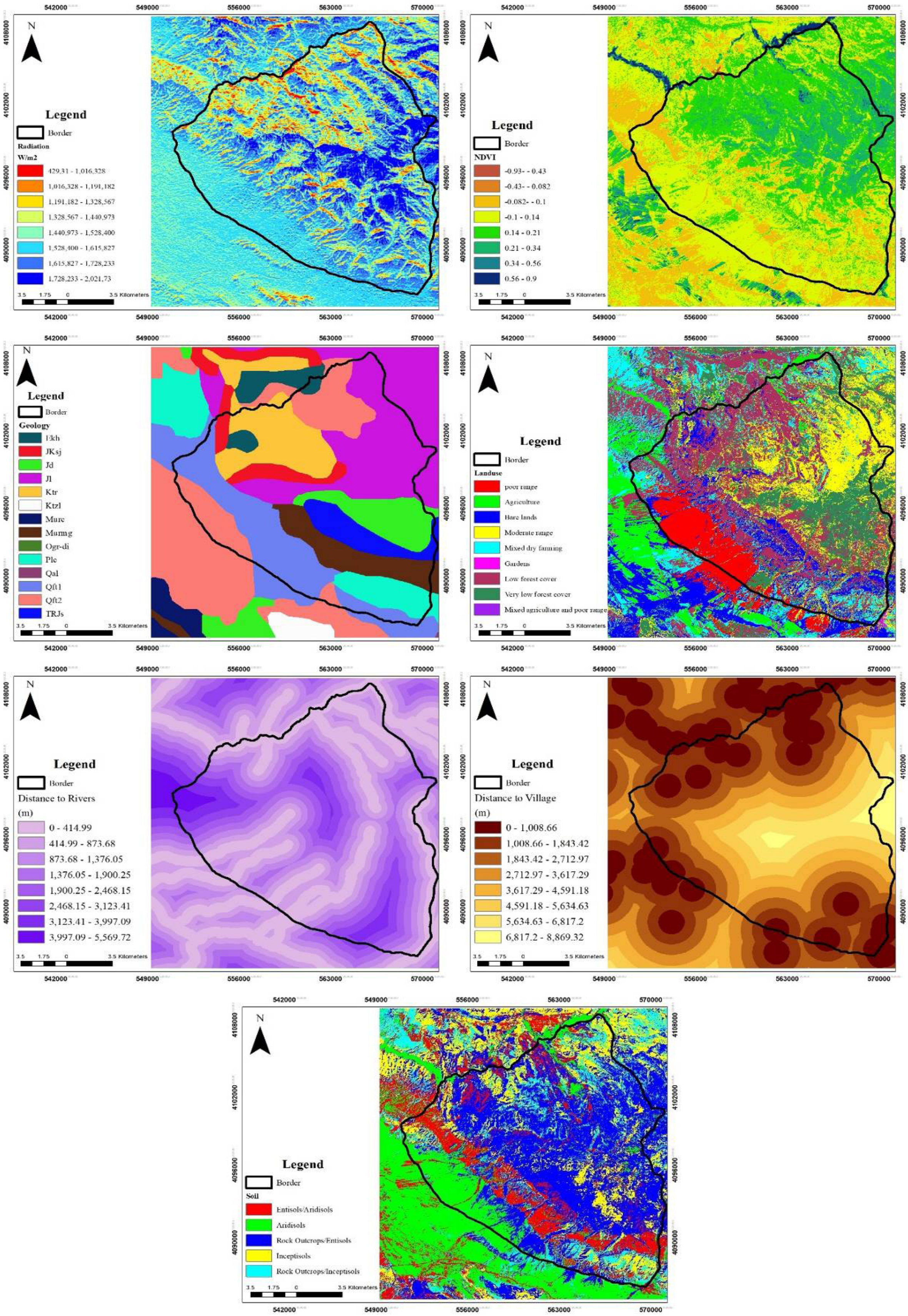

Figure 2 continued) Variables are integrated into the model for assessing environmental sensitivity to recreational trails in the Sarigol National Park and Protected Area.

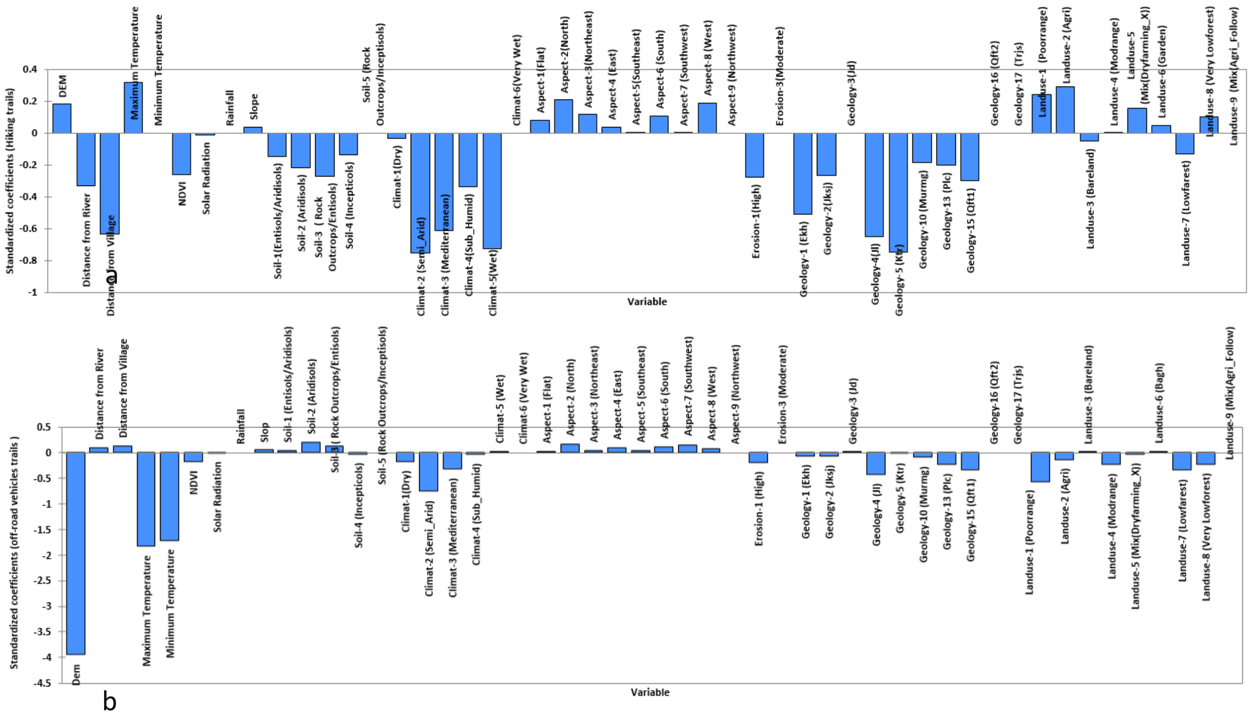

Figure 5) The standardized coefficients plot for each predictor, a) hiking trail and b) off-road vehicles trail.

Table 3) Analysis of variance and Goodness of fit statistics.

Source	Hiking	Off-road vehicles
Model		
Removed Variables (Multicollinearity)	Tmin, Rainfall	Rainfall
F	3.820	1.911
Pr > F	< 0.0001	0.002
R^2	0.73	0.34
RMSE	26.853	126.539
MAPE	18.286	26.219

independent variables were imported to XLSTAT Pro ® statistical software (version 2015; Addinsoft, Paris, France). Some 145 points on trails with a width of less than 170 cm were identified as hiking sample points (43 points, equal to 30% of the data, were considered as validation data), and 286 points on trails with a width of greater than 170 cm were defined as vehicles sample points (85 points equal to 30% of the data were distinguished as validation data).

Statistical analysis

ANCOVA is applied to test the interaction effects of multiple categorical predictors on a continuous dependent variable (39). ANCOVA primarily aims to strengthen the variance analysis model, which contains the effect of factors with one or more additional variables that depend on the response variable. This strengthening aims to reduce the error variance in the model to make the analysis more precise (40). Off-road vehicle trails

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are not allowed in the national park but are allowed in the protected area. Therefore, two separate sensitivity maps of the study area for trail degradation should be prepared. Given that the minimum width of off-road vehicles is 170 cm based on Japan International Standard (JIS) size off-road vehicles (41), the sampled points (431 points) were separated by width. Points with a width of less than 170 cm were used to provide a hiking sensitivity map, and points with a width of more than 170 cm were used to prepare a normal passenger off-road vehicle sensitivity map.

The least cost path model

The least-cost path analysis (LCPA) is a spatial optimization technique frequently used in GIS (42,43). Planners use it to find the best path from one point to another over a cost surface. This path can be calculated by integrating multiple criteria considering different issues (environmental effects and economic investment) (44). The least-cost path method using GIS-based analysis supported the best corridors for connecting landscape patches to be adopted in ecological infrastructure planning. It is based on cost-distance analysis (45). A GIS least-cost path analysis (LCPA) was performed to identify suitable corridors based on the cost of degradation through different variable types (Table 2). We performed LCPA by the Spatial Analyst extension in ArcGIS version 10.3 (ESRI). In the LCPA, a 'cost raster' was first used, calculated in this study by the ANCOVA model for hiking and off-road vehicles (motorized) trails. A cost distance function creates a cost surface distance raster that uses the source locations and accumulated cost surface. This shows a raster where each cell is assigned a value to the least accumulative cost of traveling from each cell back to the source location (46). Based on this cost distance raster, the path resulting in the lowest cost (minimal degradation) is identified to connect a source to a destination location within a cost surface (47), which is known as the least-cost path distance (48). In this study, the start and endpoints of the existing trails within the study area were considered source and destination points, respectively, with start points in rural areas and endpoints in mountainous camping spots. In total, 15 potential path width expansion factors were derived from different sources (Table 2). Before using ANCOVA models, multicollinearity was applied among conditioning factors and corrected by removing problematic independent variables (Table 3).

Findings

The model presented in this study was used to plan recreational trails within the Sarigol National Park and Protected Area located in the North Khorasan Province in the northeast of Iran (Figure 1). According to the results obtained from the ANCOVA analysis with all variables, the coefficients of determination for hiking and off-road vehicles (motorized) trail models were 0.67 and 0.33, respectively. Root Mean Square Error (RMSE) values for hiking and off-road vehicle trails were calculated at 26 cm and 126 cm, respectively. The Mean Absolute Percentage Error (MAPE) of 18% and 26% were calculated for hiking and off-road vehicle trails, resulting in a suitable model. The model's F-test was significant for hiking trails (3.8 and off-road vehicle trails to 1.9. Its p-values were 0.0001 and 0.002 for hiking and off-road vehicle trails, respectively (Table 3). The constructed model is 95 percent reliable and able to determine the extent of destruction of paths based on existing data. The results of stepwise regression suggested that the variables of altitude, geology, land use, distance from the village, vegetation cover, and distance from the river are the most critical variables for hiking trails, and variables of distance from the village, geology, and altitude are the most important

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variables affecting the rate of destruction of off-road vehicles trails in Sarigol Protected Area and National Park at the level of α = 0.05. Figure 2 represents the maps of the study area's susceptibility to destruction (considered cost surface) for hiking and off-road vehicle trails. The red color shows the areas with high sensitivity to destruction, and the blue color represents the areas with low sensitivity to destruction.

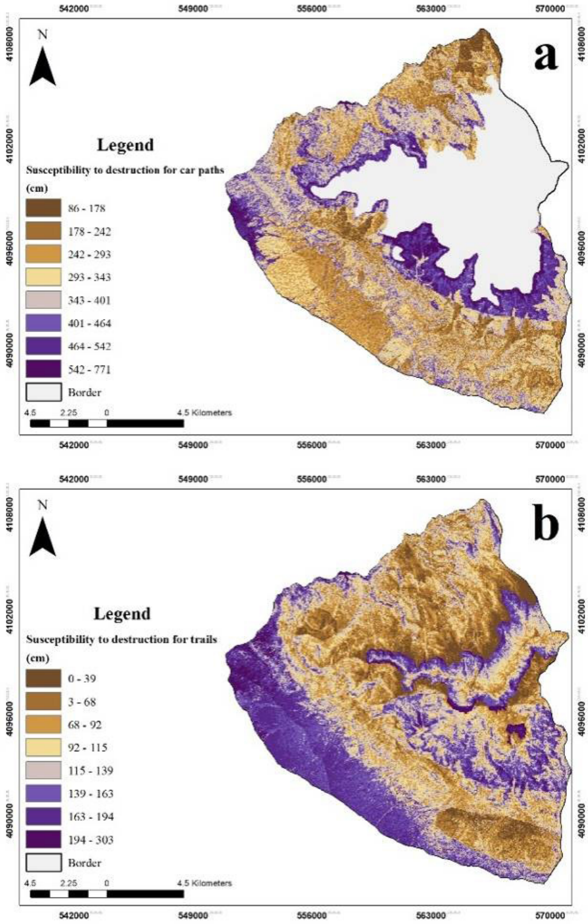

Figure 3) The maps of susceptibility to degradation for a) off-road vehicle trails and b) hiking trails in the Sarigol National Park and Protected Area.

After producing cost maps, the direction of trails was the same as the proposed source, and destination points were defined. Figure 4 (a) shows the proposed and existing hiking trails that link Izee village to Izee Waterfall in the west-south of the study area. Figure 4(b) represents the proposed optimal (red line) and existing off-road vehicle trails (black line) in the northeast of the study area (between Ghalee-Sefid and Ganjdan villages). As shown on the map, the proposed trail crosses the area with the least susceptibility to degradation.

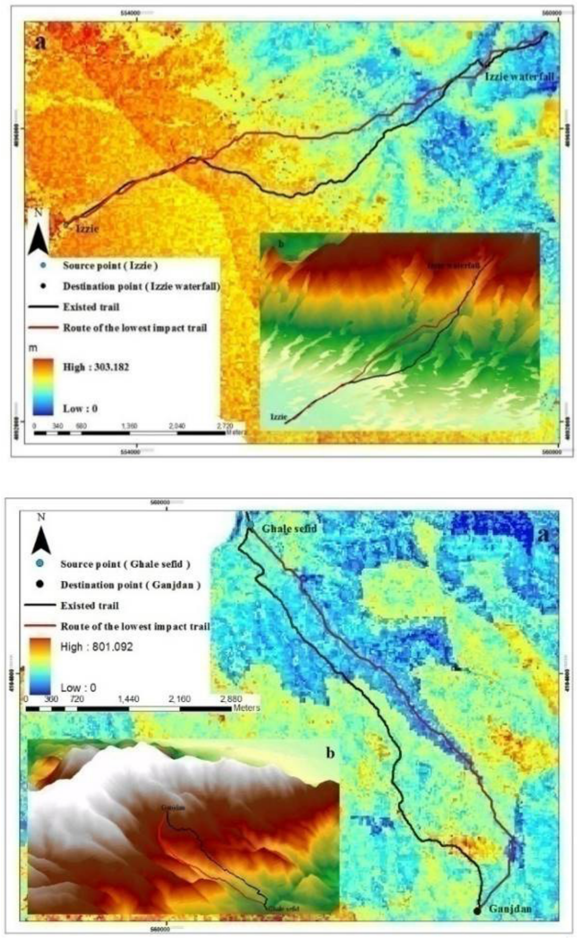

Figure 4) The least-cost paths superimposed to a cost surface and a Digital Elevation Model (DEM) of the study area. Proposed (red line) and existing (black line) a) hiking trail and b) off-road vehicles trail in the Sarigol National Park and Protected Area. The least-cost path represented closely fits the existing path (Figure 3a).

Figure 5 corresponds to the standardized coefficients for each predictor. Standardized coefficients represent the relative influence of the predictor variables on the dependent variable and the significance of their relationship. Standardized coefficients, like the correlation coefficient, range from -1 to +1, with a positive value representing a direct effect and an inverse representing a negative one. The plot makes it easier to quickly find which predictors are more or less significant on the path width expansion, even if the predictors are not on the same scale. Among the predictor variables, climate, geology, and distance from the village were identified with high predictive power for hiking trails. The elevation is the most critical variable on the off-road vehicle trails, followed by minimum and maximum temperature. By contrast, the results represent that the geology variables do not have a notable influence on the trail of the off-road vehicle in the study area. The standardized coefficient with a negative value shows that the degradation will decrease by the beta coefficient value for every 1-unit increase in the predictor variable. For example, the standardized coefficient for NDVI is negative for the hiking trail. Then, for each 1-unit decrease in the NDVI, the degradation will increase in the study area.

Discussion

Balancing tourism activities with conservation objectives is a critical challenge in protected area management .Sustainable tourism management in protected areas attempts to ensure that visitors enjoy a destination while not causing severe damage to biophysical/ human environments or the living conditions of local people. Visitor movements interact with the biophysical environment through trails (15). Access trails link human and natural ecosystems in protected areas, and their spatial pattern is an important issue in protected area management. Crossing access trails through sensitive and vulnerable areas will increase ecosystem degradation. Therefore, a proper route, coupled with the construction and maintenance of trails, is an essential task for protected area managers (16). The magnitude of negative impacts on trails is influenced by factors related to recreational use (such as type and amount of use, visitor behavior) and environmental attributes (such as vegetation type and density, topography, soil type, and climate) (11). Trail design elements such as grade, trail alignment with the prevailing landform, rockiness of tread substrates, and soil type influence how a trail will resist degradation over time. Generally, in rocky terrain with thin soils over bedrock, extensive soil loss cannot occur, though steep rocky trails are exposed to trail-widening behaviors (49). Identifying factors that influence trail conditions is necessary for planning sustainable recreation trails. Results from this study suggest that geology is the most influential variable on the susceptibility of off-road vehicle trails to degradation. As revealed in Figure 2, the presence of the geological layer Jd and JKsj (Figure 2) has increased the susceptibility of off-road vehicle trails to degradation. The northern parts of the study area are less sensitive to degradation factors, and the proposed trails will show more resistance against erosion and widening. In the case of hiking trails, as Figure 3 represents, the hiking trails located in the southwest of the study area are susceptible to widening, and those in the northern parts show less sensitivity. Kalateh et al. (2023) also confirmed the potential of northwestern and northeastern parts of the area for developing ecotourism (49). Our findings revealed that climate plays a primary role in trail degradation.

The humid climate in the northeastern and central Sarigol area has increased hiking trails' susceptibility to degradation. Eagleston and Marion (2020) also confirm the importance of precipitation as an influential factor in trial degradation. Precipitation determines how much water falls onto the trail and surrounding areas that may generate runoff onto the trail, so the more precipitation received, the more soil loss occurs, as is expected (50). Meadema et al. (2022) found that landform grade influences the vulnerability of trails to muddiness and widening (18). Modeling by Evju et al.

(2021) determined that Soil moisture was the most critical environmental predictor for trail width increase (51).

On the other hand, increasing rainfall amounts leads to extending vegetation cover so that soil erosion and trail widening would be decreased. In dry areas, soil susceptibility to erosion and trail widening is increased because of poor vegetation cover. An increase in trail width means that vegetation cover is reduced, resulting in greater exposure to soil. Bare soil is prone to geomorphic processes such as surface water flow, wind activity, and needle ice development (11). Rainfall amount causes significant impacts on trail widening (48, 52). The level of footpath susceptibility to relief change changes about climate conditions, the level of resistance of footpath parent material, and the intensity of human impact (53). From a conservation perspective, soil loss is the most significant environmental impact because it is long-term or irreversible without substantial management action. The exposed roots and rocks caused by soil loss also increase the difficulty of hiking or riding, diminish aesthetic qualities, and contribute to trail widening (54). Trail grade and slope alignment angle have been identified by Marion and Wimpey (2017) as the most significant influence on soil loss from recreational trails (55). Nearing et al. (2004) suggested that climate is one of the most critical factors in soil erosion (56).

Distance from villages and rivers has been considered an influential factor in hiking trail degradation in the Sarigol National Park and Protected Area. These variables are represented as indicators of human presence (57,58), and it has been approved that less distance from human settlements and rivers leads to more trail degradation (59,32, 60, 61). The result of a study carried out by Allnutt et al. (2013) in a forest showed that disturbances were significantly higher in areas near rivers and villages. They showed that 82 percent of the disturbances occurred in the villages around the park (59). Vuohelainen et al.(2012) found that human presence is important for disturbance and destruction in Peru's Madre de Dios Protected area (62). In woodlands, the impacts of different types of trails on the forest vary in type and extent (5). Land use is also an influential factor in trial widening and degradation, especially in the case of off-road vehicle trails (63). Trampling, as well as soil susceptibility, accelerates the soil erosion process (7).The extent of trail widening changes based on visitors' activity types (64). The type of activities undertaken and the sensitivity of habitats to these activities should be considered as major factors in the tourism planning process (65). The study findings confirmed the potential of widening hiking and off-road vehicle trails. According to Wimpey and Marion (2011), informal trails have less sustainable topographic alignments than their formal counterparts. Therefore, visitors' informal trails can be considered a threat to the protected area. They may remove vegetation, displace wildlife, alter hydrology, change habitat, introduce invasive species, and fragment landscapes (66). Because of the study area's susceptibility to degradation and trail widening, it is required to monitor existing off-road vehicles and hiking trails.

Conclusion

LCPA is a fast assessment tool and replicable process that allows users to integrate information from different sources and helps design corridors. Protected areas are established for nature conservation and decelerating the loss of biodiversity. Furthermore, they provide opportunities for ecotourism activities. Often, these activities occur on trails, where park visitors can experience unique landscapes, wild habitats, and local human and natural heritage. Trails have been essential infrastructures for tourism and traveling for centuries, which has helped movement patterns form. Visitors crowding on trails causes negative impacts on vegetation, wildlife, water, and soil. Soil erosion, trampling, changes in plant communities, and trail widening are the most common impacts on trails. The relationship between trial use level and human and natural factors has been surveyed in this study. Analysis of Covariance (ANCOVA) has been used for estimating the potential of pathwidth expansion. The model's accuracy was estimated using root mean square error for hiking trails equal to 29 cm and off-road vehicles equal to 126 cm. Three new trails in the Sarigol National Park, four new hiking trails, and four new off-road vehicle trails (with minimum infrastructure) in the Sarigol Protected Area were suggested using susceptibility maps and the least cost model. Study findings indicated that existing trails are located in areas with a high risk of widening as a result of crowding. New trail construction or decreasing impacts of crowding on existing trails are recommended. The approach applied in this study can be used in recreation ecology to support the planning of corridors. The framework used in this study has direct implications for managers of protected areas who are searching for a way to conserve nature while at the same time providing recreational opportunities to visitors. Future research could use machine learning predictive models and neural networks to estimate degradation along the recreational trails in protected areas. However, this research has several limitations, including time and budget-consuming data collection process and a high level of training required to analyze data.

Appendix

Description of geology units

Jl	Light grey, thin-bedded to massive limestone (LAR FM)
Jd	Well-bedded to thin-bedded, greenish-grey argillaceous limestone with intercalations of calcareous shale (DALICHAI FM)
TRJs	Dark grey shale and sandstone (SHEMSHAK FM.)
Qft2	Low-level Piedmont fan and valley terrace deposits
Plc	Polymictic conglomerate and sandstone
Qft2	Low-level Piedmont fan and valley terrace deposits
Mur	Red marl, gypsiferous marl, sandstone, and conglomerate (Upper red Fm.)
JKsj	Pale red argillaceous limestone, marl, gypsiferous marl, sandstone, and conglomerate (SHURIJEH FM)
Ktr	Grey oolitic and bioclastic orbitolina limestone (TIRGAN FM)
Qft2	Low-level Piedmont fan and valley terrace deposits
Ekh	Olive-green shale and sandstone (KHANGIRAN FM)
Jl	Light grey, thin-bedded to massive limestone (LAR FM)

Appendix Continued

Qft1	High-level Piedmont fan and valley terrace deposits
JKsj	Pale red argillaceous limestone, marl, gypsiferous marl, sandstone, and conglomerate (SHURIJEH FM)
Murmg	Gypsiferous marl
Ktr	Grey oolitic and bioclastic orbitolina limestone (TIRGAN FM)
Ekh	Olive-green shale and sandstone (KHANGIRAN FM)
Jd	Well-bedded to thin-bedded, greenish-grey argillaceous limestone with intercalations of calcareous shale (DALICHAI FM)
JKsj	Pale red argillaceous limestone, marl, gypsiferous marl, sandstone, and conglomerate (SHURIJEH FM)
TRJs	Dark grey shale and sandstone (SHEMSHAK FM.)
Murmg	Gypsiferous marl
Ogr-di	Granite to diorite
Qft2	Low-level Piedmont fan and valley terrace deposits
Murc	Red conglomerate and sandstone
Mbv	Basaltic volcanic rocks
Plc	Polymictic conglomerate and sandstone
Plac	Fluvial conglomerate, Piedmont conglomerate, and sandstone.
Qft2	Low-level Piedmont fan and valley terrace deposits
Qft1	High-level Piedmont fan and valley terrace deposits
Qft2	Low-level Piedmont fan and valley terrace deposits
Qft1	High-level Piedmont fan and valley terrace deposits
Jd	Well-bedded to thin-bedded, greenish-grey argillaceous limestone with intercalations of calcareous shale (DALICHAI FM)
Murmg	Gypsiferous marl
Ktzl	Thick bedded to massive, white to pinkish orbitolina-bearing limestone (TIZKUH FM)
Qal	Stream channel, braided channel, and floodplain deposits
TRJs	Dark grey shale and sandstone (SHEMSHAK FM.)
Murmg	Gypsiferous marl

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