ISSN: 2538-2152; ECOPERSIA 2024;12(4):391-404.

Tarbiat Modares University

Economic Valuation of Atmospheric Gas Regulation Services through Spatial Modeling in Kerman Province, Iran

ARTICLEINFO

Article Type
Original Research

Authors
Malihe Erfani, *Ph.D.*[1*]
Fatemeh Jahanishakib, *Ph.D.*[2]

How to cite this article
Erfani M., Jahanishakib F. Economic Valuation of Atmospheric Gas Regulation Services through Spatial Modeling in Kerman Province, Iran. ECOPERSIA 2024;12(4): 391-404.

DOI:
10.22034/ECOPERSIA.12.4.391

[1] Department of Environmental Sciences, Faculty of Natural Resources, University of Zabol, Zabol, Iran.
[2] Environmental Science Department, Faculty of Natural Resources and Environment, University of Birjand, Birjand, Iran

*** Correspondence**
Address: University of Zabol, Zabol, Sistan and Baluchestan Province, Iran.
Tel: +989151604366
Email: maliheerfani@uoz.ac.ir

Article History
Received: September 2, 2024
Accepted: November23, 2024
Published: November 30, 2024

ABSTRACT

Aims: The absorption of atmospheric Carbon dioxide for Carbon sequestration plays a vital role in regulating the climate. This study aimed to economically evaluate Carbon absorption and Oxygen supply in Kerman Province using ecosystem service modeling.
Materials & Methods: Terrestrial Carbon storage was assessed using InVEST software, considering aboveground biomass, belowground biomass, soil, and litter/ dead organic matter. Oxygen supply in the ecosystem was also calculated based on Carbon relationships. The economic valuation of Carbon and Oxygen supply was determined using the social cost of Carbon dioxide and replacement cost, respectively.
Findings: In 2021, Kerman Province was estimated to sequester 6,896,182.89 $t.y^{-1}$ of Carbon and produce 18,481,770.36 $t.y^{-1}$ of Oxygen. The economic value of Carbon sequestration and Oxygen supply in the Province was calculated at 354,325,877 and 1,686,461,545 $\$.y^{-1}$, totaling $2,040,787,422 in 2021.
Conclusion: The economic valuation of Carbon sequestration and the Oxygen supply spatially demonstrate the multiple roles of vegetation cover in the economy, which help maintain and restore it. Economic valuation maps of studied ecosystem services have comprehensive land management and planning applications. Furthermore, they underscore the importance of incentives for long-term Carbon storage to encourage sustainable practices.

Keywords: Carbon dioxide; Climate Regulation; Gas Regulation Function; Replacement Cost; Social Cost.

CITATION LINKS

[1] Yin C., Zhao W., Ye J., Muroki ... [2] Change I. 2006 IPCC guidelines for national greenhouse gas i ... [3] Lal R., Augustin B. Carbon sequestration in urban ecosystems ... [4] Shahzad K., Sintim H., ... [5] Gibbs H.K, Brown S, Niles J.O, Foley J.A. Monitoring and est ... [6] Bitoun R.E., David G, Devillers R. Strategic use of ecosyste ... [7] Kim J., Hong M., Choi S-E., Song C., Lim C-H., Choi YE, *et a* ... [8] Gamon J.A. Revisiting the Carbon–biodiversity connection. Gl ... [9] Miles D.C. Exploring ... [10] World Bank. State and Trends of Carbon Pricing 2022le [Inter ... [11] Erfanzadeh R., Motamedi J. Effect of slope and vegetation on ... [12] Varamesh S., Abdi N. Effect of afforestation with broadleaf ... [13] Yeganeh H., Azarnivand H., ... [14] Nasri M., Ghorbani M., Azarnivand H., Rafiee H. Economic val ... [15] Rastgar S., Najafpour Z., Jafarian Z., Ghorbani J. Investiga ... [16] Tarnian F., Amoli ... [17] Soleimanipour S.S., Adeli K., Mafi-Gholami D., Naghavi H. Ec ... [18] Janparvar H., Salarpour M., Pourmardan V. Estimation of econ ... [19] Khatoony N., Kolahi M. Economic valuation of Arghavandareh f ... [20] Brander L.M., de Groot R., Schägner J.P., Guisado-Goni V., v ... [21] Asadollahi Z., SalmanMahiny A. Assessing the Impact of Land ... [22] Fadaei E., Mirsanjari M.M., Amiri M.J. Modeling of ecosystem ... [23] Jahandari J., Hejazi R., Jozi S.A., Moradi A. Impacts of urb ... [24] Adelisardou F., Jafari H.R., Malekmohammadi B., Minkina T., ... [25] Adelisardou F., Zhao W., Chow R., Mederly P., Minkina T., Sc ... [26] Sharp R., Tallis H.T., Ricketts T., Guerry A.D., Wood S.A., ... [27] Erfani M., Jahanishakib F., Ardakani T. Habitat Quality Asse ... [28] Karra K., Kontgis C., Statman-Weil Z., Mazzariello J.C., Mat ... [29] Nowak D.J., Hoehn R., Crane D.E. Oxygen production by urban ... [30] Interagency Working Group on the SC-GHG (IWG). Technical Sup ... [31] Olfati F., Mosleh A.A., ... [32] Ghanbarian G.A., Hassanli A., Rajabi V. Comparing potential ... [33] Farhadi M. Determining ... [34] Joneidi H., Chahouki Z., Azarnivand H., Sadeghipour A. Effec ... [35] Jariyani M., Poyafar A., Mohammadkhan S. Collection of artic ... [36] Abdi N. The potential of plant types along the playas of Ira ... [37] Ghorbanian D., Zandi ... [38] Ghamemi RaeiniNejad M., Sadeghi H. The evaluation of Carbon ... [39] Bayranvand M., Kooch Y., Bahmani M. Variability analysis of ... [40] Ansari S., Sadeghi H. Carbon ... [41] Forouzeh M.R., Heshmati GH.A., Ghanbarian GH.A, Mesbah S.H. ... [42] Mirzaei Bahlouli H. Investigating and comparing the Carbon s ... [43] Sadeghi M., Ajorlo M., ... [44] Ahmadi H., Heshmati G., Naseri H. ... [45] Mirtalebi A., Gaikani S., Abdi N. Comparison of soil organic ... [46] Gholami H., Azarnivand ... [47] Naghipour B., Haidarian A.M., ... [48] Kolahchi N., Zahedi A. ... [49] Azad B., Afzali S.F. Evaluation of ... [50] Kusi K.K., Khattabi A, ... [51] Cademus R., Escobedo F.J., ... [52] Ghoreyshi R., Motamedi J., Sheidai ... [53] Rahimi L., Malekmohammadi B., Yavari A.R. The Ecosystem Serv ...

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

Introduction

Ecosystem Carbon sequestration services are vital for mitigating climate change by absorbing atmospheric CO_2 [1]. Land Carbon sequestration, achieved through practices like adding biochar and conservation tillage, helps decrease CO_2 emissions in the atmosphere. In essence, ecosystems contribute to regulating the Earth's climate by absorbing and releasing greenhouse gases (GHGs) such as Carbon dioxide (CO_2) from the atmosphere [2]. Currently, terrestrial ecosystems store four times more Carbon than what is present in the atmosphere (3,060 versus 760 gigatons) [3]. The extended storage of organic Carbon on continental shelves also has a vital impact on controlling atmospheric CO_2 levels, substantially contributing to decreasing global pCO_2 [4]. The Land Use and Land Cover (LU/LC) changes resulting from timber harvesting, land clearing for agriculture, and fires release substantial amounts of stored Carbon [2,5]. By storing Carbon in wood, biomass, and soil, ecosystems prevent CO_2 from entering the atmosphere. Management strategies such as reforestation or alternative agricultural practices can also lead to the significant storage of CO_2. Therefore, diverse management approaches for terrestrial ecosystems are crucial for climate regulation. Terrestrial Carbon storage and sequestration are among the most well-known ecosystem services.

Ecosystem Carbon sequestration services (ECSS) are crucial for advancing sustainable land use and management practices as they significantly contribute to various Sustainable Development Goals (SDGs) [1,6]. By comprehensively understanding the trade-offs and synergies among multiple ecosystem services, tailored strategies can be devised to propel the SDGs forward and enhance the progress of sustainable development [7].

Carbon sequestration can help conserve biodiversity by providing expected benefits through nature-based water and air solutions [8]. Conservation initiatives like preserving and restoring natural ecosystems can help conserve biodiversity while sequestering Carbon reserves and aligning climate actions to protect biodiversity [9]. Furthermore, assessing Carbon sequestration and storage within ecosystems has been underscored as a viable approach for addressing and controlling climate change, underscoring the necessity of enduring Carbon storage compensations to encourage sustainable methodologies. The recent publication by the World Bank delves into the evaluation and trajectory of Carbon pricing in the same year. Carbon pricing, as delineated in this publication, encompasses efforts that establish a precise value on emissions of greenhouse gases, articulated as a specific monetary value per metric ton of Carbon dioxide equivalent. These efforts encompass mechanisms such as Carbon levies or the Emissions Trading System. Carbon pricing demonstrates annual fluctuations and a consistent upward trend [10].

Throughout 2020, there were positive indications, particularly concerning the rise in Carbon prices, income growth, and the endorsement of new rules for global Carbon markets as per Article 6 of the Paris Agreement. In 2021, heightened Carbon costs, proceeds from novel mechanisms, and expanded auctioning within emissions trade systems resulted in a historic \$84 billion worldwide Carbon pricing revenue, representing approximately a 60 percent surge from the previous year. This substantial escalation underscores the escalating potential of Carbon pricing [10]. An alternate approach to assessing the Carbon sequestration service involves utilizing the social cost of Carbon dioxide, which factors in the importance of unpolluted air or the absence of emissions for the beneficiaries.

In Iran, a specific Carbon price has yet to be established, and examinations indicate varied methodologies are employed for computations in the country, some of which are mentioned below.

The economic value derived from atmospheric Carbon refining is used in some studies [11,12] to evaluate the Carbon sequestration of broadleaf forests and semi-dry rangelands, respectively. Varamesh and Abdi studied the effect of afforestation with broadleaf species on Carbon sequestration in the soil of Chitgar Forest Park. The findings indicated that the overall sequestered Carbon within a specific area occupied by stands of *Robinia Pseudoacacia* and *Fraxinus rotundifolia* was recorded as 78.19 and 48 $t.ha^{-1}$, in that order. In contrast, the amount measured in deteriorated rangeland reached 10.8 $t.ha^{-1}$. The economic value resulting from soil Carbon sequestration by the mentioned masses was calculated as \$79857143 and \$1919643, respectively, in the entire area of Chitgar Forest Park in Tehran [12]. Erfanzadeh and Motamedi researched the impact of vegetation cover alterations on the rangelands' Carbon sequestration in Urmia's Khanghah Sorkh region. Their findings revealed that the organic Carbon content has been sequestered in plant types *Pteropyrum aucheri- Astragalus microcephulus*, *Astragalus microcephalus-Aanthophyllum microcephalum* and *Pteropyrum aucheri-Prangus uloptera* 96.10, 73.84 and 52.00 $t.ha^{-1}$, respectively. Moreover, the estimated economic value of these plant types amounted to 19,220, 14,768, and 10,570 $\$.ha^{-1}$ [11].

The Carbon tax rate and replacement cost methods were extensively utilized in assessing the function of Carbon sequestration and Oxygen supply of ecosystems, respectively. Some researchers utilized these methods to assess the economic value of Carbon sequestration in the rangelands of the Taham Watershed. They demonstrated that 1.9 tons of Carbon dioxide (0.54 Carbon in $t.ha^{-1}$) are absorbed annually, producing an average of 1.5 tons of Oxygen. This process holds a value of 683941 and 3169823 $\$.y^{-1}$ [13]. In addition, Nasri *et al.* used the mentioned methods in the Rangelands of the Malard District. Their investigation revealed that the aggregate Carbon sequestration within the experimental zone amounted to 2.43 $t.ha^{-1}$, whereas the provision of Oxygen stood at 2 $t.ha^{-1}$. In general, the monetary value attributed to the Carbon sequestration function was approximated at \$255,658,701 billion, while the valuation of Oxygen supply was estimated to be \$13,290,338,850 billion [14]. Rastgar *et al.*, Tarnian *et al.*, and Soleimanipour *et al.* estimated the economic value of Carbon sequestration using the social cost approach via the Carbon tax method [15,16,17]. Rastgar *et al.* studied the economic implications of the Carbon sequestration capacity of vegetation cover within the biological processes carried out in the Sarbisheh rangelands in South Khorasan Province. As outlined in their findings, the rangelands in the specified region exhibited a Carbon capture rate of 774 tons. Concerning their Carbon sequestration function, the monetary worth assigned to each hectare of these rangelands was approximated at \$17.35 [15]. Tarnian *et al.* evaluated the damage caused by dams in terms of Carbon sequestration resulting from the destruction of forests in Kordestan Province. Using a social cost approach, they found that it amounts to \$45,418.89 annually [16]. Soleimanipour *et al.* evaluated the Carbon sequestration of Pahnus forest habitat in Zagros oak forests in Chaharmahal and Bakhtiari Province. They showed that the economic value of Carbon sequestration is approximately \$44.47 to \$50.05 [17]. Another method for economic evaluation of Carbon sequestration is the

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

replacement cost method used by Janparvar *et al.* to estimate the financial benefits of Carbon sequestration in the wheat fields of the Sistan Plain. Their results showed that the absorption value of each ton of Carbon dioxide is $94,897 [18]. Khatoony and Kolahi estimated and evaluated gas regulation in the Arghavandareh Forest Ecosystem, Razavi Khorasan Province. They utilized a literature review to calculate Carbon sequestration and FAO estimations for Oxygen supply (2.5 $t.ha^{-1}$). Subsequently, an economic evaluation was conducted using the replacement method [19]. Recently, Brander *et al.* have prepared a spatial database of the ecosystem services valuation that contains information from over 1,300 studies, yielding over 9,400 value estimates from 23 ecosystem services and 15 biomes in monetary units. The map results of this study are ecosystem-oriented and display the valuation results as point locations rather than integrated into the land surface. This marks the last attempt at creating a global data bank, acknowledging that there is still a significant amount of time and effort ahead [20].

Few studies in Iran have done the work of spatial modeling for the regulation of atmospheric gases, among which we can mention some studies like Asadollahi and SalmanMahiny, Fadaei *et al.*, and Jahandari *et al.* [21,22,23]. In these investigations, the process of representing the Carbon sequestration service has been conducted spatially. However, the economic valuation of this particular ecosystem service has yet to be undertaken. Asadollahi and Salman [21] and Fadaei *et al.* [22] studies using IPCC guidelines for the amount of Carbon stored in aboveground biomass, belowground biomass, soil, and dead organic matter. In a study by Jahandari *et al.* [23], these amounts were extracted from a map of Iran's soil and water research institute with five classes of LU/LC. Adelisardou *et al.* [24,25] also used the number of Carbon pools of the five classes of LU/LC in the InVEST user's guide [26]. The studies referenced have yielded overall findings by utilizing broad categories, which are beneficial for gaining a preliminary understanding of these ecosystem services. Therefore, in this study conducted in Kerman Province, additional details and a more significant number of specific categories were considered to enhance the precision of the estimates for valuing atmospheric gas regulation services. Another innovation of this study is that, unlike earlier studies that focused on limited areas and specific plant stands, this research considers broader landscape integrity at the provincial level. This research establishes a valuable database that provides evidence-based insights and recommendations for the sustainable conservation of ecosystems in the study area.

Materials & Methods

Study Area

The studied area in this research is Kerman Province. Kerman Province covers an area of more than 182 thousand square kilometers, which is about 11.2% of the entire country. It has a population of approximately 3 million people, between 25 degrees and 55 minutes to 32 degrees north latitude and 53 degrees and 26 minutes to 59 degrees and 29 minutes east longitude (Figure 1). This Province boasts rich plant diversity due to its unique geographical features, including topography, altitude, and climate variations [27]. Figure 1 displays various types of vegetation found in the forests and rangelands of this Province. From Iran's five ecological forest zones, two regions in Kerman consist of the Iran-Turani and Persian Gulf-Omani zones, which host more than 53 tree species together. The most important tree species in the Iran-Turani ecological zone include *Pistacia atlantica*, *Pistacia khinjuk, Amygdalus scoparia* and *Juniperus excelca*.

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

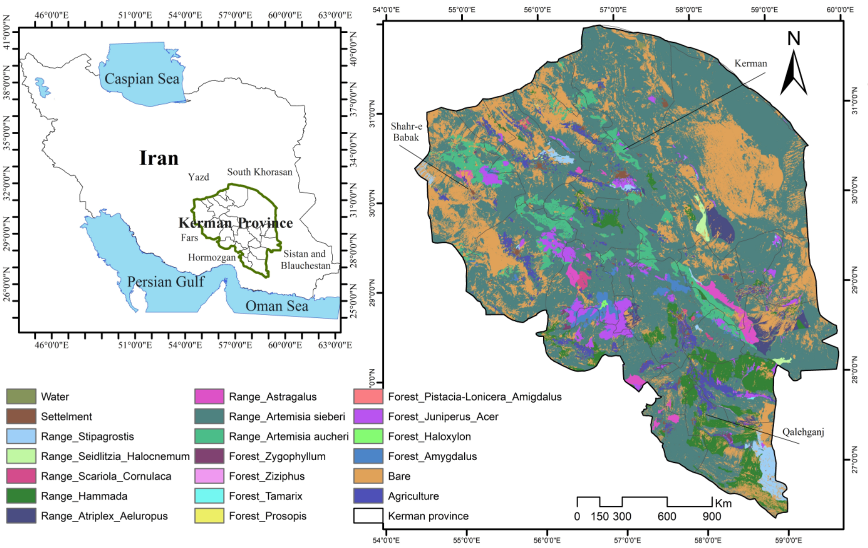

Figure 1) Geographical location of the study area in Iran (left) and distribution of its plant types and LU/LC (right).

In contrast, the dominant tree species in the Persian Gulf-Omani ecological zone are *Calotropis procera*, *Prosopis cineraria*, *Ziziphus spinosa*, and *Acacia* sp. 57 rangeland types have been identified in the Province. The primary plants in these types include Artemisia in 19 types, Astragalus in 5, and Calligonum in 6. Additionally, Cousinia is present in 3 types, Cormulaca in 3 types, Ephedra in 1 type, Gaillonia in 1 type, Hammada in 4 types, Peganum in 1 type, Rheum in 2 types, Salsaola in 5 types, Salvia in 1 type, Seidlitzia in 2 types, Stipa in 1 type, and finally, Zygophyllum is the main element in the last type.

Ecosystem Service Modeling of Carbon Sequestration and Oxygen Supply

The present study investigated terrestrial Carbon sequestration within the InVEST software package, utilizing storage sources: 1) aboveground biomass, 2) belowground biomass, 3) soil, 4) other organic matter (litter/dead organic matter), and 5) harvested wood products (HWPs). The Carbon sequestration model calculates the amount of dry Carbon storage based on Eq.(1) [26].

$$C_{xt} = C_{pxt} + \sum_{j=1}^{J} A_{xjt}\left(C_{aj} + C_{bj} + C_{sj} + C_{oj}\right)' \quad \text{Eq.(1)}$$

In Eq.(1), C_{xt} denotes the quantity of Carbon contained in the pixel under examination at time t, equivalent to the overall Carbon stored in the Carbon storage resources C_{aj}, C_{bj}, C_{sj}, and C_{oj}. These resources encompass deceased organic matter, aboveground biomass, belowground biomass, soil, and other organic matter, contributing to LU/LC composition. The symbol J signifies the various types of LU/LC within the research area, while A_{xjt} stands for the area of the LU/LC in Pixel x at the respective time. C_{pxt} represents the Carbon storage in HWPs. Aboveground biomass comprises all living plant components above the soil surface (leaves, branches, tree bark, and tree trunk). The belowground biomass encompasses the aboveground biomass root system. Carbon storage in the soil is associated with the soil's organic Carbon (SOC). Another source of Carbon storage is the organic matter of plant litter and dead wood. HWPs include the Carbon stored in products made with wood harvested from the ecosystem (furniture, paper, charcoal) [26]. Since the information about HWPs is not reliable and complete due to unauthorized harvesting, only the first four parts were used for modeling in this study.

Due to the significance of plant cover and type, the LU/LC map (adapted from Karra *et al.* [28]) utilized in this model was enhanced with forest and pasture types (the corresponding shapefile acquired from the Natural Resources and Watershed Management Organization in 2013), as depicted in Figure 1. LU/LC map was created by interpreting Centile 2 satellite images with a resolution of ten meters, achieving accuracy higher than 85% for the year 2020. The map was generated from the Esri website and classified using trained deep-learning models [28]. Subsequently, it was cross-referenced with Google Earth images to ensure high accuracy in the study area. The classification of forests and rangelands was based on the median statistics of the Normalized Difference Vegetation Index (NDVI) extracted from MODIS images with a resolution of 250 meters on September 11, 2020 (eModis NDVI V6 downloaded from the website https://earthexplorer.usgs.gov/), dividing them into low-density and high-density classes. The pixel size of the two-layer was then converted to 30 meters, resulting in eight classes: playa and water body, low-density forest, high-density forest, agriculture, settlement, barren land, low-density rangeland, and high-density rangeland. This map summarized the findings and updated the plant types used for ECSS modeling.

Various studies were conducted in regions with comparable climates and types to acquire the quadruple Carbon values. The quantity of Oxygen vegetation generation is determined by the Oxygen produced during photosynthesis (Eq. 2) minus the Oxygen consumed during respiration (Eq. 3).

$$n(CO_2) + n(H_2O) + \text{light} \rightarrow (CH_2O)n + nO_2 \qquad \text{Eq. (2)}$$

$$(CH2O)n + nO_2 \rightarrow n(CO_2) + n(H_2O) + \text{energy} \qquad \text{Eq. (3)}$$

Carbon sequestration by vegetation occurs when the Carbon sequestered from photosynthesis is more than its release through respiration. The ecosystem service of Oxygen production through Carbon sequestration was estimated based on the atomic weights in Eq. (4) [29]:

$$\text{net } O_2 \text{ release } (kg.y^{-1}) = \text{net C sequestration } (kg.y^{-1}) \times 2.68 \qquad \text{Eq. (4)}$$

Economic Valuation of the Ecosystem Service of Carbon Sequestration and Oxygen Supply

Economic valuation is done through the social cost of Carbon dioxide. The frequency distribution of the social cost of Carbon dioxide for the United States in 2020 is shown in Figure 2 [30]. Based on this figure, the value of each ton of Carbon is considered with a discount rate of 5% [30]. The discount rate is the rate of decline that the value of a capital experiences over time compared to its present value. The rationale behind selecting the specified value lies in the resemblance of the Carbon emission regulation measures in Iran and the United States. According to the figure, the price of Carbon is \$14 (\$.t^{-1} of CO_2 equivalent). By multiplying this number by the conversion factor for Carbon dioxide to Carbon (3.67), the share of Carbon is obtained, equal to \$51.38.

The value of Oxygen production has been assessed using the replacement cost method. This approach considers the relevant costs of producing Oxygen for industrial and medical purposes. According to an inquiry in 2021 into the market price of internet stores, the cost of charging a 40-liter capsule was \$4.166. The volume percentage of Oxygen is 20%, and the density of liquid Oxygen is 1141 kg/m^3. Each liter (one-thousandth of a cubic meter) of liquid Oxygen is 1.141 kg. Therefore, each kilogram of liquid Oxygen is equivalent to \$0.91. After converting the Oxygen production layer from tons to kilograms, the economic value map of

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

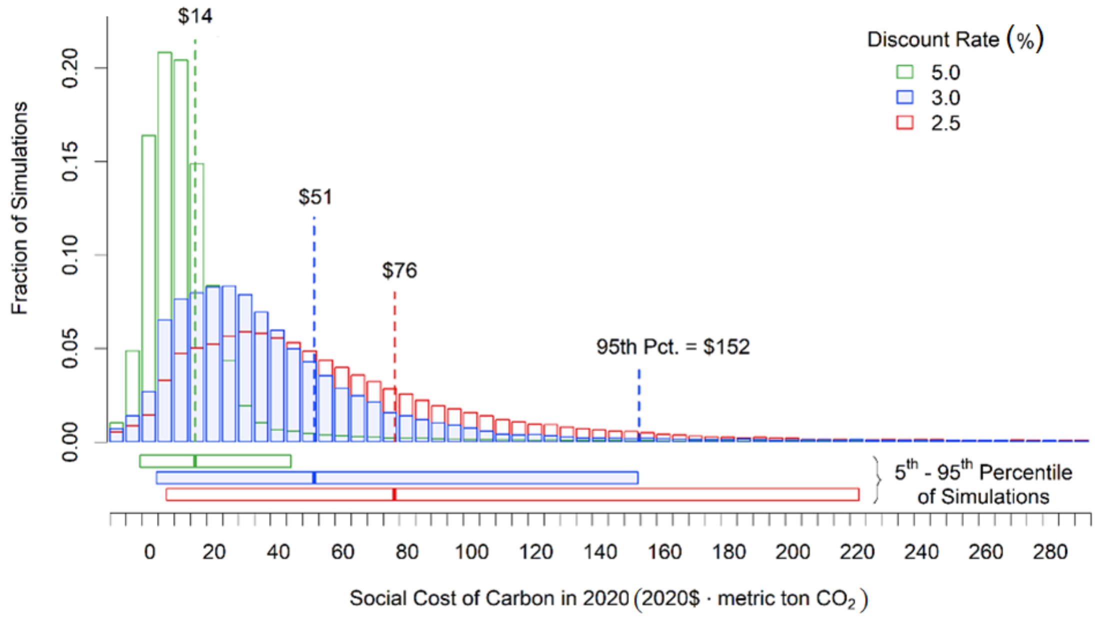

Figure 2) Frequency distribution of the social cost of Carbon dioxide varies with the choice of near-term discount rates. Colors correspond to near-term average discount rates of 5.0% (green), 3.0% (blue), and 2.5% (red). Dashed vertical lines highlight the mean social cost of Carbon dioxide values [30].

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

Oxygen production for Kerman Province was obtained.

Findings

Carbon Storage, Carbon Sequestration, and Oxygen Supply

In the Carbon storage and sequestration model, the LU/LC map (Figure 1), categorized by plant type, served as the primary framework for Carbon sequestration and its quadruple values. A range of studies conducted in areas with comparable climates and characteristics were utilized and compiled in Table 1 to derive these quadruple Carbon values.

The modeling amount of Carbon storage in each pixel of LU/LC (Figure 1) is shown in Figure 3. The distribution of annual Carbon sequestration ($t.pixel^{-1}$) is calculated in Figure 4. Carbon storage represents the total Carbon stored in aboveground biomass, belowground biomass, soil, and other organic matter. In contrast, Carbon sequestration indicates the Carbon accumulation in these parts over a specific period. This study considers the economic value of ecosystem services for one year. Then, the average annual growth rate, obtained from a resource review, is used to convert the Carbon storage layer into Carbon sequestration. This conversion involves multiplying the Carbon storage layer by 0.155 to represent Carbon deposition in one year (Figure 4).

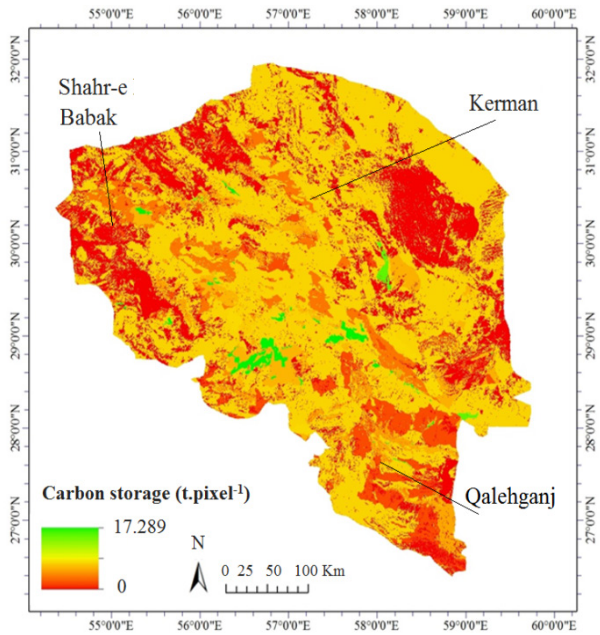

Figure 3) Amount of Carbon storage ($t.pixel^{-1}$) in Kerman Province.

Table 1) Quadruple Carbon values used in the Carbon storage and sequestration model (t.ha^{-1}).

LU/LC	Aboveground Biomass	Belowground Biomass	Soil	Other Organic Matter	References
Water body and playa	0	0	0	0	[26]
Juniperus - Acer forest type	6.11	2.5	13	5.6	[31]
Amygdalus forest type	86.1	5.5	98.6	1.9	[32]
Pistacia-Lonicera_ Amigdalus forest type	13.3	3.88	158.3	1.9	[33]
Haloxylon forest type	8.4	1	50	0.1	[34] [35]
Tamarix forest type	2	1	22	0.2	[36] [37]
Zygophyllum forest type	2.87	1.4	14.5	0.2	[38]
Ziziphus forest type	17	9.03	65.1	3	[39]
Prosopis forest type	23	9.03	45.75	0.75	[39] [40]
Agriculture forest type	1	0	23	0	[26]
Settlement forest type	2	1	5	0	[26]
Bare lands forest type	0	0	0	0	[26]
Artemisia sieberi rangeland type	3.59	3.92	24.4	1.25	[41]
Hammada rangeland type	0.6	0.24	6.31	0.2	[42]
Seidlitzia – Halocnemum rangeland type	0.36	0.71	67.26	0.11	[42]
Scariola-Cornulaca rangeland type	2	1	28.6	0.1	[36]
Stipagrostis rangeland type	1.1	0.5	22.66	0.1	[44]
Atriplex – Aeluropus rangeland type	3.4	2	18.63	2.48	[45] [46]
Artemisia aucheri rangeland type	0.3	0.4	14.4	0.1	[34] [47]
Astragalus rangeland type	0.4	0.6	32.28	0.3	[48] [49]

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

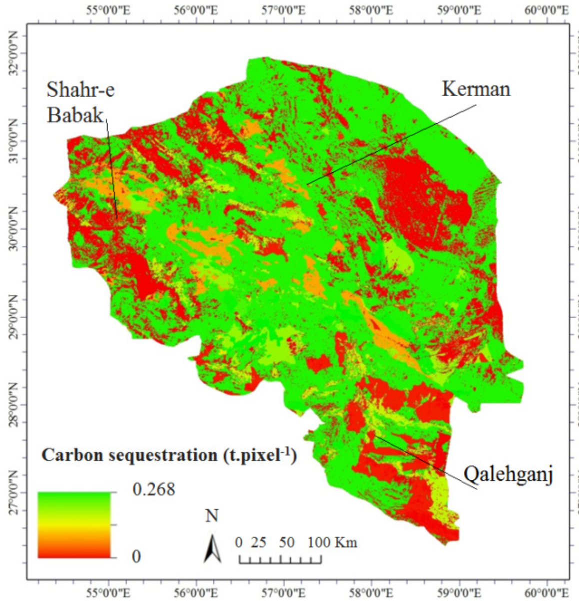

Figure 4) Amount of Carbon sequestration (t.pixel^{-1}) in Kerman Province.

According to Table 2, which illustrates the Carbon sequestration values (t.pixel^{-1}) across overall classes of LU/LC (comprising 8 classes), it is evident that the high-density rangeland area substantially impacts Carbon sequestration within the Province. The Province's average and total Carbon sequestration statistics (t.pixel^{-1}) in 2021 are estimated to be 0.034 and 6,896,182.892 tons, respectively.

In conformity with Eq. (3), the Carbon sequestration service (Figure 4) was converted to Oxygen supply services in tons for each pixel, as illustrated in Figure 5. The figure suggests that most of the Province has an average level of Oxygen production. Furthermore, small dark blue spots, as depicted in the figure, indicate areas with the highest Oxygen production levels.

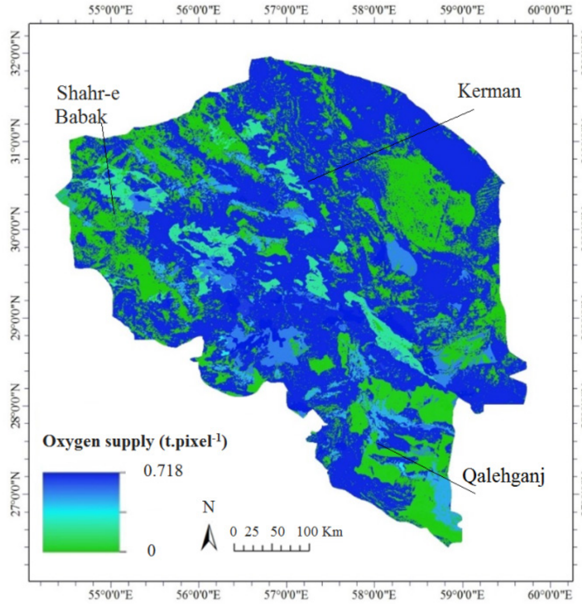

Figure 5) Oxygen supply service of Kerman Province (t.pixel^{-1}).

Economic Evaluation of Carbon Storage, Sequestration, and Oxygen Supply

Figure 6 shows the economic value of Carbon sequestration in the Province. Based on this, Carbon sequestration hotspots can be seen in red in small spots in the Province. Table 3 displays the economic evaluation of Carbon sequestration and Oxygen supply in LU/LC classes. According to the table, dense and low-density rangelands, followed by dense and low-density forests, have the highest Carbon

Table 2) Carbon Sequestration and Oxygen supply services by LU/LC in 2021 in Kerman Province.

LU/LC	Carbon sequestration (t.y^{-1})			Oxygen Supply (t.y^{-1})		
	Total	Mean	SD	Total	Mean	SD
Playa and water body	0.000	0.000	0.000	0.000	0.000	0.0000
Low-density forest	361841.120	0.084	0.092	969734.230	0.226	0.2474
High-density forest	365184.333	0.112	0.107	978694.040	0.299	0.2870
Agriculture	190479.155	0.034	0.000	510484.120	0.090	0.0001
Settlement	19615.901	0.011	0.000	52570.610	0.030	0.0001
Barren land	1.133	0.000	0.000	3.040	0.000	0.0001
Low-density rangeland	2459903.468	0.042	0.012	6592541.370	0.113	0.0317
High-density rangeland	3499157.783	0.041	0.011	9377742.950	0.111	0.0302

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

Table 3) Economic evaluation of Carbon sequestration and Oxygen supply service by LU/LC in 2021 in Kerman Province.

LU/LC	Carbon sequestration ($.y^{-1})			Oxygen supply ($.y^{-1})		
	Total	Mean	SD	Total	Mean	SD
Playa and water body	0.000	0.000	0.000	0.000	0.000	0.0000
Low-density forest	18591396.760	4.325	4.744	88488248.490	20.586	22.5753
High-density forest	18763171.040	5.737	5.502	89305831.150	27.302	26.1888
Agriculture	9786818.979	1.720	0.002	46581675.950	8.185	0.0091
Settlement	1007864.987	0.573	0.001	4797068.163	2.728	0.0091
Barren land	58.192	0.000	0.002	277.400	0.000	0.0091
Low-density rangeland	126389840.200	2.168	0.607	601569400.000	10.320	2.8926
High-density rangeland	179786726.900	2.129	0.579	855719044.200	10.129	2.7558

sequestration and Oxygen supply values. Each pixel in Kerman Province can store Carbon worth 1.73 $.y^{-1} on average, with the total value of the Province being $354,325,877. The Province's maximum statistics and standard deviation in 2021 were estimated to be 13.76 and 1.55, respectively. Also, each pixel of the Province can produce Oxygen in the amount of 8.24 $.y^{-1}, and the total value of the Province is 1,686,461,545 $.y^{-1}. The maximum statistics and standard deviation of the value of each pixel from the Province are 65.53 and 7.39, respectively.

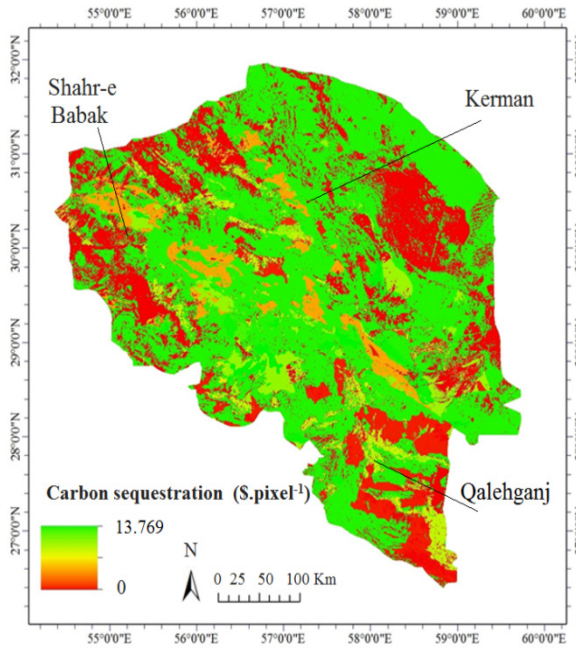

Figure 6) Economic value of Carbon sequestration in Kerman Province ($.pixel^{-1}).

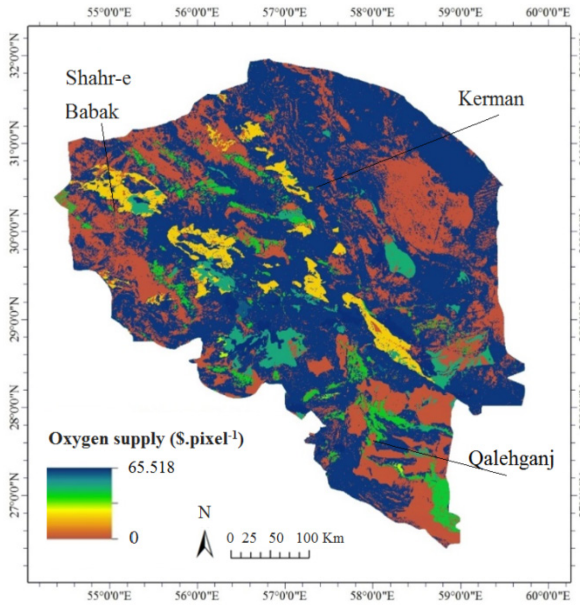

Figure 7) Economic value of Oxygen supply in Kerman Province ($.pixel^{-1}).

Discussion

The spatial patterns of atmospheric gas regulation services in Kerman Province varied across the study area. The economic value of Carbon sequestration ranged from 0 to 13.769 $.y^{-1}, while the value for Oxygen supply ranged from 0 to 65.518 $.y^{-1}. Generally, higher values were observed in the central areas of the Province (Figures 6 and 7). Brander *et al.* estimated the mean values (int$ 2020.h^{-1}.y^{-1}) of rangeland, natural grasslands, and savannas to be approximately 3.1 based on 8 studies worldwide, more than our results for rangelands [20]. The base year of 2020, the valuation method, and similar ecosystems can be the reasons for this proximity. Also, the mean values of temperate forest and woodland and urban in Brander *et al.* reported 1,124 and 10,384 from 302 and 93 studies, respectively [20], significantly higher than the values for forest and settlements in the present study. Compared to the case studies used in the database, the dry climate of the Province is one of the most important reasons for the poverty of urban vegetation and forests. Therefore, the results are the same.

Regarding the proximity to the current research in Iran, Janparvar *et al.*'s findings revealed that the absorption value of each ton of Carbon dioxide using the replacement cost method in the wheat fields of the Sistan Plain is $94896.7 [18]. While the timing of these two studies is similar, the comparison differs in evaluation methods. Also, the study being compared is solely focused on the agricultural lands of the Sistan Plain, whereas the current study encompasses all lands in the Kerman Province. Furthermore, Janparvar *et al.*'s research method is confined to organic Carbon, whereas the current study includes all four Carbon sources (aboveground biomass, belowground biomass, soil, and other organic matter). Consequently, the present study's results differ from those of this study. However, it reveals a crucial point: different methods yield varying estimates and are sometimes significantly different. In essence, diverse perspectives on the economic valuation of an ecosystem service unveil distinct facets of the economic value of that service, offering decision-makers more valuable information. As a result, it is also advisable to use alternative economic valuation methods in Kerman Province.

Tarnian *et al.* utilized the same research method in the forest lands of Lorestan Province [16]. Comparing the amount of Carbon sequestered with the present study reveals that the Lorestan forests can sequester between 44 and 336 $t.ha^{-1}.y^{-1}$. In contrast, Kerman Province's dense forests are estimated to sequester 1.22 $t.ha^{-1}.y^{-1}$. Consequently, the value of the forests studied in Lorestan exceeds that of the forest lands in the present study. The value of Carbon sequestration in Sarbishe rangelands in South Khorasan Province was reported as $17.35 [16], significantly higher than the present study's findings and Brander *et al.* (2024).

Some researchers only value Carbon sequestration in a single type of ecosystem [16,17,18,19], while some are only modeling [22,23,24,25], and the method of the present study includes both cases. In the present study, the modeling result was valued, providing detailed economic information for each pixel of every LU/LC. Furthermore, the LU/LC in this study was more thorough and had more classes due to integrating the vegetation type map into the LU/LC map. This approach significantly enhanced the accuracy of the study.

Khatoony and Kolahi utilized FAO estimates for Oxygen supply in semi-arid forest ecosystems [19], which closely align with our findings for low-density forests (2.55 $t.ha^{-1}$) and are lower than those for high-density forests (3.33 $t.ha^{-1}$). Yeganeh *et al.* reported results for rangelands obtained from field and laboratory surveys, applying the photosynthesis equation (1.5 $t.ha^{-1}$) [13], which also closely corresponds to the findings of our present study (1.22 $t.ha^{-1}$). A comparison of the method used in this research with a review of sources showed that few studies have comprehensively integrated the landscape of land, considering various habitats and ecosystems [50], and there is no example in Iran. The studies conducted in Iran have been in a small geographical

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

area and limited to a specific ecosystem [11,12,14,16,18,19,51,52,53]. Therefore, conducting economic valuation studies considering spatial factors and the landscape's integrity is advisable.

Conclusions

The research emphasizes evaluating atmospheric gas regulation services within the integrated landscape context. It was conducted to quantify and model the services of Carbon sequestration and Oxygen supply in the ecosystems of Kerman Province, which was associated with using spatial data. Therefore, the model output showed the results spatially in the scale of pixels equivalent to 0.09 hectares (30 meters by 30 meters). As the results showed, with the help of geostatistical techniques, it is possible to express various statistics at the desired levels, including LU/LC. It is necessary to express the differences and similarities of the results of this research with other related research, such as modeling method and value estimation method, biological climate, location, and study time, especially in the field of economic valuation due to the existence of the discount rate and fluctuation in different years. In this research, the total Carbon sequestered in the lands of Kerman Province was 6,896,182.892 tons, while 18,481,770.36 tons of Oxygen was produced. Also, the total economic value for Carbon sequestration in the Province is $354,325,877, and the value of the Oxygen supply obtained $1,686,461,545 in 2021. The sum of both services equals $2,040,787,422 in 2021, demonstrating the value of gas regulation ecosystem services in the Province. In the present study, a part of the economic value of vegetation cover has been investigated in terms of two ecosystem services. Therefore, the study results show only a tiny part of the value of vegetation from the studied aspects. Also, due to their wide distribution, rangelands and forests play a significant role in this service. These results highlight the importance of vegetation cover in regulating atmospheric gases, underscoring the need to protect them. With the help of the economic values reported in this research, decision-makers and policymakers can be encouraged to use this spatial information to make rational decisions in locating development sites, protecting and restoring vegetation, and assessing the damage caused to the environment. Moreover, gathering the data bank for the spatial database of ecosystem services valuation is recommended, and the results of various studies should be compiled into a national data bank.

Conflict of interest

There is no conflict of interest.

References

1. Yin C., Zhao W., Ye J., Muroki M., Pereira P. Ecosystem Carbon sequestration service supports the Sustainable Development Goals progress. J. Environ. Manage. 2023; 330(1):117155.
2. Change I. 2006 IPCC guidelines for national greenhouse gas inventories. Inst. Glob. Environ. Strateg Hayama, Kanagawa, Japan. 2006.
3. Lal R., Augustin B. Carbon sequestration in urban ecosystems. Springer Science and Business Media; 2011.
4. Shahzad K., Sintim H., Ahmad F., Abid M., Nasim W. Importance of Carbon sequestration in the context of climate change. Build. Clim. Resil. Agric. Theory Pract. Futur. Perspect. 2022; 1(1):385–401.
5. Gibbs H.K, Brown S, Niles J.O, Foley J.A. Monitoring and estimating tropical forest Carbon stocks: making REDD a reality. Environ. Res. Lett. 2007; 2(4):45023.
6. Bitoun R.E., David G., Devillers R. Strategic use of ecosystem services and co-benefits for Sustainable Development Goals. Environ. Res. Lett. Sustain Dev.2023;31(3):1296–1310.
7. Kim J., Hong M., Choi S-E., Song C., Lim C-H., Choi YE, *et al.* Supply and demand assessment and mismatch analysis of ecosystem services to support sustainable land management. In: EGU General Assembly Conference Abstracts. 2023:. EGU-11101p.

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

8. Gamon J.A. Revisiting the Carbon–biodiversity connection. Glob. Chang. Biol. 2023; 29(18): 5117–5119.
9. Miles D.C. Exploring faunal conservation in Carbon projects through Map of Life: A case study. Nat. Sci. Educ. 2022; 51(2):e20079.
10. World Bank. State and Trends of Carbon Pricing 2022le [Internet]. Washington, DC: World Bank; 2022: 74 p.
11. Erfanzadeh R., Motamedi J. Effect of slope and vegetation on Carbon sequestration in a semi-dry rangeland of western Iran, case study: Khanghah Sorkh, Urmia. Water Soil. 2013; 27(4): 703–711.
12. Varamesh S., Abdi N. Effect of afforestation with broadleaf species on Carbon sequestration in the soil of Chitgar Forest Park of Tehran. Iran. J. Soil Res. 2011; 25(3): 187–196.
13. Yeganeh H., Azarnivand H., Saleh I., Arzani H., Amirnejad H. Estimation of the economic value of the gas regulation function in rangeland ecosystems of Taham watershed basin. Rangeland. 2015; 9(2): 106–119.
14. Nasri M., Ghorbani M., Azarnivand H., Rafiee H. Economic valuation of stocked Carbon function in arid and semi-arid rangelands (case study: Malard District). Iran. J. Range Desert Res.2016;23(2):403–396.
15. Rastgar S., Najafpour Z., Jafarian Z., Ghorbani J. Investigation and Comparison of the Economic value of Carbon sequestration function of vegetation cover in biological operations (Case study: Sarbishe Rangelands-South Khorasan Province). J. Environ. Stud. 2018; 44(1): 131–148.
16. Tarnian F., Amoli Kondori A., Mansouri M., Asadolahi Z. Economic valuation of Carbon sequestration in dam lakes of Chuman and Kani Goizhan and their water transfer systems in Kordestan Province. PEC. 2020; 7(15): 71–87.
17. Soleimanipour S.S., Adeli K., Mafi-Gholami D., Naghavi H. Economic evaluation of Carbon sequestration in Zagros oak forests (Case study: the Pahnus forest habitat, Chaharmahal and Bakhtiari Province). PEC. 2022; 10(20): 185–206.
18. Janparvar H., Salarpour M., Pourmardan V. Estimation of economic benefits from Carbon sequestration in wheat fields of Sistan Plain. Sustain. Agric. Res. 2021; 1(2): 77–90.
19. Khatoony N., Kolahi M. Economic valuation of Arghavandareh forest's ecosystem goods and services.Iran.J.For.Range.Prot. Res.2022;19(2):297–325.
20. Brander L.M., de Groot R., Schägner J.P., Guisado-Goni V., van't Hoff V., Solomonides S. Economic values for ecosystem services: A global synthesis and way forward. Ecosyst. Serv. 2024; 66(1): 101606.
21. Asadollahi Z., SalmanMahiny A. Assessing the Impact of Land Use Change on Ecosystem Services Supply (Carbon Storage and Sequestration). Environ. Res.2017; 8(15), 203-214.
22. Fadaei E., Mirsanjari M.M., Amiri M.J. Modeling of ecosystem services based on land cover change and land use using InVEST software in Jahannama Conservation Area (case: Carbon sequestration ecosystem service). TCPA. 2020; 12(1):153–173.
23. Jahandari J., Hejazi R., Jozi S.A., Moradi A. Impacts of urban expansion on spatio-temporal patterns of Carbon storage ecosystem services in Bandar Abbas Watershed using InVEST software. Water Soil Manag. Model. 2022; 2(4): 91–106.
24. Adelisardou F., Jafari H.R., Malekmohammadi B., Minkina T., Zhao W., Karbassi A. Impacts of land use and land cover change on the interactions among multiple soil-dependent ecosystem services (case study: Jiroft plain, Iran). Environ. Geochem. Health. 2021; 43(10): 3977–3996.
25. Adelisardou F., Zhao W., Chow R., Mederly P., Minkina T., Schou J.S. Spatiotemporal change detection of Carbon storage and sequestration in an arid ecosystem by integrating Google Earth Engine and InVEST (the Jiroft plain, Iran). Int. J. Environ. Sci. Technol. 2022; 19(1): 1–16.
26. Sharp R., Tallis H.T., Ricketts T., Guerry A.D., Wood S.A., Chaplin-Kramer R. InVEST user's guide. The natural capital project. Nat. Cap. 2014.
27. Erfani M., Jahanishakib F., Ardakani T. Habitat Quality Assessment Using InVEST Model and its Valuation Through Cost Compensation Method in Kerman Province. Iran. J. Appl. Ecol. 2023; 12(2):11–23.
28. Karra K., Kontgis C., Statman-Weil Z., Mazzariello J.C., Mathis M., Brumby S.P. Global land use/land cover with Sentinel 2 and deep learning. In: 2021 IEEE international geoscience and remote sensing symposium IGARSS. IEEE; 2021:4704–4707.
29. Nowak D.J., Hoehn R., Crane D.E. Oxygen production by urban trees in the United States. Arboric Urban For. 2007;33(3):220-226.
30. Interagency Working Group on the SC-GHG (IWG). Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide, Interim Estimates under Executive Order 13990. 2021.
31. Olfati F., Mosleh A.A., Azimzadeh H.R. Estimating Carbon sequestration in *Pistacia atlantica*, *Acer monspessulanum*, *Amygdalus scoparia*, and *Ephedra procera* in the protected area of bagh-e shadi herat in Yazd Province. Plant Ecosyst. 2013; 9(36): 65–75.
32. Ghanbarian G.A., Hassanli A., Rajabi V. Comparing potential Carbon sequestration of different parts of mountain almond and grape plants and soil in Fars Province. J. Nat. Environ. 2015; 68(2): 257–265.

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]

33. Farhadi M. Determining the Carbon sequestration potential in the natural and hand-planted mass of *Amygdalus scoparia* spach . Sari University of Agricultural Sciences and Natural Resources;2012.
34. Joneidi H., Chahouki Z., Azarnivand H., Sadeghipour A. Effect of *Haloxylon ammodendron* and *Pistachia Vera* plantation on Carbon and nitrogen storage in *Artemisia sieberi* shrubland of Semnan Province. J. Arid. Biome. 2011; 1(4): 15–25.
35. Jariyani M., Poyafar A., Mohammadkhan S. Collection of articles of the first national conference of Haloxylon and Haloxylon plantation in Iran. Kerman: Rah-e-Sobhan; 2013; 352 p.
36. Abdi N. The potential of plant types along the playas of Iran from the point of view of Carbon sequestration. In 2nd national conference on combating desertification and sustainable development of Iran Desert Wetlands (Relying on Meighan Desert Wetland). Arak: Islamic Azad University Arak Branch; 2013.
37. Ghorbanian D., Zandi Esfahan E., Amirjan M., Nejatian A. Evaluation of Carbon sequestration potential *Suaeda fruticosa*, *Tamarix aphylla*, *Tamarix leptoptala* and *Alhagi camelorum* Species (Halophyte Species) *andArtemisia sieberi* (Non Halophyte Species). Iran J. Range Desert Res. 2022; 29(3):171–180.
38. Ghamemi RaeiniNejad M., Sadeghi H. The evaluation of Carbon sequestration at plant's organs and soil characteristics in understory of *Zygophyllum atriplicoides* and *Gymnocarpus decander* (Case study: Saleh-Abad, Hormozgan). Iran J. Range. Desert Res. 2017; 24(4): 699–707.
39. Bayranvand M., Kooch Y., Bahmani M. Variability analysis of soil Carbon and nitrogen storage under *Prosopis cineraria*, *Calotropis procera* and *Ziziphus spinosa* species in the South of Kerman. J. Arid Biome. 2019; 8(2):91–101.
40. Ansari S., Sadeghi H. Carbon storage assessment in soil and plant organs: the role of *Prosopis* spp. on mitigate soil degradation. Environ. Monit. Assess. 2022; 194(1):1–10.
41. Forouzeh M.R., Heshmati GH.A., Ghanbarian GH.A, Mesbah S.H. Comparing Carbon sequestration potential of three shrub species *Heliantemum lippii*, *Dendrostellera lessertii* and *Artemisia sieberi* (case study: Gareh Bygone, Fasa). J. Environment. Studie. 2008; 34(46): 65-72.
42. Mirzaei Bahlouli H. Investigating and comparing the Carbon sequestration capability of *Hammada Salicornica* and *Sedlitzia rosmarinus* plants in the desert pastures of Khosuf. University of Birjand; 2020.
43. Sadeghi M., Ajorlo M., Shahriari A. Comparison of plant litter quality in three range plant species and its relationship with soil characteristics. J. Water Soil Conserv. 2019; 26(1):218–205 .
44. Ahmadi H., Heshmati G., Naseri H. Soil Carbon sequestration potential in desert lands affected two species of *Haloxylon aphyllum* and *Stipagrostis plumosa* (Aran-o-Bidgol, Iran). Desert Ecosyst. Eng. 2022;3(5):29–36.
45. Mirtalebi A., Gaikani S., Abdi N. Comparison of soil organic Carbon content using rangelands and hand-planted pasture with *Atriplex canescens* species in the northern edge of Meighan desert. In 3rd national conference on combating desertification and sustainable development of Iran Desert Wetlands (Relying on Meighan Desert) . Arak: Islamic Azad University Arak Branch; 2013.
46. Gholami H., Azarnivand H., Biniaz M. Study and comparison of the Carbon sequestration by *Atriplex canescens* and *Hulthemia persica* in Nowdahak range research station, Qazvin Province.J. Environ. Erosion Res.2014;4(2):40–52.
47. Naghipour B., Haidarian A.M., Nasri M. An investigation of Carbon sequestration and plant biomass in modified rangeland communities (Case study: Sisab rangelands of Bojnord). Pajouhesh and Sazandegi. 2012; 25(1): 19–26.
48. Kolahchi N., Zahedi A.GH., Khorasani N. Carbon sequestration in shrubs, perennial grasses and soil in closed range (Heidare) of Hamedan. Pajouhesh and Sazandegi 2008; 80(1): 18-25.
49. Azad B., Afzali S.F. Evaluation of two soil Carbon models performance using measured data in semi-arid rangelands of Bajgah, Fars Province. Iran. J. Soil Water Res. 2019;50(4):819–835.
50. Kusi K.K., Khattabi A, Mhammdi N, Lahssini S. Prospective evaluation of the impact of land use change on ecosystem services in the Ourika Watershed, Morocco. Land Use Policy 2020; 97(1):104796.
51. Cademus R., Escobedo F.J., McLaughlin D., Abd-Elrahman A. Analyzing trade-offs, synergies, and drivers among timber production, Carbon sequestration, and water yield in Pinus elliotii forests in southeastern USA. Forests. 2014;5(6):1409–1431.
52. Ghoreyshi R., Motamedi J., Sheidai Karkaj E. Estimating economic value of Carbon sequestration services in rangelands with replacement cost method (Case study: Khoy Dizaj Batchy rangeland). Environ. Sci. 2014;12(2):55-64.
53. Rahimi L., Malekmohammadi B., Yavari A.R. The Ecosystem Services Assessment of Wetlands Based on the Classification of Hydrological-Ecological Structures and Functions (Case Study: Shadegan Wetland). Geogr. Environ. Sustain. 2019;9(1):51–72.

[DOI: DOI: 10.22034/ECOPERSIA.12.4.391]