



A new ecosystem-based land classification of Iran for conservation goals

Mona Azizi Jalilian · Kamran Shayesteh ·
Afshin Danehkar · Abdolrassoul Salmanmahiny

Received: 23 October 2019 / Accepted: 5 February 2020 / Published online: 18 February 2020
© Springer Nature Switzerland AG 2020

Abstract Land management and biodiversity protection are highly dependent on ecosystem classification. To identify the ecosystems, often ecologically homogeneous areas are distinguished based on physical and biological features at various scales. These areas can also be considered as biodiversity surrogates for protection policies and planning. We classified the terrestrial areas of Iran into ecosystems using revised and updated layers of landform and climate as our two main criteria. Moreover, we applied a revised vegetation layer as the confirmatory criterion. At a scale of 1:1,000,000, we obtained a total of 119 homogenous ecological units, and based on the dominant vegetation types, we

classified them into 21 terrestrial ecosystems at the national level. Of these ecosystems, 11 were dominated by vegetation, and the remaining 10 had sparse non-dominant vegetation. Evaluation of the least and most frequent ecosystem patches and ranking of their size classes using landscape metrics provided an information basis for better land protection planning. We maintain that each ecosystem needs to be represented by a protected area and its size and distribution also helps us form a comprehensive and effective protection network in Iran.

Keywords Terrestrial ecosystem classification · Land protection planning · Representative areas · Iran

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s10661-020-8145-1>) contains supplementary material, which is available to authorized users.

M. Azizi Jalilian · K. Shayesteh (✉)
Department of Environmental Sciences, Malayer University,
Malayer, Iran
e-mail: ka_shayesteh@yahoo.com

M. Azizi Jalilian
e-mail: mona.azizijalilian@stu.malayeru.ac.ir

A. Danehkar
Department of Environmental Science, University of Tehran,
Karaj, Iran
e-mail: danehkar@ut.ac.ir

A. Salmanmahiny
Department of Environmental Science, Gorgan University of
Agricultural Sciences and Natural Resources, Gorgan, Iran
e-mail: rassoulmahiny@gmail.com

Introduction

Ecosystems are the result of interaction between the physical and biological factors and function under the impact of material and energy exchange which often are affected by the human activities (Chapin et al. 2002; Pickett and Cadenasso 2002; Cardinale et al. 2012). Land management and biodiversity protection are highly dependent on the definition of ecosystems (Bennett 2004; Jennings 2006). Ensuring ecosystem diversity at different spatial scales of protected areas has been emphasized by the International Strategies of Biodiversity Protection and Sustainable Development. The Convention on Biological Diversity (1992), European Habitats Directive (1992), Pan European Biological and

Landscape Diversity Strategy (1996), and the European Landscape Convention (2000) have all underscored the diversity of environment, ecosystems, and landscapes.

It is almost impossible to describe completely the biological communities that exist in the ecosystems, and as such, mature and prevailing vegetation types are usually used as a representative feature or surrogate of the ecological conditions of each ecosystem. Besides, vegetation cover has a relatively stable distribution and generates habitat resources for different species. If satellite imagery is used and vegetation composition is defined in the process, then the vegetation mapping becomes highly dependent on the structural features that can be derived from this data sources. However, the compositional data are less available, and land cover extracted from satellite images is often used as their surrogate in ecosystems studies. To represent ecosystems, the vegetation mapping should incorporate structural and compositional features and vegetation communities. In other words, vegetation mapping in its physical environment is considered to be a good surrogate for ecosystem boundary determination (Frisk 2014; Sayre et al. 2014).

In recent years, different approaches have been adapted for ecological land classification, ecological units' determination, and ecosystems identification, and the research is still ongoing. Ecological land classification identifies land units based on their homogeneity in terms of physical and biological resources at different scales (Loveland and Merchant 2004; Bailey 2005; Rankin et al. 2010). The land units provide a geographical framework relevant to the environmental topics for ecological boundaries (Omernik 2004), and, especially, these units are considered as surrogate of different aspects of biodiversity which can effectively be used in support of the protection policies (Pressey et al. 2000; Oliver et al. 2004).

The protected areas are normally thought to be representative samples of large ecosystem units. It is obvious that the efficiency of the unified land protection is only possible with an effective management of the protected areas comprised of ecosystems at the national level. Through developing a network of protected areas in each country, besides supporting the ecological structure of the identified ecosystems, the ecological diversity of that country will be also supported more effectively. For Iran, we can find ecosystem classifications provided at different spatial scales and varied aims. According to Udvardy (1975), Bailey (1996), Olson et al. (2001), and Sayre et al. (2014), Iran consists of three biogeographical provinces, three terrestrial eco-regions,

18 terrestrial eco-regions, and 865 ecological land units, respectively. Javanshir (1976) identified five floristic regions, Djamali et al. (2011) recognized three macro-bio-climates, and Yusefi et al. (2019) introduced nine biogeographical units for Iran. However, no study has been undertaken so far on ecologically homogenous land units of Iran at the spatial scale of this study using the revised and updated data layers, as these new data sources have become available or amenable to generation. Our land classification is different from other land classification systems in Iran in terms of study scale, the criteria, and methodology used. Hence, we aimed at providing an objective oriented ecosystem-based map for the ultimate goal of conservation planning and land monitoring at the national level. We seek to clarify the issue of ecosystems units and their classification across Iran. Our paper is grounded on extensive literature review and many expert discussions on the appropriate criteria for ecological land classification in Iran.

Material and methods

Study area

The Iranian plateau is a specific geographical unit of mountainous highlands formed in southwest of Asia following the young folding in the third geological era. This vast highland includes a considerable part of Iran, a part of central Asia, Afghanistan and Pakistan, Iraq, as well as a part of northern lands; and it is adjacent to the Tibetan Plateau in the east and Anatolia Plateau (Asia Minor) in the west (Minaee 2002).

With a land area of about 1,632,210 Km², Iran is placed between 44° 02' to 63° 09' eastern longitudes and 25° 03' 45" to 39° 46' 30" northern latitudes (Jafari 2012). In terms of biogeographical situation, Iran includes three biomes of the 14 biome types of Udvardy's classification (Udvardy 1975). Three prominent realms of Palearctic, Afrotropic, and Indomalayan influence natural characteristics of Iran.

Ecologically, Iran land has two major landscapes: desert and mountain. Two mountain ranges of Alborz and Zagros encompass the two central plains of Iran, with key effects on the climatic conditions of the country. Remarkably, the encounters of the topographic and climatic features are two chief factors of forming biodiversity. Altitude ranges from -26 to 5671 m above sea level, and the annual average temperature ranges from 8

to 55 °C. Due to these varieties, many fauna and flora species inhabit Iran (Rahnemai 2014). How to define homogenous areas among this rich fauna and flora has been and still is a question of debated research.

Criteria

Researchers have applied ecosystem classification for conservation using different factors such as climate, landform, geology climate, vegetation, and management (Table 1). In spite of global classifications with different aims for Iran, there are limited studies in this field at the national level.

Based on literature review, expert judgments, available data, and considering diversity and complexity of the geographical and ecological conditions of Iran, we selected two main criteria for ecosystem classification including *climate*, as climate type using climatic classes, and *land*, as landform composed of elevation and slope classes. Here, we added vegetation criterion; using dominant vegetation type indicator, as a confirmatory criterion, meaning the ecological land units thus recognized should also correspond to vegetation units.

The climate can be considered as the most effective factor in shaping the content and evolution of the ecosystems (Bailey 1996). In fact, it is the most important factor in formation of land, formation and evolution of soil, and distribution and evolution of plants and animals. Therefore, in similar climatic conditions, similar landscapes are witnessed, which indicates that the ecological conditions are repeatable (Woodward et al. 2004; Neishabouri 2013). Also, literature review strongly suggests that the climate is the main driving factor in forming the main biomes of the planet. The studies of Holdridge (1967), Udvardy (1975), and Walter and Box (1976) have placed biomes classifications inside the climatic boundaries.

After climate, topography, represented by landform in this study, is the key and determining factor for ecosystem's establishment and stabilization (Bailey 1996). The landform can be classified according to the various features of the earth's surface. However, what makes the landform so important is its function in forming the terrestrial ecosystems. The ruggedness and elevation variations can change many environmental factors and affect climatic conditions. High altitudes can change meteorological patterns and the distribution of weather elements (Najafikani 2002). Elevation fluctuation and changes in distribution of vegetation on

different slopes and aspects are factors that create the mosaic of communities in the ecosystem (Ardakani 2003). The study of Singers and Rogers (2014) has confirmed the role of these two factors in the formation of the ecosystems.

In regions where climate and landform are responsible for the creation, development, evolution, and stability of the soil, the vegetation is dominant in the landscape. Since the evolved and viable vegetation is the result of climate and landform function, vegetation can be considered as the representative of these two criteria. Moreover, in regions with mature and dominant vegetation, green cover provides an important criterion to draw the boundary of the ecosystems. Usually, the boundaries of the regions determined based on vegetation are consistent with landform units and the main topography of the region (Bailey 1996). Madjnoonian (1995) suggests that in lands with vegetation cover, examining, measuring, and mapping the ecosystems should be carried out through identification of the prominent vegetation components and vegetation units. The concept of climatic impact on vegetation has been used frequently as a basis for large-scale zoning of the ecological regions (Herbertson 1905; Udvardy 1975; Walter and Box 1976; Bailey 1980). Here we see two main factors: climate and landform and the interplay between the two. As such, we have focused on these factors for ecosystem classification.

Methods

We attempted at identifying large-scale land units (ecosystems) of Iran based on the ecological features to provide a basis for future protected area management and other issues such as land use planning.

We took three steps in this study. Firstly, we mapped selected criteria, and, secondly, we conducted map overlays for identifying terrestrial ecosystems, and, thirdly, we analyzed and described the structure of ecosystems thus identified using landscape metrics of the ecological units.

Data layers

Climate

To classify Iran climates, different methods are used with small differences, but many similarities. According to the modified Köppen climate classification system, there are four climatic categories in Iran (Ganji 2003).

Table 1 Ecological criteria for land classification and ecosystem mapping

Criterion	Sub-criterion	Source	Level of study	
Climate	Climate elements/climate types	Pressey et al. 2000	Territorial	
		Fairbanks and Benn 2000	Territorial	
		Leathwick et al. 2003	National	
		Galicia-Herbada et al. 2011	National	
		Terauds et al. 2012	Regional	
		Capotorti et al. 2012	National	
		Martínez-Tilleria et al. 2017	National	
		Statistics Canada 2018	National	
		Bio-climate	Sayre et al. 2014	Global
			Blasi et al. 2014	National
Land	Landform/physiography/ geomorphology	Sanderson et al. 2015	National	
		Pressey et al. 2000	–	
		Fairbanks and Benn 2000	–	
		Leathwick et al. 2003	–	
		Galicia-Herbada et al. 2011	–	
		Terauds et al. 2012	–	
		Sayre et al. 2014	–	
		Blasi et al. 2014	–	
		Capotorti et al. 2012	–	
		Sanderson et al. 2015	–	
	Soil	Canu et al. 2015	Territorial	
		Statistics Canada 2018	–	
		Statistics Canada 2018	–	
		Fairbanks and Benn 2000	–	
		Leathwick et al. 2003	–	
		Sanderson et al. 2015	–	
		Lithology	Galicia-Herbada et al. 2011	–
			Terauds et al. 2012	–
			Sayre et al. 2014	–
			Capotorti et al. 2012	–
Land cover	Maes et al. 2013	Regional		
	Sayre et al. 2014	–		
	Blasi et al. 2014	–		
	Martínez-Tilleria et al. 2017	–		
Geo-climate	Geology	Pressey et al. 2000	–	
	Biogeographical regions	Pressey et al. 2000	–	
	Environmental provinces	Pressey et al. 2000	–	
Vegetation	Vegetation types	Pressey et al. 2000	–	
		Fairbanks and Benn 2000	–	
		Benson 2006	Territorial	
		Carranza et al. 2008	Territorial	
		Sayre et al. 2009	National	
		Kusbach 2010	Territorial	
		Blasi and Frondoni 2011	National	

Table 1 (continued)

Criterion	Sub-criterion	Source	Level of study	
Management	Phytogeography	Capotorti et al. 2012	–	
		Singers and Rogers 2014	National	
		Reddy et al. 2015	National	
		Blasi et al. 2017	National	
		Martínez-Tilleria et al. 2017	–	
		Statistics Canada 2018	–	
		Blasi et al. 2014	–	
		Blasi et al. 2018	National	
		Land tenure	Pressey et al. 2000	–
		Major administrative boundaries	Pressey et al. 2000	–
	Land use	Pressey et al. 2000	–	

The classifications of Gaussen and Emberger have revealed 12 and 14 climatic regions for Iran, respectively (Vakilinezhad et al. 2018); in contrast, according to the De Martonne’s classification, seven climatic regions are distinguished for Iran (Rahimi et al. 2013). The extended De Martonne’s method is the mostly preferred by Iranian climatologists (GhorbanizadehKharazi and ChelemaalDezfulnejad 2014; Ghorbani et al. 2016); hence, its use in our study.

In the De Martonne’s classification which is based on the aridity index, the factors average annual

precipitation and average annual daily temperature are considered. Moreover, in the extended method, the arid class is further divided into two other sub-classes of extra arid and arid, and also based on the third factor which is mean daily minimum temperature in the coldest month of the year, each climatic class is classified into four sub-climates. The layer of the climatic classes in this study was prepared at the scale of 1:1,000,000 which showed 30 classes for Iran (Table 2 and Fig. 1 in the Supplementary Material S1).

Table 2 Climate types of Iran

Temperature index	Aridity index	Mean daily minimum temperature in the coldest month (°C)			
		<-7 Extra cold	-7-0 Cold	0-5 Moderate	> 5 Warm
Extra arid	0-5	Extra arid-Extra cold (01)	Extra arid-Cold (02)	Extra arid-Moderate (03)	Extra arid-Warm (04)
Arid	5-10	Arid-Extra cold (05)	Arid-Cold (06)	Arid-Moderate (07)	Arid-Warm (08)
Semiarid	10-20	Semiarid-Extra cold (09)	Semiarid-Cold (10)	Semiarid-Moderate (11)	Semiarid-Warm (12)
Mediterranean	20-24	Mediterranean-Extra cold (13)	Mediterranean-Cold (14)	Mediterranean-Moderate (15)	Mediterranean-Warm (16)
Semi humid	24-28	Semi humid-Extra cold (17)	Semi humid-Cold (18)	Semi humid-Moderate (19)	Semi humid-Warm (20)
Humid	28-35	Humid-Extra cold (21)	Humid-Cold (22)	Humid-Moderate (23)	Humid-Warm (24)
Per-humid A	35-55	Per-humid A-Extra cold (25)	Per-humid A-Cold (26)	Per-humid A-Moderate (27)	–
Per-humid B	> 55	Per-humid B-Extra cold (28)	Per-humid B-Cold (29)	Per-humid B-Moderate (30)	–

Figures in parentheses represent map codes

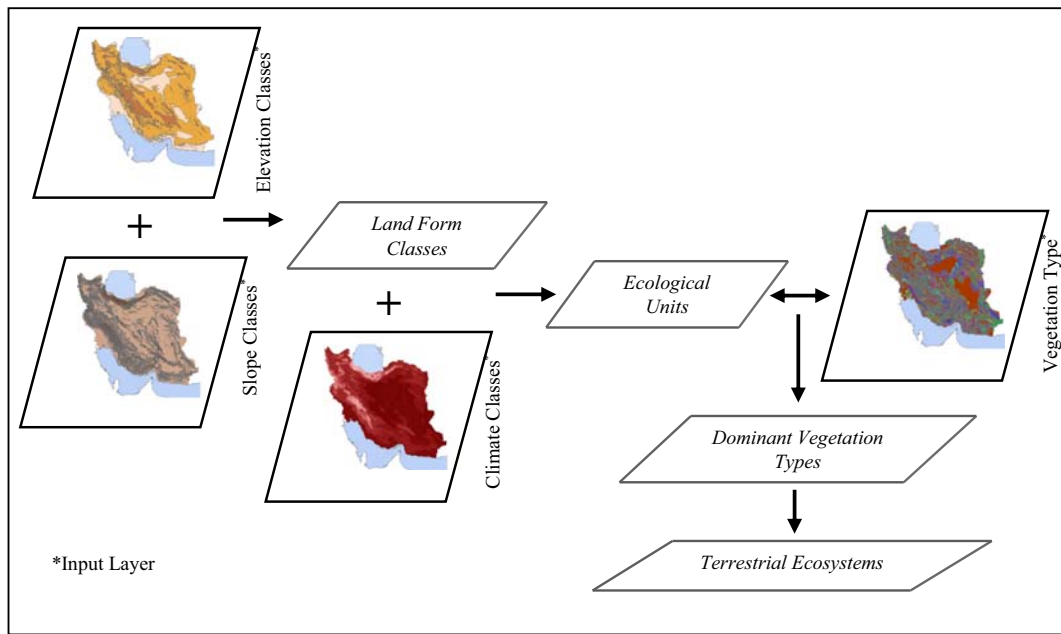


Fig. 1 The steps taken in this study

Landform

Using SRTM 90 m DEM layer resampled to 500-m resolution, elevation and slope classes were prepared, converted to vector format, and overlaid in ArcGIS 10.2 to form the main landforms of Iran. The landform thus acquired consisted of six categories including lowlands, low plains, medium plains, high plains, hills, and mountains (Table 3).

Vegetation type

The vegetation type was used to identify and confirm the boundaries of the ecosystems in Iran. The layer of Iran’s vegetation types at the scale of 1: 250,000 including 185 forest types with an area of around

17,000,000 ha and 376 range types with an area of about 85,000,000 ha was prepared by the Research Institute of Forests and Rangelands of Iran in the year 2015. These data were revised and edited using views of the experts of the relevant organizations with high field experience and doubly checked to ensure consistency and accuracy.

Ecological land classification and identification of the ecosystems’ boundaries

After preparation of the layers landform, climatic classes, and vegetation types, the landform and climatic classes’ layers were overlaid to derive the main ecological land units of the country (Fig. 1). Then, for each ecological land unit polygon, information was extracted on vegetation type and its percentage area. In the process, the multi-conditional function in Excel was used and the dominant type of each polygon was identified, assessed and coded for vegetation presence or absence.

Using the existing phytogeographic and vegetation type classifications of the country (Supplementary Material S2) and also experts’ opinion, the polygons with dominant vegetation were grouped based on the similarity of the vegetation types. The ecosystems’ boundaries were determined based on these ecological land units, and the ecosystems with dominant vegetation were identified. Other polygons with sparse, or no

Table 3 Main land form classes of Iran

Slope		< 8%	> 8%
Elevation variation			
<=500	Near sea	Lowland (LL*)	Hill (HI)
	Far from the sea	Low plain (LP)	
500–2000	Far from the sea	Medium plain (MP)	Mountain (MO)
> 2000		High plain (HP)	

*Map code

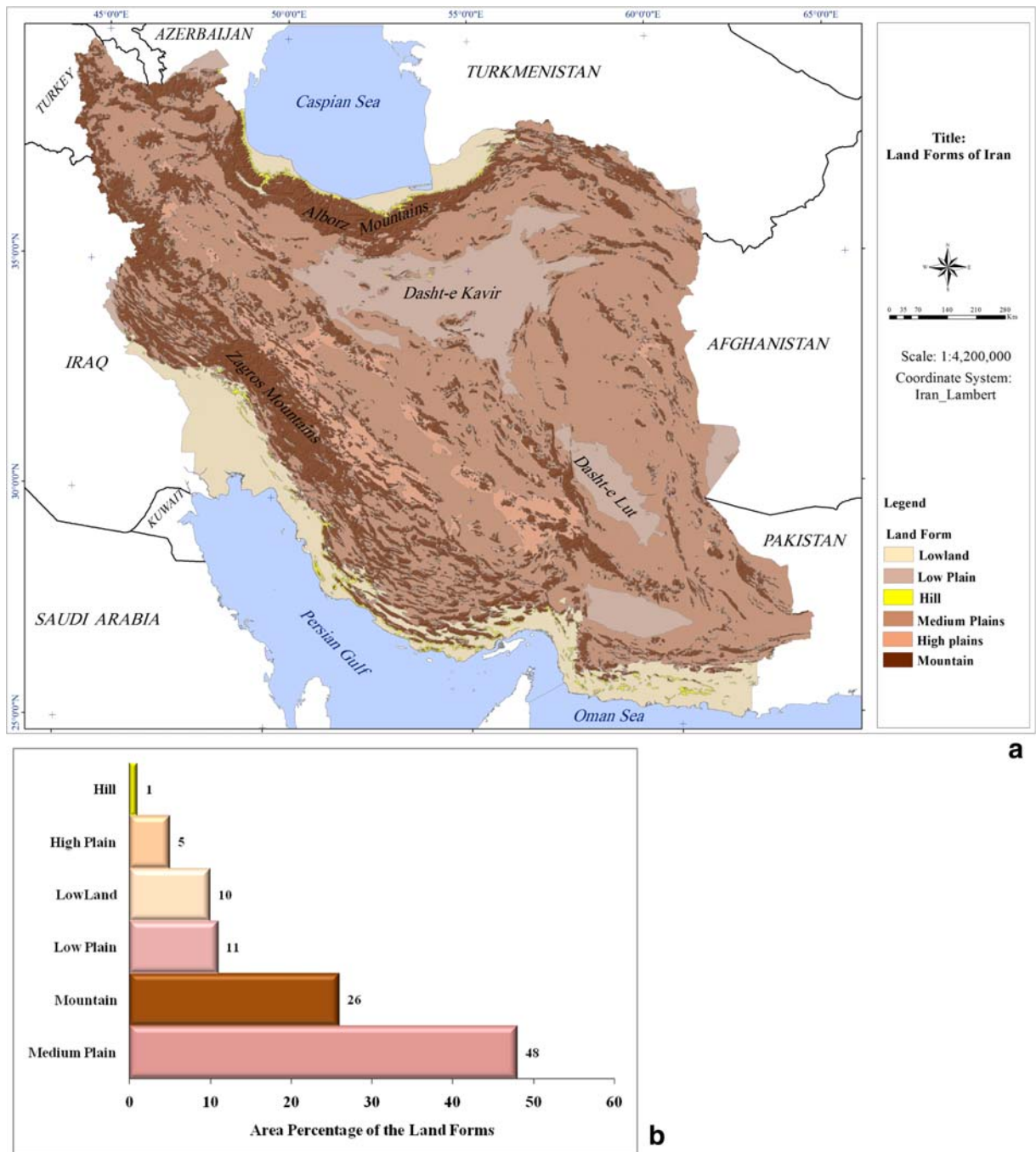


Fig. 2 Main landforms of Iran in 6 categories (a). Area percentage of landforms (b)

vegetation were also classified into homogenous groups based on their land-climate characteristics.

The classification of vegetation types and their placement in specific ecosystems was carried out hierarchically using vegetation type, climate, altitude, and precipitation. Based on the vegetation type, we assigned

polygons to ecosystems and then through climate and altitude factors, and with the aid of precipitation, the affinity of each polygon to a defined ecosystem was evaluated and confirmed.

We followed the standards for naming and the plant species locations offered in reference books such as A

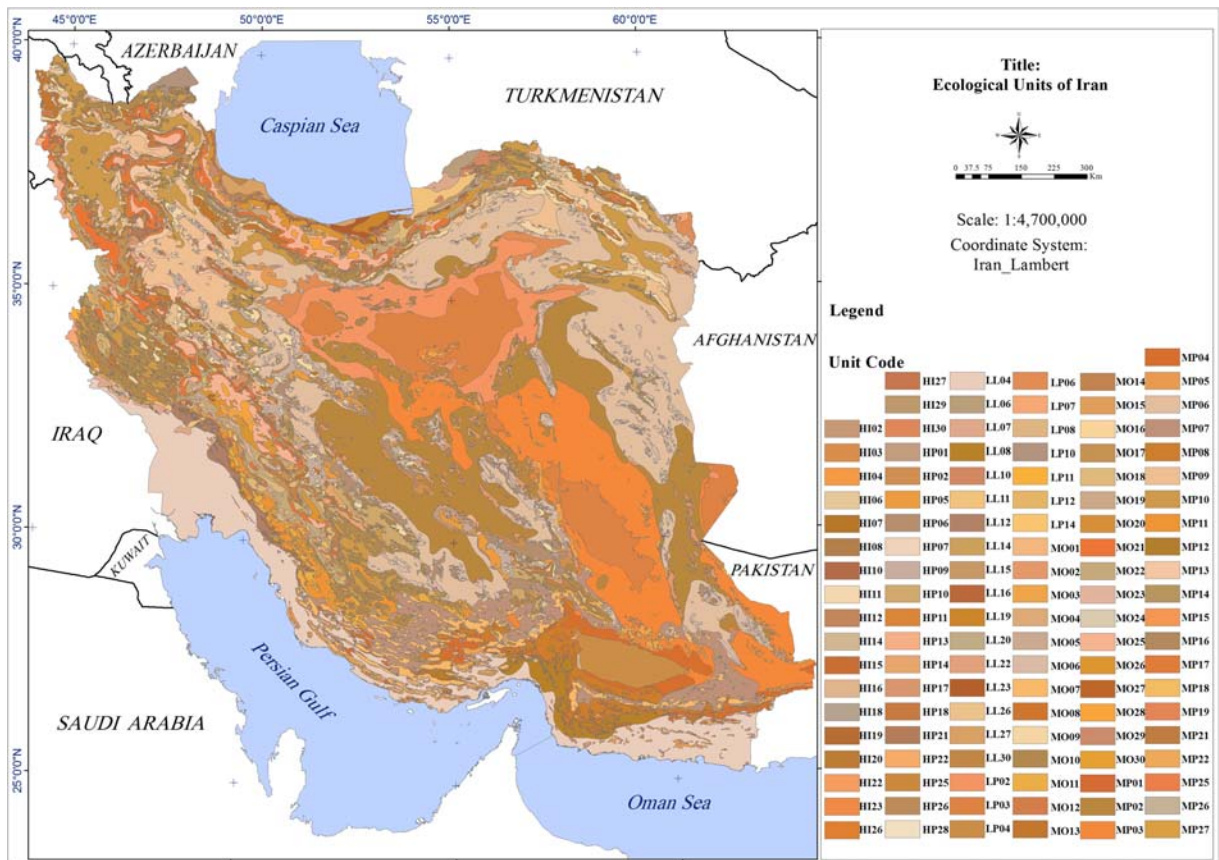


Fig. 3 Ecological units including 119 unique units with special landform and climate

Dictionary of Iranian Plant Names by Mozaffarian (1996). The recognized ecosystems contain several polygons (patches) located in different parts of the country. Evenness of ecosystems distribution in terms of their area and number of patches was analyzed using box plots and quartile indices.

Results

Below, the results of this study are presented for landform, ecological units, and terrestrial ecosystems.

Landform

According to our results, Iran is mainly covered by medium plains with moderate altitude and slopes less than 8% (48% of the land) enclosed in the western and southern parts with sloping highlands of Alborz and Zagros mountain ranges. Lands with low altitude and gentle slope are located in the form of vast low

plains (e.g., Dasht-e Kavir and Dasht-e Lut) and also appear as two lowlands in the northern and southern margins (21% of the country is low plains and lowlands). In addition to the two main mountain ranges covering 26% of the country, the northeast, central, and southeast mountains can also be taken into account. Five percent of Iran land area is high plains that are mostly located along mountain areas. Also, the hills often appear in the form of narrow strips between the lowlands and the highlands, which occupy only a very small area of the country (1%) (see Fig. 2).

Ecological units and terrestrial ecosystems at the national level

Overlaying the landforms with climatic zones formed 119 unique homogenous units, which contain around 6000 polygons (Fig. 3). The largest unit has an area of 254,000 ha, and the smallest one has an area of 1005 ha (Table 3 in Supplementary Material S3). The minimum

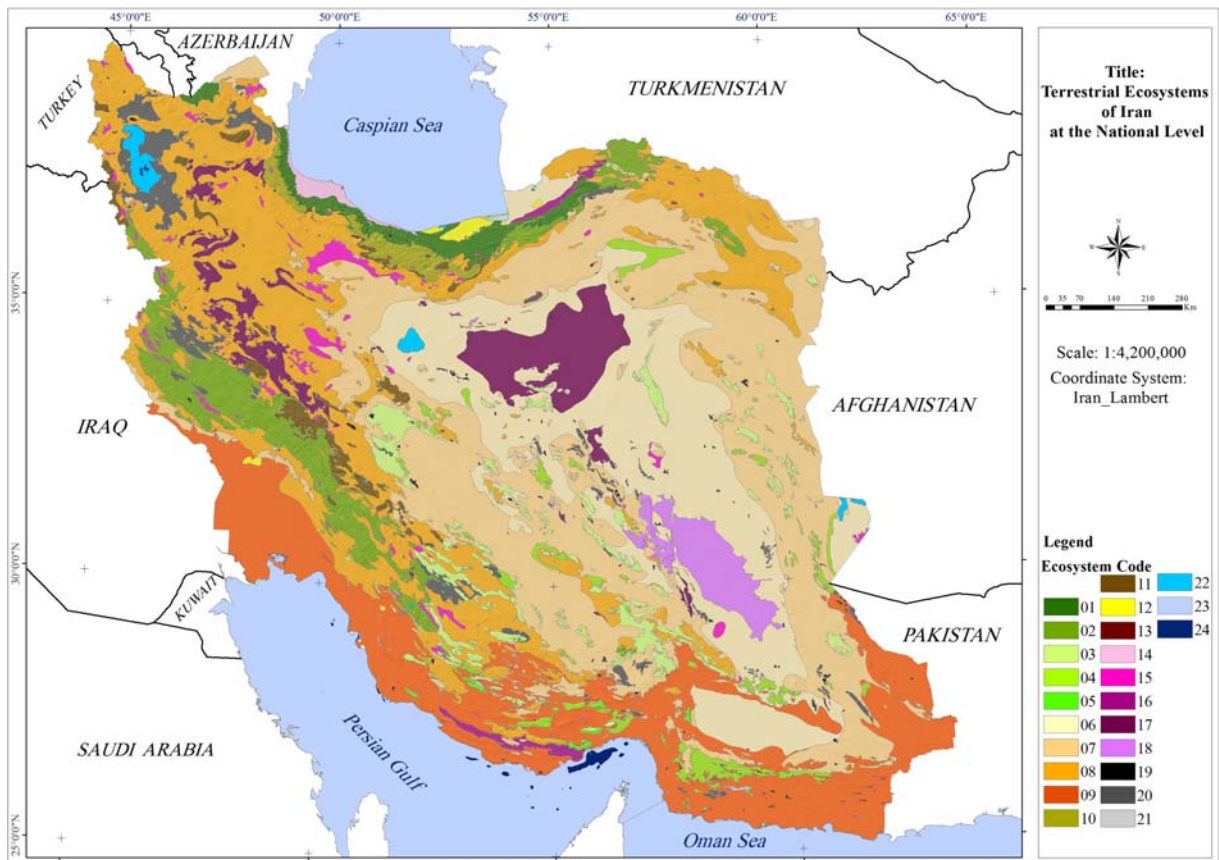


Fig. 4 Map shows distribution of terrestrial ecosystems in the country

and maximum number of patches of unique ecological units composed of 1 and 497 patches, respectively. These are considered as basic units for identifying ecosystems.

Polygons of homogenous ecological land units comprising 21 ecosystems were grouped into two categories of those with dominant vegetation (11 ecosystems) and those with sparse or no vegetation (10 ecosystems, here called land-climate ecosystems). Figure 4 shows location of these ecosystems, and in Table 4 and Fig. 5, a short description of each ecosystem is given. Also Figs. 6 and 7 are presented for better understanding of the relationship between distribution of ecosystems and macroclimate-land units.

The naming of the ecosystems with dominant vegetation was based on the vegetation form and type of the dominant climate, while those without vegetation were named based on landform and type of the dominant climate. The cold desert steppe ecosystem is the most extensive terrestrial ecosystem and covers nearly one-quarter of the country. Then cold and arid semi-steppe

scrublands and grasslands (19.8%), arid scrublands and halophytes (16.2%), warm and arid shrublands and scrublands (14.3%), and finally, arid and semi-arid forests (4.9%) are the largest ecosystems in Iran, respectively. In contrast, the warm desert bare hill mountains (0.02%) were the ecosystems with the lowest area. In terms of the number of patches, the semi-steppe ecosystem has the largest number of patches, distinctly different from other ecosystems (Table 4).

The distribution of the ecosystems in terms of area and the number of patches is shown in Fig. 8. As shown in Fig. 8 b, the area of the ecosystems has an asymmetrical distribution and tends toward larger areas. Ecosystems with an area greater than the median (about 2,500,000 ha) occupy 96.5% of the country. The areas above the upper quartile and also those between the minimum and the first quartile belong to the ecosystems that need further examination and study (marked with color in Table 4). The asymmetrical distribution of the numbers of the ecosystems' patches can also be seen in Fig. 8 d, where distribution tends to the larger number of

Table 4 Quantitative characteristics of terrestrial ecosystems in Iran

Code	Ecosystem Name	Number of Patch	Area (ha [*])	Area (%)	Dominant Vegetation Type
Ecosystems with Dominant Vegetation					
01	Humid&Semi-Humid Forests Ecosystem	7	2,491,605	1.54	<i>Carpinus betulus</i>
02	Arid&Semi-Arid Forests Ecosystem	34	7,930,617	4.91	<i>Quercus brantii</i>
03	Cold-Desert Woodland&Shrublands Ecosystem	177	4,831,572	2.99	<i>Amygdalus</i> spp.
04	Warm-Desert Woodland&Shrublands Ecosystem	89	2,762,792	1.71	<i>Haloxylon</i> sp.
05	Moderate-Desert Woodland&Shrublands Ecosystem	19	319,888	0.20	<i>Acacia tortilis</i>
06	Arid Scrubland&Halophytes Ecosystem	77	26,176,599	16.21	<i>Artemisia sieberi</i> – <i>Salsola</i> spp.
07	Cold-Desert Steppe Scrubland Ecosystem	142	40,641,863	25.16	<i>Artemisia sieberi</i> – <i>Zygophyllum</i> sp.
08	Cold&Arid Semi steppe Scrubland&Grasslands Ecosystem	238	32,036,352	19.83	<i>Astragalus</i> spp.
09	Warm&Arid Shrubland&Scrublands Ecosystem	32	23,141,047	14.33	<i>Taverniera</i> spp. – <i>Tephrosia</i> sp.
10	Cold&Humid Prairies Ecosystem	2	1,333,318	0.83	<i>Trifolium</i> spp.
11	Cold&Humid Cushion Scrublands Ecosystem	44	2,097,823	1.30	<i>Astragalus</i> spp. – <i>Daphnae</i> sp.
Ecosystems Without Vegetation					
12	Moderate-Semi humid Bare Lowlands Ecosystem	10	421,497	0.26	-
13	Warm&Arid Bare Hills Ecosystem	29	69,972	0.04	-
14	Humid&Moderate Bare Hill Lowlands Ecosystem	3	511,489	0.32	-
15	Semi arid&Cold Bare Mixed Plains Ecosystem	127	1,836,436	1.14	-
16	Warm&Arid Bare Mountain Hills Ecosystem	2	716,291	0.44	-
17	Moderate&Arid Bare Mountain Plains Ecosystem	24	7,180,114	4.44	-
18	Moderate&Arid Bare diverse land forms Ecosystem	2	3,096,454	1.92	-
19	Moderate&Arid Bare Sparse Mountains Ecosystem	140	378,403	0.23	-
20	Cold&Arid Bare Mountains Ecosystem	85	3,527,326	2.18	-
21	Warm-Desert Bare Hill Mountains Ecosystem	1	31,706	0.02	-
22	Inland Water				
23	Marine				
24	Islands				

*Hectare legend

	Ecosystems with Small Area and Limited Numbers of Patches
	Ecosystems with Small Area
	Ecosystems with Limited Numbers of Patches
	Ecosystems with Large Area and Large Numbers of Patches
	Ecosystems with Large Area

patches. Around 90% of the country is occupied by ecosystems with the number of patches higher than the median (39 patches). Ecosystems with a number of patches higher than the upper quartile and also lower than the first quartile also warrant further examination and investigation (shown in Table 4).

In total, 89% of the country is covered with ecosystems in which vegetation types has a predominant role, and in the remaining, ecosystems can be distinguished only based on the non-vegetated landscape (Fig. 9). In Fig. 9 b, both scrublands and grasslands account for the highest percentage of the ecosystems with dominant vegetation, whereas the woodlands and the shrublands have the minimum share.

Because of the small size of the grove ecosystem, we removed them from the current study as we did for inland water bodies.

Discussion and conclusion

Land protection planning requires identification of the homogeneous units in terms of ecological characteristics. These units, distinguishable from each other based on factors affecting ecosystem boundaries, may largely depict land ecological diversity. Based on the global experiences, ecosystems can be used as the basis for evaluating and analyzing the

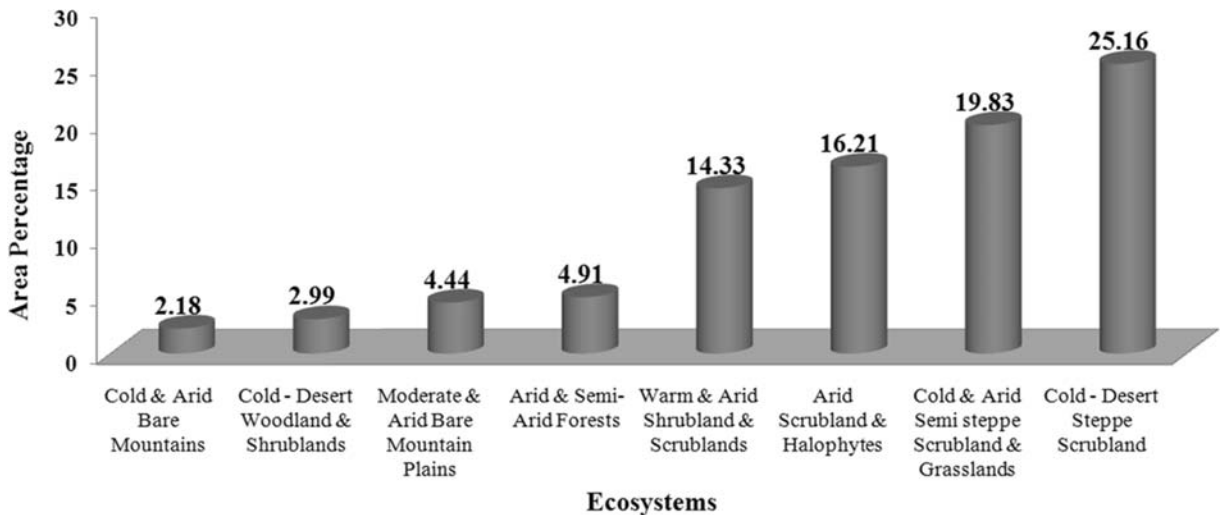


Fig. 5 Percent of Iran’s land area covered by each ecosystem (ecosystems that cover below 2% are not shown)

existing protected areas, modifying the protected areas network, selecting new, and eventually establishing a comprehensive and representative network of these areas. Accordingly, in this study, the

terrestrial ecosystems of Iran were identified and mapped anew in several stages. These ecosystems were classified firstly according to the characteristics of the landform-climate and then substantiated by

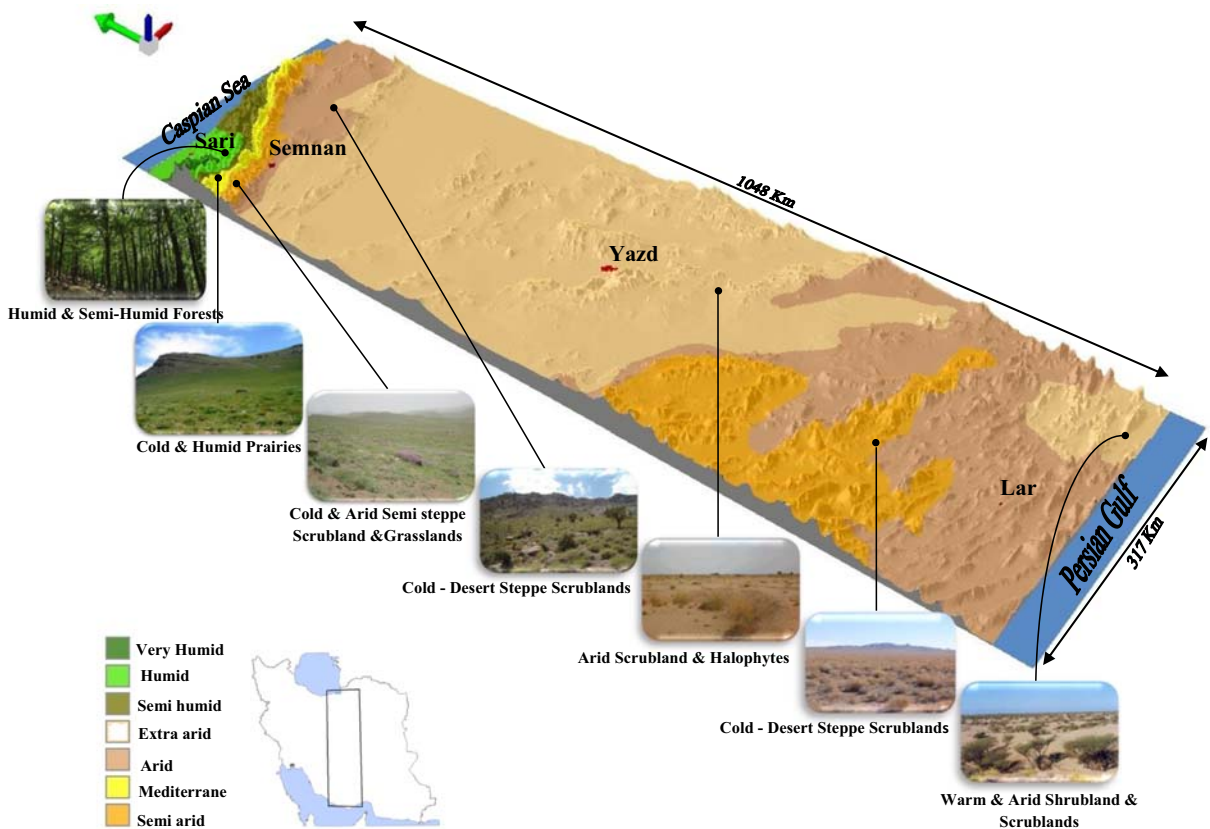


Fig. 6 Three-dimensional north-south macroclimatic profile of Iran and the main vegetated ecosystems

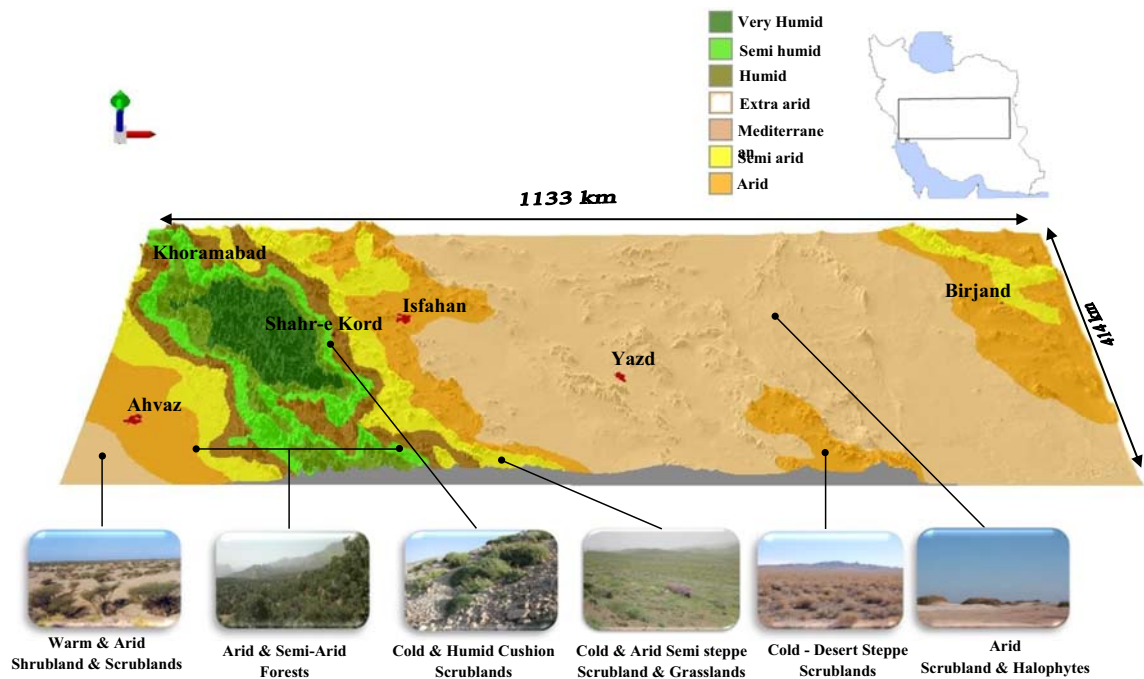


Fig. 7 Three-dimensional west-east macroclimatic profile of Iran and the main vegetated ecosystems

vegetation layer. The landform was generated using revised and edited slope and elevation classes, and the climate layer was produced based on and the revised and edited climate map of Iran.

Data layers with suitable and agreeing scales and proper accuracy were chosen, and also experts' opinion were sought when deciding on the factors and layers and analyzing the results. This first-time approach to ecosystems identification in Iran may provide a better framework for land protection, which has been the main focus in this study.

The identified terrestrial ecosystems are homogeneous ecological units in two categories of vegetated and non-vegetated lands in diverse climates from extra arid to very humid. Based on Figs. 6 and 7, the small humid climate zones in the north and west of the country have led to the creation of different forest types with high protection value. A good example of other protection capabilities is the south-north and west-east gradient of increasing aridity, which has a notable effect on the diversity of the vegetation landscapes. We applied patch metrics analyses to derive more information on the distribution of ecosystem classes that would ultimately help in better selection of the candidate protected areas. The highest proportion of the country is covered by ecosystems that are widely distributed and exist across large numbers of independent

patches (Fig. 8a and c). These ecosystems including cold and arid semi-steppe scrubland and grasslands (08), cold desert steppe scrubland (07), arid scrubland and halophytes (06), and warm and arid shrubland and scrublands (09) represent the dominant vegetation in more stable conditions (green color in Table 4). Therefore, they are potentially at lower risk from disturbance events and threats. Selection of the protected areas in these ecosystems assumes lower priority than others. Those ecosystems with a small area and limited number of the patches comprising humid and moderate bare-hill lowlands (14) and warm desert bare hill mountains (21) (dark red color in Table 4) occupy a small part of the country on the northern and southern borders. These characteristics make the mentioned ecosystems unique, potentially vulnerable, and important when selecting representatives for protected areas.

The information thus provided can also help provincial authorities to unanimously participate in the management of Iran's natural areas beyond administrative boundaries.

The land classification goal in our study is in line with Olson et al. (2001) and Yusefi et al. (2019). In spite of this similarity, terrestrial ecosystems identified here describe ecological capability of Iran's land area while also depicting the ecological diversity and complexity of the country. The arid scrubland and halophytes ecosystem is

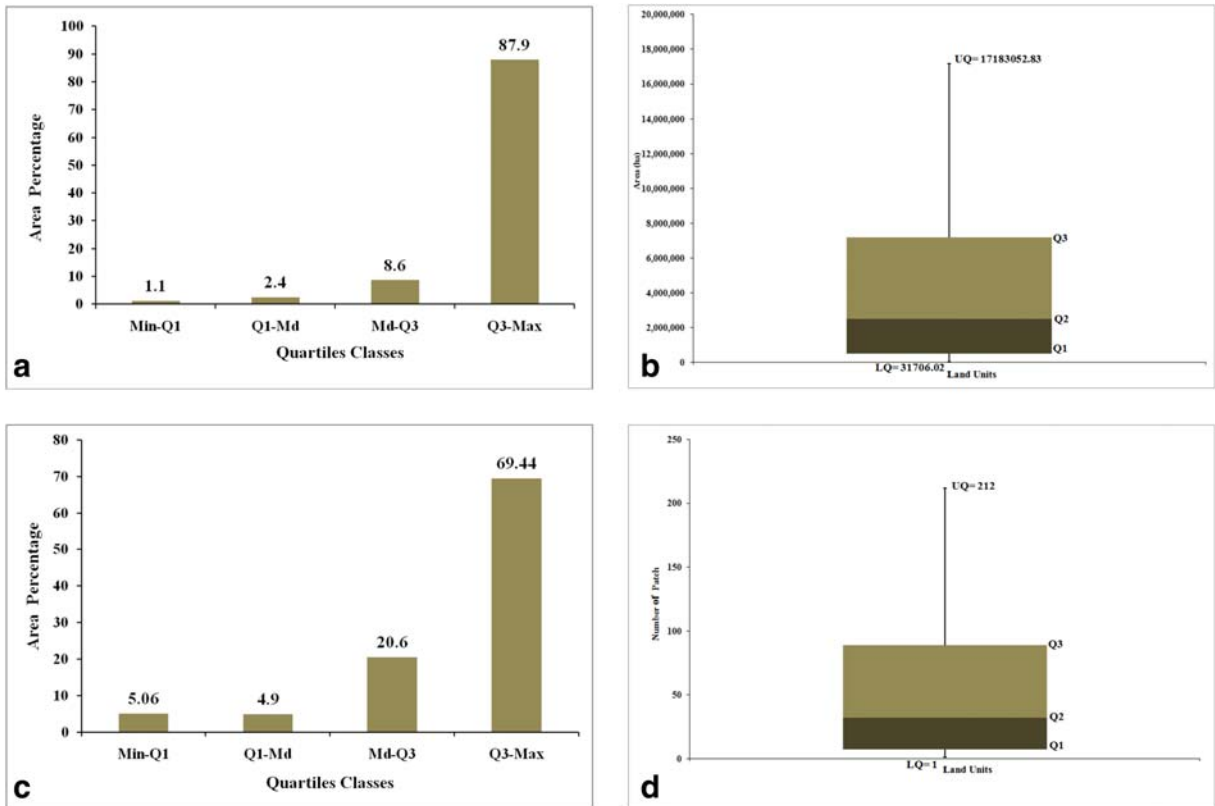


Fig. 8 Area percentage of the ecosystems in quartile classes (a). Area distribution of the quartiles of ecosystems (b). Percentage of the number of patches of ecosystems in quartile classes (c). Distribution of the quartiles of the ecosystems (d)

found in the central part of the country and along the southeast coast of the Caspian Sea bear similarities with

two Turkmen Plain and Central Basin bioregions. Other ecosystems have no similarity with bioregions (Fig. 10).

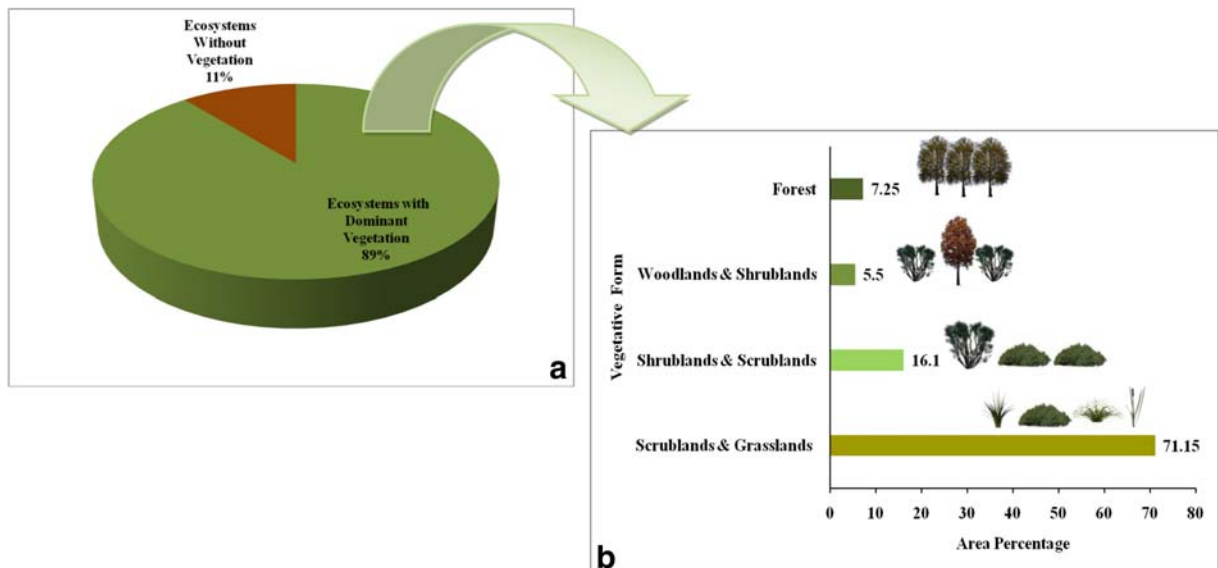


Fig. 9 Percentage of the ecosystems with dominant vegetation and those without it (a). Percentage of different vegetative forms in the vegetation-dominated ecosystems (b)

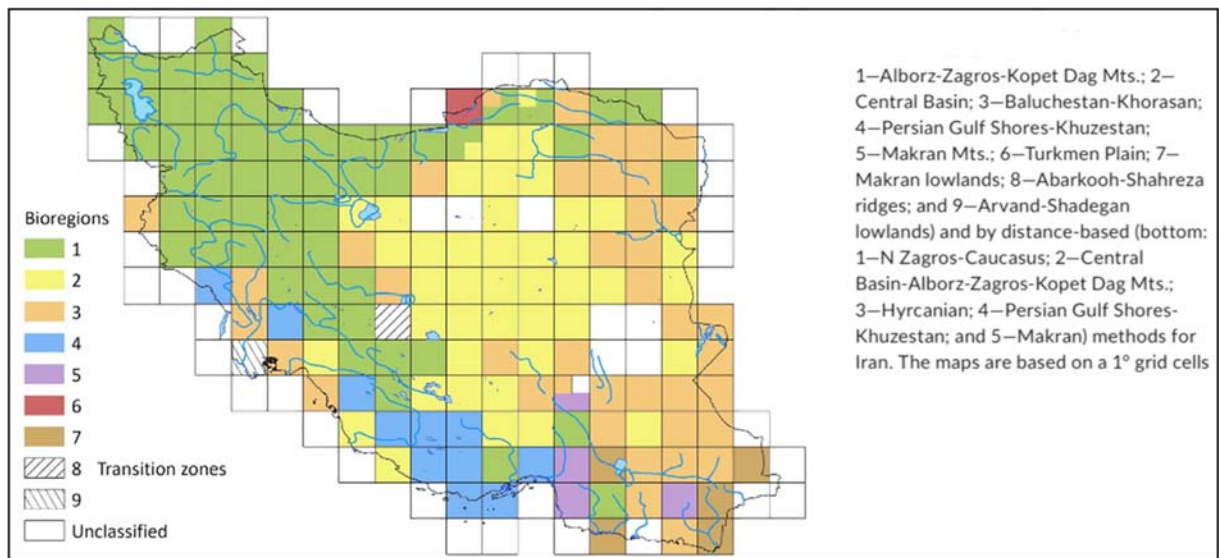


Fig. 10 Bioregions of Iran (according to Yusefi et al. 2019)

However, our classification shows little similarity with the global ecosystem classifications, as the scale

of our study has been more detailed. For example, the average size of 18 terrestrial eco-regions in Olson et al.'s

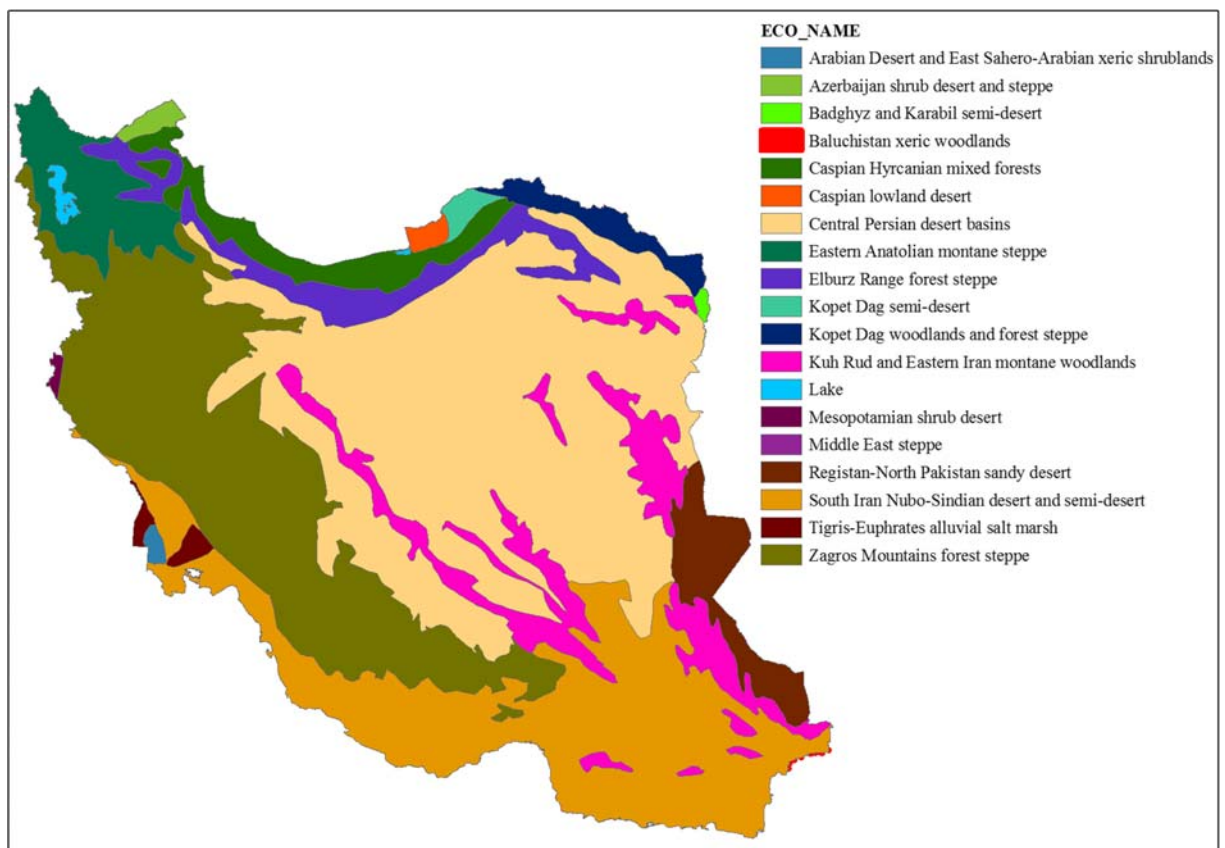


Fig. 11 Terrestrial eco-regions of Iran (according to Olson et al. 2001)

study (2001) is about 9,000,000 ha, whereas the 21 terrestrial ecosystems in our study have an approximate mean area of 7,700,000 ha. Realms and biomes were the two first factors used in the hierarchical classification of Olson et al. (2001). Zagros Mountains forest steppe, Central Persian desert basins, and South Iran Nubio-Sindian desert and semidesert which are located in the west, center, and south of Iran respectively contain diverse ecological conditions that can be recognized as separate eco-regions as in our study, but these are absent in the study of Olson et al. (Fig. 11). In comparison, a similarity is seen between the Caspian lowland desert eco-region and the arid scrubland and halophytes ecosystem along the southeast coast of the Caspian Sea.

Large ecosystems with dominant vegetation are important in terms of vegetation species and the habitat they create for dependent wildlife (Fig. 9a). The small share of the forest among these ecosystems, after woodlands and shrublands (Fig. 9b) gives more priority to forested areas for protection. In addition, the wide range of scrublands and grasslands, and especially steppe scrublands with a dominant arid-cold climate makes it possible for land protection planners to easily select the integrated areas with sufficient size.

Despite their small area, non-vegetated ecosystems in Iran are also remarkable for protection. These ecosystems include representative areas with specific geological structures. Moreover, along with other ecosystems with dominant vegetation, they can contribute to complete the protected areas' network.

The diversity of the identified ecosystems including a wide range of different forms of vegetation and various landforms provides a favorable point, but it also makes land protection planning even more difficult. For this reason, it is necessary to take a comprehensive knowledge-based action in this regard.

Toward this action and to improve our understanding of the ecological land diversity, ecosystems classification, and to complete the present study, we think that in future studies, the focus should be placed on the likely overlap between vegetation types/communities or other classifications thereof and the landform/climate classification of the country. This could shed light on the degree of complementarity and the correspondence between the two. Looking at how the defined ecosystems might as well contribute to wildlife species modeling or their habitat descriptions is another issue which warrants further investigations.

Acknowledgments Our greatest thanks and gratitude goes to Mr. Mashhadi Rafiee (responsible for GIS section of Sazeh Pardazi Iran Consulting Engineers Company) for providing data and professional contribution in preparing the maps and Dr. Eftekhari (researcher at the Research Institute of Forests and Rangelands), Dr. Shirvani (faculty member of forestry engineering department, University of Tehran), and Dr. Tavili (faculty member of Restoration of Arid and Mountainous Regions Department, University of Tehran) for their professional contribution in classifying vegetation. Also, Mr. Bayani (general manager of engineering and studies office, Forests, Range and Watershed Management Organization of Iran) and Dr. Fahmi (deputy of general manager for the Bureau of Water and Wastewater Master Planning of Iran's Ministry of Energy) shared their valuable data with us.

Funding information This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

Conflict of interest None.

References

- Ardakani, M. R. (2003). *Ecology*. Tehran: University of Tehran.
- Bailey, R. G. (1980). Description of the ecoregions of the United States. U.S. Department of Agriculture, miscellaneous publication no. 1391. *United States Department of Agriculture*, (1391), 77 pp. <https://doi.org/10.1017/CBO9781107415324.004>.
- Bailey, R. G. (1996). *Ecosystem geography*. New York: Springer.
- Bailey, R. G. (2005). Identifying ecoregion boundaries. *Environmental Management*, 34(1 SUPPL), 14–26. <https://doi.org/10.1007/s00267-003-0163-6>.
- Bennett, G. (2004). *Integrating biodiversity conservation and sustainable use: Lessons learned from ecological networks*. IUCN.
- Benson, J. S. (2006). New South Wales vegetation classification and assessment: Introduction — The classification, database, assessment of protected areas and threat status of plant communities. *Science and Public Programs Royal Botanic Gardens and Domain Trust AUSTRALIA. Cunninghamia*, 9(3), 331–382.
- Blasi, C., & Frondoni, R. (2011). Modern perspectives for plant sociology: the case of ecological land classification and the ecoregions of Italy. *Plant Biosystems*, 145(SUPPL. 1), 30–37. <https://doi.org/10.1080/11263504.2011.602747>.
- Blasi, C., Capotorti, G., Copiz, R., Guida, D., Mollo, B., Smiraglia, D., & Zavattono, L. (2014). Classification and mapping of the ecoregions of Italy. *Plant Biosystems*, 3504(May 2015), 37–41. <https://doi.org/10.1080/11263504.2014.985756>.
- Blasi, C., Capotorti, G., Alós Orti, M. M., Anzellotti, I., Attorre, F., Azzella, M. M., Carli, E., Copiz, R., Garif, V., Manes, F., Marando, F., Marchetti, M., Mollo, B., & Zavattono, L. (2017). Ecosystem mapping for the implementation of the European biodiversity strategy at the national level: the case

- of Italy. *Environmental Science and Policy*, 78(June), 173–184. <https://doi.org/10.1016/j.envsci.2017.09.002>.
- Blasi, C., Capotorti, G., Copiz, R., & Mollo, B. (2018). A first revision of the Italian ecoregion map. *Plant Biosystems - An International Journal Dealing with All Aspects of Plant Biology*, 3504, 1–4. <https://doi.org/10.1080/11263504.2018.1492996>.
- Canu, S., Rosati, L., Fiori, M., Motroni, A., Filigheddu, R., & Farris, E. (2015). Bioclimate map of Sardinia (Italy). *Journal of Maps*, 11(5), 711–718. <https://doi.org/10.1080/17445647.2014.988187>.
- Capotorti, G., Guida, D., Siervo, V., Smiraglia, D., & Blasi, C. (2012). Ecological classification of land and conservation of biodiversity at the national level: the case of Italy. *Biological Conservation*, 147(1), 174–183. <https://doi.org/10.1016/j.biocon.2011.12.028>.
- Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S., & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, 486(7401), 59–67. <https://doi.org/10.1038/nature11148>.
- Carranza, M. L., Acosta, A. T. R., Stanisci, A., Pirone, G., & Ciaschetti, G. (2008). Ecosystem classification for EU habitat distribution assessment in sandy coastal environments: an application in Central Italy. *Environmental Monitoring and Assessment*, 140(1–3), 99–107. <https://doi.org/10.1007/s10661-007-9851-7>.
- Chapin, F. S., Matson, P. A., & Mooney, H. A. (2002). Principles of terrestrial ecosystem ecology. *Springer*. <https://doi.org/10.4049/jimmunol.175.9.5701>.
- Djamali, M., Akhiani, H., & Khoshravesh, R. (2011). Application of the global bioclimatic classification to Iran: implications for understanding the modern vegetation and biogeography. *Ecologia Mediterranea*, 37(1), 91–114.
- Fairbanks, D. H. K., & Benn, G. A. (2000). Identifying regional landscapes for conservation planning: a case study from KwaZulu-Natal, South Africa. *Landscape and Urban Planning*, 50(4), 237–257. [https://doi.org/10.1016/S0169-2046\(00\)00068-2](https://doi.org/10.1016/S0169-2046(00)00068-2).
- Frisk, C. (2014). Examination and classification of ecosystem vegetation and ecosystem services in Messinia, Greece. Stockholm. Retrieved from <http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-1>.
- Galicia-Herbada, D., González, J. H., Torres, R. M., Pinilla, J. S., & Martín, R. H. (2011). An environmental land classification of Spain. *Fitosociologia*, 48(2), 101–110.
- Ganji, M. (2003). Climatic divisions of Iran. *Scientific Bulletin Of Climatological Research Institute*, 3(1), 41–51.
- Ghorbani, K., BazrafshanDaryasary, M., MeftahHalaghi, M., & Ghahreman, N. (2016). The effects of climate change on DeMartone climatic classification in Golestan province. *Iranian Journal of Soil and Water Reserarch*, 47(2), 319–332 Retrieved from https://ijswr.ut.ac.ir/article_58337.html.
- GhorbanizadehKharazi, H., & ChelemaalDezfulnejad, M. (2014). Innovation of a new climate classification method based on hydrometeorology. *Quarterly Journal of Water Engineering*, 2(2), 97–108 Retrieved from http://jwe.iau-shoushtar.ac.ir/article_529621_en.html.
- Herbertson, A. J. (1905). The major natural regions : an essay in systematic geography. *The Geographical Journal*, 25(3), 300–310.
- Holdridge, L. R. (1967). Life zone ecology. *Tropical Science Center*, 206. Via <https://doi.org/10.1046/j.1365-2699.1999.00329.x>.
- Jafari, A. (2012). *History of natural geography of Iran*. Tehran: Gitashenasi Geographical & Cartographic Institute.
- Javanshir, K. (1976). *Atlas of woody plants of Iran*. Tehran: National Society of Natural Resources and Human Environment Conservation.
- Jennings, S. (2006). From single species to ecosystem-based management: prospects for effective biodiversity conservation. In: *Biodiversity: Science and Governance*. UNESCO, (June), 1–4. Retrieved from <https://ueaeprints.uea.ac.uk/id/eprint/31533>.
- Kusbach, A. (2010). Terrestrial ecosystem classification in the Rocky Mountains, northern Utah, 213. Retrieved from <http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1675&context=etd>.
- Leathwick, J. R., Overton, J. M., & McLeod, M. (2003). An environmental domain classification of New Zealand and its use as a tool for biodiversity management; Una Clasificación Ambiental de Nueva Zelanda y Su Utilización Como una Herramienta para el Manejo de Biodiversidad. *Conservation Biology*, 17(6), 1612–1623. <https://doi.org/10.1111/j.1523-1739.2003.00469.x>.
- Loveland, T. R., & Merchant, J. M. (2004). Ecoregions and ecoregionalization: Geographical and ecological perspectives. *Environmental Management*, 34(Suppl 1), 1–13. <https://doi.org/10.1007/s00267-003-5181-x>.
- Madjnoonian, H. (1995). *Biosphere reserves*. Tehran: Department of the Environment of Iran.
- Maes, J., Teller, A., Erhard, M., Liqueste, C., Braat, L., Berry, P., Egho, B., Puydarrieus, P., Fiorina, C., Santos, F., Paracchini, M.L., Keune, H., Wittmer, H., Hauck, J. (2013). *Mapping and assessment of ecosystems and their services: an analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020*. Publications office of the European Union, Luxembourg. <https://doi.org/10.2779/12398>.
- Martínez-Tillería, K., Núñez-Ávila, M., León, C. A., Pliscoff, P., Squeo, F. A., & Armesto, J. J. (2017). A framework for the classification Chilean terrestrial ecosystems as a tool for achieving global conservation targets. *Biodiversity and Conservation*, 26(12), 2857–2876. <https://doi.org/10.1007/s10531-017-1393-x>.
- Minaee, M. (2002). *An introduction to political geography of Iran*. Tehran: Ministry of Foreign Affairs.
- Mozaffarian, V. (1996). *A dictionary of Iranian plant names*. Tehran: Farhang Mo'ser.
- Najafikani, A. (2002). *An introduction to the physical geography of Iran*. Tehran: National Geographical Organization.
- Neishabouri, A. (2013). *Biogeography*. Tehran: Samt Press.
- Oliver, I., Holmes, A., Dangerfield, J. M., Gillings, M., Anthony, J., Britton, D. R., Holley, M., Montgomery, M. E., Raison, M., Logan, V., Pressey, R. L., & Beattie, A. J. (2004). Land systems as surrogates for biodiversity in conservation planning. *Ecological Applications*, 14(2), 485–503.
- Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt,

- T. F., Ricketts, T. H., Kura, Y., Lammoreux, J. F., Wettengel, W. W., Hedao, P., & Kassem, K. R. (2001). Terrestrial ecoregions of the world: a new map of life on earth. *BioScience*, 51(11), 933. [https://doi.org/10.1641/0006-3568\(2001\)051\[0933:TEOTWA\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2).
- Omernik, J. M. (2004). Perspectives on the nature and definition of ecological regions. *Environmental Management*, 34, S27–S38. <https://doi.org/10.1007/s00267-003-5197-2>.
- Pickett, S. T. A., & Cadenasso, M. L. (2002). The ecosystem as a multidimensional concept: meaning, model, and metaphor. *Ecosystems*, 5(1), 1–10. <https://doi.org/10.1007/s10021-001-0051-y>.
- Pressey, R. L., Hager, T. C., Ryan, K. M., Schwarz, J., Wall, S., Ferrier, S., & Creaser, P. M. (2000). Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. *Biological Conservation*, 96(1), 55–82. [https://doi.org/10.1016/S0006-3207\(00\)00050-1](https://doi.org/10.1016/S0006-3207(00)00050-1).
- Rahimi, J., Ebrahimpour, M., & Khalili, A. (2013). Spatial changes of extended De Martonne climatic zones affected by climate change in Iran. *Theoretical and Applied Climatology*, 112(3–4), 409–418. <https://doi.org/10.1007/s00704-012-0741-8>.
- Rahnemai, M. T. (2014). *IRAN: The spatial and natural potentials*. Tehran: Mahkameh.
- Rankin, R., Austin, M., & Rice, J. (2010). Ecological classification system for the ecosystem status and trends report. *Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 1*, (1), ii+14. Retrieved from <http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-1>.
- Reddy, C. S., Jha, C. S., Diwakar, P. G., & Dadhwal, V. K. (2015). Nationwide classification of forest types of India using remote sensing and GIS. *Environmental Monitoring and Assessment*, 187(12), 1–30. <https://doi.org/10.1007/s10661-015-4990-8>.
- Research Institute of Forests and Rangelands. (2015). *National project of recognition of Iran ecological regions*. Tehran: Agricultural Research Education And Extension Organization.
- Sanderson, E. W., Segan, D. B., & Watson, J. E. M. (2015). Global status of and prospects for protection of terrestrial geophysical diversity. *Conservation Biology*, 29(3), 649–656. <https://doi.org/10.1111/cobi.12502>.
- Sayre, R., Comer, P., Warner, H., & Cress, J. (2009). A new map of standardized terrestrial ecosystems of the conterminous United States: US geological survey professional paper 1768, 17.
- Sayre, R., Dangermond, J., Frye, C., Vaughan, R., Aniello, P., Breyer, S., Cribbs, D., Hopkins, D., Nauman, R., Derrenbacher, W., Wright, D., Brown, C., Convis, C., Smith, J., Benson, L., Paco VanSistine, D., Warner, H., Cress, J., Danielson, J., Hamann, S., Cecere, T., & Reddy, P. (2014). *A new map of global ecological land units — an ecophysiological stratification approach* (p. 46). Washington, DC: Association of American Geographers. <https://doi.org/10.1007/BF02858199>.
- Singers, N. J. D., & Rogers, G. M. (2014). A classification of New Zealand 's terrestrial ecosystems. *Science for Conservation*, 325, 1–87.
- Statistics Canada. (2018). *Ecological Land Classification, 2017*. Minister of industry. Retrieved from <https://www.statcan.gc.ca/eng/subjects/standard/environment/elc/12-607-x2018001-eng.pdf>.
- Terauds, A., Chown, S. L., Morgan, F., Peat, H. J., Watts, D. J., Keys, H., Convey, P., & Bergstrom, D. M. (2012). Conservation biogeography of the Antarctic. *Diversity and Distributions*, 18(7), 726–741. <https://doi.org/10.1111/j.1472-4642.2012.00925.x>.
- Udvardy. (1975). *Udvardy - A classification of the Biogeographical Provinces of the world*.
- Vakilinezhad, R., MofidiShemirani, S. M., & MehdizadehSeraj, F. (2018). New method for climatic classification of Iran based on natural ventilation potential (case study: Yazd). *Journal of Climate Research*, 8(32), 13–22.
- Walter, H., & Box, E. (1976). Global classification of natural terrestrial ecosystems author (s): Heinrich Walter and Elgene Box published by : Springer stable URL : <http://www.jstor.org/stable/20036922>. *Your use of the JSTOR archive indicates your acceptance of the Terms & Condit*, 32(2), 75–81.
- Woodward, F. I., Lomas, M. R., & Kelly, C. K. (2004). Global climate and the distribution of plant biomes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 359, 1465–1476. <https://doi.org/10.1098/rstb.2004.1525>.
- Yusefi, G. H., Safi, K., & Barito, J. C. (2019). Network- and distance-based methods in bioregionalization processes at regional scale: An application to the terrestrial mammals of Iran. *Journal of Biogeography*, 46(11), 2433–2443.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.