Effect of Landscape Fragmentation on Soil Quality and Ecosystem Services in Land Use and Landform Types

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Abstract

This study was carried out according to the following objectives in the Shoor River Basin in southwestern Iran: (i) Evaluation of ecosystem services (ES) including habitat quality (HQ), carbon storage (CS), nutrient export (NE), and soil export (SE) using the InVEST approach as well as soil quality (SQ) using an integrated quality index; (ii) Assessment of the relationship between ES and SQ with landscape metrics using Pearson correlation test; and (iii) Investigation of the interaction between ES efficiency, SQ and landscape fragmentation using a ternary plot. The results showed that the northern and eastern parts of the region are prioritized for HQ, CS, and SQ but the southern and western parts for NE and SE. The highest ES efficiency and SQ were found for the forests as well as for the ridge/tops landforms. Statistical analysis clarified that there was a positive and significant relationship between HQ and CS ($R > 0.8$) while the relationship of the two with NE was inverse and significant ($-0.55 < R < -0.50$). The correlation between SE and NE was also positive and significant ($R > 0.50$). SQ was also correlated positively and significantly with HQ and CS ($0.43 < R < 0.5$) while no relation with NE and SE was found. It was also perceived that increasing the landscape fragmentation decreases HQ, CS, and SQ but increases NE and SE. Besides, the interaction between ES, SQ, and landscape fragmentation across the sub-basins of the study area can change under the influence of the dominant land use and landform types.

Keywords

Ecosystem services, Soil quality, Landscape fragmentation, Landscape metrics, Land use, Landforms

Introduction

Human is highly dependent directly and indirectly on nature to obtain plenty of goods and benefits, referred to as ecosystem services (De Groot et al. 2002; MEA 2005; Zhang et al. 2018). Ecosystem services are critical to human well-being and sustainable socio-economic development around the world while the benefit to people (Costanza et al. 2017). With the emergence of the ecosystem services concept, various studies have been conducted to quantify, classify, and evaluate the different services throughout many countries. Ecosystem services are classified into four main categories of provisioning, regulating, supporting, and cultural services (MEA 2005; Sukhdev et al. 2014; Feng et al. 2021). These services are affected by various ecological and biological characteristics of ecosystems, management conditions, and land use changes (Bryan et al. 2018; Chen et al. 2019).

Soils are a fundamental and complex ecosystem consisted an important part of the natural environment (Zhang et al. 2018; Delibas et al. 2021). Soils establish many ecosystem services such as purification of water, production of food and raw materials, regulation of climate, storage of carbon all essential for the survival and protection of human life (Costanza et al. 1997; Pereira et al. 2020; Wang et al. 2021). Soils are the basic link between earth, air, and water and play a vital role in regulatory cycles such as carbon, oxygen, and water in the biosphere. In addition, soils are considered as a reservoir of plant nutrients (Li et al. 2012; Dominati et al. 2014). Hence, the essential role of soils is obvious in providing a wide range of goods and services for human well-being, creating sustainable socio-economic development, and determining ecosystem efficiency (Daily et al. 1997; Dominati et al. 2010; Ellili-Bargaoui et al. 2021). Some basic processes in the soil, such as the nutrient cycles, contribute to providing ecosystem services. These processes reflect the soil support capacity for ecosystem services and can be assessed based on the chemical, physical, and biological properties of soils (Kibblewhite et al. 2008; Duran-Bautista et al. 2020).

Soil quality is an important and measurable characteristic that has a major impact on the function and sustainability of ecological systems and the provision of ecosystem services throughout the world (Baveye et al. 2016; Soto et al. 2020). It reflects the capacity of soil to maintain and enhance climate quality, increase habitat diversity, produce plant and animal products, and support human health (dos Santos et al. 2021). Soil quality depends mainly on soil fertility and reflects the potential of soil to support the structure and function of the ecosystems. Assessment of soil quality should be based on a set of physical, chemical, and biological properties that interact with soil function. Various methods have been developed to evaluate soil quality. The most important of

which are soil quality indicators (SQI) and fuzzy methods (Qi et al. 2009; Askari and Holden 2014; Jahany and Rezapour 2020; Tian et al. 2020). The SQI approach has been used extensively to evaluate different soil types due to its flexibility and performance (Nabiollahi et al. 2017; Raiesi 2017; Tian et al. 2020; dos Santos et al. 2021). Soil quality has been also studied concerning various landscape properties including land use, topographic and morphological features (Davari et al. 2020; Shao et al. 2020; Derakhshan-Babaei et al. 2021).

Land use is one of the most important criteria affecting ecosystem services and soil quality as it is closely related to human activities such as urbanization and agricultural activities (Pereira et al. 2020; Ma et al. 2021b). Land use change alters the soil properties and the structure and function of ecosystems, resulting in a reduction and variation in ecosystem services, soil quality, and biodiversity (Lawler et al. 2014; da Silva et al. 2018). Yang et al. (2021a) investigated the effect of land use change on water yield ecosystem services in China's Yellow River Basin using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool. Kusi et al. (2020) examined the effects of land use change on carbon storage, soil conservation, and water yield ecosystem services based on different scenarios. Wu et al. (2021) evaluated water-related ecosystem services in the Luanhe watershed in China using InVEST software and assessed their relationship to land use change. Derakhshan-Babaei et al. (2021) evaluated the relationship of soil quality with erosion, land use, and landform characteristics in the Kan watershed in Iran. Davari et al. (2020) conducted the relationship between soil quality and deforestation and emphasized that soil quality decreases under the impacts of agricultural and deforestation activities. However, determining the effects of land use on ecosystem services and soil quality has received little attention based on the quantification of landscape characteristics. Landscape metrics can be applied to quantify the land use characteristics in terms of area, shape, composition, distribution, and geometry as quantitative values, which facilitates the analysis, evaluation, monitoring, and spatial planning of land use patterns (McGarigal et al. 2012; Peng et al. 2016).

Landforms are another important land features that affect ecosystem services and soil quality. They have different visual and physical properties that obtain a lot of information about environmental conditions and resources. Landforms are natural forms that shape the earth's surface in basic spatial units under the influence of various environmental processes over a long period while providing conditions for various environmental processes (Du et al. 2019; Derakhshan-Babaei et al. 2021). Landforms can be identified based on land geomorphic characteristics such as altitude, slope, aspect, and curvature using artificial intelligence models and either supervised or unsupervised classification methods (Zhao et al. 2017; Du et al. 2019; Li et al. 2020).

Due to specific environmental conditions, the Shoor River Basin is one of the most important catchments of Karoon River located in the northeast of Khuzestan province, southwestern Iran. The basin has a semi-arid climate, extensive morphological and topographic changes, and diverse vegetation. These factors have led to diversity and change in characteristics and quality of soils following the provision of various ecosystem services. Human activities and agricultural development have severely affected environmental conditions, natural resources, and ecosystem services of the basin, especially in the southern and western parts. Identifying and evaluating the ecosystem services and soil conditions can be important in accurately understanding the differences and spatial potential of the basin. In addition, it leads to produce new information based on which local managers and decision-makers can make more appropriate decisions to protect and manage the region (Ahmadi Mirghaed and Souri 2020). Accordingly, the present study was conducted for the following objectives:

- (i) Evaluation of four ecosystem services including habitat quality, carbon storage, nutrient (phosphorus and nitrogen) export, and soil export in the study area using the InVEST approach as well as soil quality using integrated quality index (IQI).
- (ii) Investigation of the relationship between ecosystem services and soil quality at the sub-basins.
- (iii) Considering the effects of landscape fragmentation on the ecosystem services efficiency and soil quality.

Material and Methods

Study area

The study area was the Shoor River Basin with an area of about 2865 km² located in Khuzestan province, southwestern Iran (Fig. 1). The region with a semi-arid climate has an average annual rainfall and temperature of 781 mm and 22 °C, respectively. The basin has severe topographic changes and high roughness having average altitude and slope of 1136 m and 41%, respectively. Morphologically, the mountains are spread in the northern and eastern parts of the basin while the southern and western parts contain plains. Moreover, forests predominantly cover the northern and eastern parts of the region but agriculture and rangeland are more widespread in the south and west. Diverse environmental conditions have provided a significant capacity to produce various ecosystem services in the study area (Ahmadi Mirghaed and Souri 2020).

Fig. 1 Location of the study area alongside with land use and landform maps

Data preparation

The list of data used in this research and their descriptions are presented in Table 1. Random sampling was applied to prepare soil data during which 213 samples were taken from a depth of 0 to 20 cm throughout the study area.

The supervised maximum likelihood method in ENVI software was used to produce land use and landform maps of the study area (Fig. 1). Landsat 8 satellite multispectral data map download from the United States Geological Survey (USGS) site, were obtained for mapping the land use. The required data for creating the landform map were

elevation, slope, aspect, topographic position index (TPI), topographic roughness index (TRI), valley depth extracted using digital elevation model (DEM) in SAGA software. The statistics of climatological stations in the region created by the Meteorological Organization of Iran were considered for the preparation of climatic data. Sub-basins were mapped based on a DEM using the Arc Hydro tool in a GIS environment.

Table 1 Description of soil properties used in this study alongside with fuzzy function and control points for soil quality assessment

Property	unit	Method	Fuzzy Function	Control point				Reference
				a	b	c	d	
Clay	%	Hydrometer	LI*	9.4	26.7	26.7	26.7	(Fathizad et al. 2020; Tian et al. 2020)
Sand	%	Hydrometer	S	51.3	51.3	51.3	85.3	
Silt	%	Hydrometer	LI	4.0	4.0	4.0	32.7	
BD	g cm ⁻³	Core method	LD	0.9	0.9	0.9	1.57	(Dane et al. 2002; Davari et al. 2020; Karaca et al. 2021)
PD	g cm ⁻³	Pycnometer	LD	1.42	1.42	1.42	4.02	
TP	%	TP = 1-(BD/PD)	S	38	50	50	74	
CaCO ₃	%	Titration	LD	2.85	2.85	2.85	26.9	(Walkley and Black 1934)
OM	%	Dichromate oxidation	LI	2.1	6.71	6.71	6.71	
EC	dsm ⁻¹	Saturated soil-paste	LD	177	3439	3439	3439	
pH	-	Saturated soil-paste	LI	7.57	7.57	7.57	8.5	(McLean 1983; Karaca et al. 2021)
CEC	meq (100g) ⁻¹	Ammonium acetate	LI	2.92	66.4	66.4	66.4	
Ca	mg kg ⁻¹	Flame photometer	LI	100	385	385	385	
K	mg kg ⁻¹	Flame photometer	LI	1.28	51.1	51.1	51.1	(Lu 2000; Paul et al. 2020; Derakhshan-Babaei et al. 2021; Karaca et al. 2021)
Na	mg kg ⁻¹	Flame photometer	LI	8.12	93.1	93.1	93.1	
Mg	mg kg ⁻¹	AAS*	LI	0.3	25.9	25.9	25.9	
Fe	mg kg ⁻¹	AAS	LI	5.53	24	24	24	(Carter and Gregorich 2007)
P	g kg ⁻¹	Olsen method	LI	0.01	0.36	0.36	0.36	
N	%	Kjeldahl	LI	0.27	6.1	6.1	6.1	
SAR	SAR = Na ⁺ /[((Ca ²⁺ +Mg ²⁺)/2) ^{0.5}]		LD	0.91	0.91	0.91	9.22	(Yao et al. 2013)

* Atomic Absorption Spectrophotometer

+ Fuzzy membership function: linear increasing (LI), linear decreasing (LD), and symmetric (S)

Ecosystem services

Ecosystem services of habitat quality, carbon storage, nutrient export, and soil export were considered using the InVEST approach. Data collection and the conditions of the region have been influential to consider these ecosystem services. The InVEST approach has been frequently used in various studies in recent decades due to its simplicity and appropriate efficiency (Ahmadi Mirghaed et al. 2020; Kusi et al. 2020; Li et al. 2021; Yang et al. 2021b). Ma et al. (2021a) evaluated the ecosystem services of soil conservation, habitat quality, carbon storage, and water yield using the InVEST tool. Feng et al. (2021) also evaluated several ecosystem services, including carbon storage and nutrient storage, using the InVEST software.

Habitat quality

Habitat is the natural territory of various organisms, including communities, species, and organisms. Habitat quality indicates the ability of ecosystems to create suitable conditions for the survival of animal and plant species in

ecosystems and is influenced by various factors such as human activities (Ma et al. 2021b). InVEST model uses land use and land cover features and threat resource information to estimate habitat quality according to equation 1. Threat sources are considered based on four factors: the relative impact of the threat, habitat distance from the threat source, habitat sensitivity, and conservation measures (Sharp et al. 2020).

$$Q_{xj} = H_j \left(1 - (D_{xj}^z / D_{xj}^z + k^z) \right) \quad (1)$$

where Q_{xj} represents the habitat quality in the grid cell x with LULC j . H_j and D_{xj} show the suitability and habitat degradation in pixel x with LULC j , respectively. K is a semi-saturated constant. D_{xj} is calculated as follows:

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^{Y_r} (w_r / \sum_{r=1}^R w_r) r_y i_{rxy} \beta_x S_{jr} \quad (2)$$

w_r is the weight of the threat factor r , which varies from 0 to 1. r_y represents the value of the total level of the threat factor in pixel y , which is 0 or 1. i_{rxy} is the effect of threat r in pixel y for habitat in grid cell x . β_x is the total level of access in pixel x , and S_{jr} is the sensitivity of LULC j to the threat factor r . Biophysical information in this regard was prepared based on scientific literature (Ahmadi Mirghaed and Sourì 2021).

Carbon storage

Carbon is stored in ecosystems over time in various parts of it, including plants and animals. Photosynthesis is the process by which ecosystems absorb carbon dioxide so that carbon is stored in biological materials, soil, and living things. Four important sources including soil, surface biomass, underground biomass, and dead organic matter were applied to estimate carbon storage based on the InVEST model calculated as follows (Sharp et al. 2020).

$$C_t = C_a + C_u + C_s + C_d \quad (3)$$

where C_t is the amount of carbon (Mg) stored in each pixel. C_a , C_u , C_s , and C_d are the carbon pools in aboveground biomass, underground biomass, soil, and dead organic matter, respectively. Biophysical information required to estimate carbon storage in the study area was obtained based on scientific literature and field surveys (Ma et al. 2021b).

Nutrient export

The nutrient delivery ratio (NDR) model in InVEST measures the nutrient sources of an ecosystem and their transfer to the stream, as well as the evaluation of nutrient storage services by natural plants. This model uses the mass balance approach to describe the travel of nutrient masses (especially nitrogen and phosphorus). The NDR model

calculates the ratio of nutrient deliveries transmitted by surface and subsurface flows. Nutrient export for pixel i and its total amount for a basin was calculated as follows (Yan et al. 2018; Sharp et al. 2020):

$$x_{expi} = load_{sur,i} \times NDR_{sur,i} + load_{sub,i} \times NDR_{sub,i} \quad (4)$$

where x_{expi} is the quantity of nutrients (nitrogen or phosphorus) in pixel i . $load_{sur,i}$ and $load_{sub,i}$ are the amount of nutrient charge per pixel displaced by surface and subsurface flows, respectively. $NDR_{sur,i}$ and $NDR_{sub,i}$ are the nutrient delivery ratios in pixel i displaced by surface and subsurface flows, respectively.

Soil export

Erosion is a natural phenomenon that changes under the influence of various environmental and anthropogenic factors. The measurement of erosion in InVEST model was carried out based on the revised universal soil loss equation (RUSLE) which uses the climatic characteristics, altitude, soil characteristics, and land use as follows (Ahmadi Mirghaed et al. 2018; Sharp et al. 2020):

$$USLE_i = R \times K \times LS \times C \times P \quad (5)$$

$$Soil\ export = \sum_i USLE_i \times SDR_i \quad (6)$$

where $USLE_i$ represents the amount of soil erosion ($t\ ha^{-1}\ yr^{-1}$). R shows rainfall erosivity ($MJ\ mm\ (ha\ hr)^{-1}$) and K is soil erodibility ($t\ ha\ hr\ (MJ\ ha\ mm)^{-1}$). LS is the slope length-gradient factor. C and P indicate cover-management, and support practice factors, respectively. The SDR_i ratio is derived from the conductivity index (Vigiak et al. 2012; Sharp et al. 2020).

Ecosystem services efficiency (ESE)

ESE was estimated per pixel relative to the whole basin for the ecosystem services of habitat quality, carbon storage, nutrient export, and soil export using the following equation (Asadolahi et al. 2017):

$$ESE = (\sum_{i=1}^N \left[\frac{ES_i - ES_{i\ min}}{ES_{i\ max} - ES_{i\ min}} \right]) / N \quad (7)$$

where N is the number of ecosystem services types. ES_i represents the value of ecosystem services type i in a given grid cell. $ES_{i\ max}$ and $ES_{i\ min}$ show the highest and lowest values of ecosystem services type i in the whole study area, respectively.

Soil quality assessment

Soil quality has been previously evaluated based on various soil characteristics using different indices, especially integrated quality index (IQI) in many studies (Nabiollahi et al. 2017; Raiesi 2017). Various researchers used the soil properties affecting fertility, permeability, structure, nutrients, salinity, and sodicity for soil quality assessment. The soil quality of the study area was evaluated using the data listed in Table 1 and based on the IQI approach calculated as follows:

$$IQI = \sum_{i=1}^n W_i N_i \quad (8)$$

where n is the number of soil properties. W_i and N_i are the weights and standardized scores assigned to each soil property, respectively. Fuzzy functions were performed for scoring whereas a hierarchical analysis method (AHP) was used for criteria weighting (Hemati et al. 2020; Derakhshan-Babaei et al. 2021).

Scoring

Each soil property has a specific scale. Therefore, to integrate them in soil quality assessment, a specific scale must be defined for all characteristics. In other words, all features must be unscaled or standardized. Fuzzy membership functions are one of the most important standardization methods that can be used to score soil property values on a scale of zero to one. The values zero and one represent the minimum and maximum proportions, respectively. Standardization of soil properties was performed based on the effect of each feature on soil quality using fuzzy linear functions including increasing linear, decreasing linear, and symmetric in the TerrSet environment (Fig. 2). As shown in Table 1; determining the effect of properties on soil quality was also defined based on control points a, b, c, and d extracted from scientific literature (Derakhshan-Babaei et al. 2021).

Fig. 2 Fuzzy membership function: linear decreasing (LD), symmetric (S) and linear increasing (LI) (Eastman 2012)

Weighting

The hierarchical analysis method (AHP) was used to weigh soil properties. This method has been frequently used in various studies because of its simplicity, flexibility, and appropriate efficiency for determining the weights of criteria for evaluating a problem. The AHP was performed in three general steps in Super decision software: (i) Creating a hierarchical diagram based on purpose and physical-chemical properties of soil; (ii) Consisting of a matrix of pairwise comparisons and completing them based on the scale proposed by Saaty (1980) (Supplementary data, Table S1) and expert's opinions; (iii) Determining the global weights of soil properties and calculating the rate of the inconsistency of judgments. Inconsistency rates less than 0.1 for the AHP results were accepted (Derakhshan-Babaei et al. 2021).

Landscape fragmentation

Landscapes are fragmented and changed under the influence of human activities and the development of various land uses. It is possible to study these changes quantitatively using landscape metrics having the ability to quantify landscape in terms of pattern, composition, shape, diversity, continuity, and area at the patch, class, and landscape scales. Various metrics have been developed in this regard. In this study, some of the most important metrics including Patch density (PD), Largest patch index (LPI), Patch cohesion index (PCI), and Effective mesh size (EMS), explained in Table 2, were used to investigate the landscape fragmentation of the study area in the FRAGSTATS software (Frank et al. 2012; McGarigal et al. 2012).

Table 2 Landscape metrics used in this study and their descriptions (McGarigal et al. 2012)

Metric*	Unit	Equation	Description
PD	ha	$PD = \frac{n_i}{A} \times 10000$, $PD > 0$ n_i = number of patches in the landscape of class i A = total landscape area (m^2)	PD shows the density of the patches in a certain landscape.
LPI	%	$LPI = (Max a_{ij}/A) \times 100$, $0 < LPI \leq 100$ a_{ij} = area of patch ij (m^2) A = total landscape area (m^2)	LPI is a simple measure of dominance that quantifies the percentage of the total landscape area contained by the largest patch.
PCI	None	$PCI = \left[1 - \frac{\sum_{j=1}^n P_{ij}}{\sum_{j=1}^n P_{ij} \times \sqrt{a_{ij}}} \right] \times \left[1 - \frac{1}{\sqrt{Z}} \right]^{-1} \times 100$, $0 < PCI < 100$ P_{ij} = perimeter of patch ij (pixel) a_{ij} = area of patch ij (pixel) Z = total number of pixel in the landscape	PCI estimates the physical connectedness of the corresponding patch type. It increases as the patch type becomes more aggregated or clumped in its distribution.
EMS	ha	$EMS = \frac{\sum_{i=1}^m \sum_{j=1}^n a_{ij}^2}{A}$, $cell\ size \leq EMS \leq A$	EMS is based on the cumulative patch area distribution and is perceived as the size of the patches when the landscape is

a_{ij} = area of patch ij (m^2)
 A = total landscape area (m^2)

subdivided into the patches.

*Patch density (PD), largest patch index (LPI), patch cohesion index (PCI), and effective mesh size (EMS)

Statistical analysis

The Pearson correlation test was used to assess the relationships of ecosystem services and soil quality with landscape metrics in the sub-basins, landforms, and land uses. In this regard, their averages in the sub-basins, landforms, and land uses were considered the input of the Pearson correlation test in the SPSS. The relation of the ecosystem services efficiency and soil quality with landscape metrics were investigated based on the dominant type of land uses and landforms in the sub-basins using ternary plot in the SigmaPlot software. For this purpose, their values were standardized on a scale of 0 to 100 and their mean values in the sub-basins were entered as the input of ternary analysis.

Results

Ecosystem services

The produced ecosystem services maps of habitat quality, carbon storage, nutrient export, and soil export are shown in Figures 3a to 3d. The results indicated that the suitability of habitat quality and carbon storage in the northern and eastern regions of the study area were higher than the southern and western regions whereas for nutrient export, and soil export the opposite trends were observed. Carbon storage, nutrient export, and soil export were estimated 5.4 Mt y^{-1} , 328 t y^{-1} , and 0.59 Mt y^{-1} , respectively, with averages of 23.8 Mg ha^{-1} , 1.4 kg ha^{-1} , and 2.6 t ha^{-1} , respectively. Figure 3 illustrates that the efficiency of ecosystem services in the northern and eastern parts of the study area was more favorable than in the southern and western parts.

For the average of ecosystem services in the landforms and land uses of the study area as presented in Table 3; the highest and lowest habitat quality is observed in the forests and built-up areas, respectively. The same is true for carbon storage, which averages 39.1 Mg ha^{-1} in the forests but there is almost no carbon storage in the built-up areas. The maximum (3.2 kg ha^{-1}) and minimum (0.81 kg ha^{-1}) nutrient export were estimated for the agriculture and forest land uses, respectively. Also, rangeland and forest land uses have the highest and lowest amount of soil export with 41.5 and 8.8 t ha^{-1} , respectively.

In terms of landform type, the highest habitat quality was seen in the ridge/tops while the lowest value of it was spotted in the plains. The maximum amount of carbon storage (30.4 Mg ha^{-1}) and soil export (4.3 t ha^{-1}) were found at the ridge/top landforms but their lowest values were seen across the plains (11.6 Mg ha^{-1} and 0.5 t ha^{-1} , respectively). The highest (2.18 kg ha^{-1}) and lowest (1.07 kg ha^{-1}) nutrient export were also estimated in the plains and ridge/tops landforms, respectively.

Fig. 3 Produced maps of (a) habitat quality, (b) carbon storage, (c) nutrient export, (d) soil export, (e) ecosystem services efficiency, and (f) soil quality of the study area

Table 3 Average of ecosystem services and soil quality in each land use and landform types

Class	HQ*	CS	NE	SE	ESE	SQ
	Unitless	Mg ha^{-1}	Kg ha^{-1}	t ha^{-1}	Unitless	Unitless
Land use						
Forest	0.87	39.1	0.81	0.9	0.54	0.39
Rangelands	0.65	13.4	1.41	4.5	0.33	0.37
Agriculture	0.28	10.4	3.20	3.1	0.32	0.36
Built-up area	0.10	0.00	1.33	1.5	0.13	0.36
Landform						

Plains	0.35	11.6	2.18	0.5	0.27	0.36
Valley	0.57	10.3	1.22	2.0	0.29	0.38
Gentle hills lope	0.58	19.1	1.78	1.7	0.36	0.37
Steep hills lope	0.76	27.8	1.22	3.2	0.45	0.38
Ridge and top	0.81	30.4	1.07	4.3	0.49	0.39

*Habitat quality (HQ), carbon storage (CS), nutrient export (NE), soil export (SE), ecosystem services efficiency (ESE), and soil quality (SQ)

The efficiency of ecosystem services based on different landforms and land uses is presented in Table 3. The lowest and highest efficiencies are observed in the plains and ridge/tops landforms, respectively. The same trend was clarified to the built-up area and forest land use, respectively.

Soil quality

Weight of soil properties calculated according to the AHP method is brought as table 4. Organic matter (OM) and particle density (PD) with weights of 0.208 and 0.004, respectively, are the most and least important criteria for evaluating the soil quality of the study area. The soil quality map produced based on the IQI index is illustrated in figure 3. The lowest quality is observed in most of the soils of the northern section and parts of the south and west of the region, while the eastern and central parts have a better soil quality. The highest and lowest average soil quality was observed in the forest and built-up areas (Table 3). In terms of landform type, the lowest and highest average soil quality were considered for the plains and ridge/tops, respectively (Table 3).

Table 4 Obtained weights of soil properties based on AHP method

Property	Weight	Property	Weight
OM	0.208	Ca	0.024
P	0.158	Na	0.020
N	0.116	TP	0.017
Clay	0.087	EC	0.015
CEC	0.086	CaCO ₃	0.014
K	0.069	Sand	0.013
Mg	0.053	SAR	0.007
Silt	0.039	BD	0.007
Fe	0.033	PD	0.004
pH	0.030	-	-

Statistical analysis

The results of the Pearson correlation test confirmed that the relationship between habitat quality and carbon storage was positively significant at $P<0.01$ ($R=0.8$), while their relationships to nutrient export were negatively significant at $P<0.01$ ($R=-0.53$, $R=-0.50$). Soil export showed a positive and relatively strong correlation ($P<0.01$, $R=0.57$) with

nutrient export, while no correlation to habitat quality and carbon storage was found. The results indicated that soil quality had a positive and significant relationship to habitat quality and carbon storage but no correlation was found to nutrient export and soil export (Table 5).

Table 5 Results of the Pearson correlation test

Ecosystem service	CS	HQ	SE	NE	SQ
Carbon storage (CS)	1				
Habitat quality (HQ)	0.88**	1			
Soil export (SE)	0.12	0.13	1		
Nutrient export (NE)	-0.5**	-0.53**	0.57**	1	
Soil quality (SQ)	0.50**	0.43*	0.10	-0.10	1

Figure 4 illustrates the relationship between the average ecosystem services and soil quality with landscape metrics at the sub-basin level. It was found that the PD index had a direct non-significant correlation to soil export and nutrient export ($P>0.05$, $0.23<R<0.34$), while its relationship was an inverse significant to habitat quality, carbon storage, and soil quality ($P<0.01$, $-0.53<R<-0.4$). The relationships between LPI, PCI, and EMS metrics with habitat quality and carbon storage were positive and relatively strong ($P<0.01$, $0.51<R<0.73$), while they are inversely and moderately related to nutrient export ($P<0.01$, $-0.52<R<-0.49$). Soil export had an indirect and non-significant correlation to LPI, PCI, and EMS metrics. Soil quality also had a positive correlation to PCI and EMS metrics ($P<0.01$, $0.48<R<0.50$) while it had a direct and insignificant relationship with LPI metric ($P>0.05$, $R=0.29$).

Fig. 4 Results of the relationship between ecosystem services (carbon storage (CS), habitat quality (HQ), nutrient export (NE), and soil export (SE)) and soil quality (SQ) with landscape metrics (patch density (PD), largest patch index (LPI), patch cohesion

The relationships between the ecosystem services efficiency, soil quality, and landscape metrics based on the dominant landform and land use groups in the sub-basins are shown in Figures 5 and 6.

Fig. 5 Results of the interaction between ecosystem services efficiency (ESE), soil quality (SQ) and landscape metrics (patch density (PD), largest patch index (LPI), patch cohesion index (PCI), and effective mesh size (EMS)) based on the dominant landform type (plain (P), valley (V), gentle hillslope (GH), and steep hillslope (SH)) in each sub-basin

Discussion

The results clarified that the provision of ecosystem services and soil quality in the Shoor River Basin is different according to variety of the land use patterns and landforms. In addition, the ecosystem services variation and soil quality changes occur under the impact of anthropogenic and agricultural activities, especially in the southern and western parts of the region. The northern and eastern parts of the study area have more suitable conditions than the southern and western parts in terms of habitat quality and carbon storage. This is while the rate of nutrient export

316 and soil export in the southern and western parts is higher than the northern and eastern parts. It was also found that
 317 the efficiency of ecosystem services in the northern and eastern parts is higher than in the south and west. These
 318 conditions are created because of the denser vegetation in the northern and eastern parts and the intensive
 319 agricultural and human activities in the southern and western parts.
 320

Fig. 6 Results of the interaction between ecosystem services efficiency (ESE), soil quality (SQ) and landscape metrics (patch density (PD), largest patch index (LPI), patch cohesion index (PCI), and effective mesh size (EMS)) based on the dominant land use type in each sub-basin

Order of the land uses' value/importance was as follows: Forest>Rangeland>Agriculture> Built-up areas for carbon storage and habitat quality; Agriculture>Rangeland>Built-up areas>Forest for nutrient export; and Rangeland>Agriculture>Built-up areas>Forest for soil export. This trend confirms that forests play an important role in increasing habitat quality and carbon storage. Conversely, built-up areas and agricultural activities reduce the ecosystem services of habitat quality and carbon storage and increase nutrient export. The highest amount of soil export occurs in rangelands because the relatively low density of vegetation and relatively steep slopes are among the important factors for increasing soil export in the rangelands. Other studies pointed to the effect of land use patterns on ecosystem services changes (Ahmadi Mirghaed et al. 2018; Aghsaei et al. 2020; Wu et al. 2020; Yee et al. 2021).

In terms of the landform type, it was found that the highest habitat quality, carbon storage, and soil export is in the ridge/tops and the lowest in the plains. Instead, the highest amount of nutrient export is estimated in the plains and the lowest for the ridge/tops.

It was also clarified that organic matter, phosphorus, total nitrogen, clay content, and CEC are the most important indicators of soil quality in the study area. Hemati et al. (2020) confirmed that soil organic carbon and total nitrogen are the most important indicators of soil quality. Ma et al. (2020) also pointed out that organic matter, nitrogen, CEC, and clay percentage are among the most important factors in soil quality. It was found that the soils of the central and eastern parts of the basin had higher quality than other parts, which can be attributed to more diverse and relatively denser vegetation to preserve soil nutrients and increase soil fertility (Hemati et al. 2020). In addition, the intensity of anthropogenic and agricultural activities in these areas is relatively low, which is another factor to increase soil quality.

The highest soil quality was observed in the forest land use but it was the lowest amongst agricultural and built-up areas. Gong et al. (2015) noted that soil quality varies according to land use pattern and it is higher in natural forests than other land uses. In terms of landform type, the highest soil quality was observed in the ridge/tops while the lowest quality was found in the plains where human activities including agricultural practices were relatively intense. Derakhshan-Babaei et al. (2021) pointed out that soil quality in rangelands is higher than in agricultural and man-made areas. In addition, they confirmed that landform type and topographic features may change soil quality.

Other studies considered the impacts of land use patterns on soil quality (Raiesi 2017; Li et al. 2019; Davari et al. 2020).

The relation of landscape fragmentation to ecosystem services and soil quality was evaluated using the Pearson correlation test in SPSS and based on some landscape metrics including patch density (PD), largest patch index (LPI), patch cohesion index (PCI), and effective mesh size (EMS). The PD index exhibits the land use density in a certain area whereas the higher the PD, the more fragmented the landscapes. LPI, PCI, EMS metrics refer to the dominance, continuity, and cumulative distribution of patches in the landscape, respectively, and the higher they are the less landscape fragmentation is expected (McGarigal et al. 2012; Ahmadi Mirghaed et al. 2020). The results illustrated that there was a direct relationship of the PD index to nutrient export and soil export, while the relationship of the PD index to habitat quality, carbon storage, and soil quality was inverse. These cases represented the opposite result about EMS, PCI, and LPI indices. Habitat quality, carbon storage, and nutrient export had the highest correlations to the EMS index. Soil export and soil quality also presented the highest correlation with LPI and PCI metrics, respectively. Accordingly, it can be concluded that further landscape fragmentation reduces ecosystem services, habitat quality, carbon storage, and soil quality but it increases nutrient export and soil export. Other studies also assessed the relationship between landscape metrics and ecosystem services. Zhang et al. (2018) examined the effect of land use patterns and landscape changes on soil erosion using 12 landscape metrics. They concluded that the LPI index is the most important metric influencing soil erosion. Ahmadi Mirghaed and Souri (2021) considered the relationship between habitat quality and land use pattern using some landscape metrics including PD, LPI, PCI, number of patches (NP), and landscape shape index (LSI). They confirmed that habitat quality increases in the forest and rangeland while it is decreased for agricultural and built-up areas.

The interaction between the ecosystem services efficiency, soil quality, and landscape fragmentation was investigated using a ternary plot at the sub-basin level. It was revealed that this interaction can be different in the sub-basins with the similar dominant of land use and landform types. PD and PCI indices showed the highest and lowest differences for the interaction between ecosystem service efficiency and soil quality in the sub-basins, respectively. These results confirmed that the interaction between ecosystem services and soil quality can be different under the influence of the dominant land use and landform types in the sub-basins across the study area.

Conclusion

This study clarified that the northern and eastern parts of the study area were prioritized for providing habitat quality, carbon storage, and soil quality but the southern and western parts for nutrient export and soil export. It was acknowledged that land use and landform patterns affect the change of ecosystem services and soil quality so that the highest efficiency of ecosystem services and soil quality were obtained for the forest's land use and the landform of ridge/tops. Statistical analysis confirmed the existence of a positive and significant relationship between habitat quality, carbon storage, and soil quality. The nutrient export had a positive and significant relationship to soil export, while its correlation to habitat quality and carbon storage was negative and significant. Also, it was revealed that the higher the landscape fragmentation, the less the habitat quality, carbon storage, and soil quality but the more the nutrient export and soil export. In addition, it was found that the interaction between ecosystem services efficiency, soil quality, and landscape fragmentation was different among sub-basins of the study area because these interactions may change under the influence of the dominant land use and landform types.

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Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

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