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Assessing carbon storage and economic valuation of stocked carbon function based on land use/land cover using the InVEST model

Hajar Merrikhpour[1,2], Jalil Badamfirooz[3*], Ardavan Zarandian[4], Roya Mousazadeh[3]

[1]Civil, Water, and Environmental Engineering Faculty, Shahid Beheshti University, Tehran, Iran
[2]Department of Agriculture, Sayyed Jamaleddin Asadabadi University, Asadabad, Iran
[3]Research Group of Environmental Economics, Research Center for Environment and Sustainable Development (RCESD), Department of Environment, Tehran, Iran
[4]Research Group of Environmental Assessment and Risk, Research Center for Environment and Sustainable Development (RCESD), Department of Environment, Tehran, Iran

Abstract

Background: Forests are crucial for countering climate change as they store and sequester CO_2 from the atmosphere. This study aimed to prepare a detailed cost estimate and evaluate the cost efficiency of forest carbon storage within the Karkheh National Park and Karkheh Protected Area in southwestern Iran.

Methods: Carbon storage was assessed using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model based on land-use/land-cover (LULC) datasets from 2021. The economic valuation of the stored carbon function was performed using the replacement cost method. As *Populus euphratica* and *Tamarix* forests are the dominant LULC types in Karkheh National Park and Karkheh Protected Area, the highest carbon storage capacity in these areas was determined based on modelling outputs.

Results: The results indicated that the mean amounts of stored carbon were 2.9 t/ha in Karkheh Protected Area and 3.5 t/ha in Karkheh National Park. The total economic values of carbon sequestration in Karkheh National Park and Karkheh Protected Area were US$4.04 million and US$3.26 million, respectively. Furthermore, the estimated total value of the ecosystem service of carbon sequestration in Karkheh National Park and Karkheh Protected Area was US$7.3 million.

Conclusion: Valuing carbon stocks can be particularly effective for ecosystem services in protected areas. One problem in environmental planning is the lack of attention to carbon sequestration, which has led to the neglect of greenhouse gas emissions and their increasing rate.

Keywords: Carbon sequestration, Forest, Climate change, *Populus*, *Tamaricaceae*

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***Correspondence to:**
Jalil Badamfirooz,
Email: badam@rcesd.ac.ir

Introduction

Carbon sequestration, the long-term storage of carbon in natural ecosystems such as forests, grasslands, soil, and ocean biomass, or through artificial methods, is one of the important proposed solutions to reduce carbon in the atmosphere. Improving the carbon storage process in soil and plants of terrestrial ecosystems is the most promising option, as it increases Earth's productive capacity and stores atmospheric carbon dioxide in soil and plant reservoirs for the long term (1). Forests act as a carbon sink, absorbing 7.6 billion metric tons of CO_2 annually, and are essential to the global carbon cycle (2,3). Forests store about 45% of the organic carbon found in biomass and soil (4).

Unfortunately, the world's forests are being rapidly destroyed due to changes in land use and cover (LULC), which also affects soil organic carbon and accounts for about 25–30% of greenhouse gas emissions (5). By taking in CO_2 from the atmosphere and using photosynthesis to turn it into biomass, forests function as essential carbon sinks. Changes in land use from forests to other uses have adverse effects on terrestrial ecosystems, leading to increased carbon emissions and subsequent climate change and global warming (6). Humans are increasing atmospheric CO_2 levels through the use of fossil fuels, land-use changes, and deforestation, thereby affecting greenhouse gas emissions and contributing to global warming (7,8). Thus, increasing concerns about global warming and climate change have drawn researchers' attention to the importance of soil and its role in carbon sequestration (9).

Changes in soil organic carbon are among the most important indicators for assessing the impact of land-use changes on soil quality. The soil organic carbon stock is susceptible to land use and management (10), such that the type of land use and its management are considered the most important factors in the soil carbon sequestration capacity of the ecosystem (11), and soil organic carbon stock changes with land cover and land use change (12). Rapid urbanization worldwide in recent decades has encroached on vast tracts of ecological land, degrading around 60% of ecosystem functions and reducing the ecosystems' capacity to absorb carbon (13,14). It is well known that modifying and enhancing ecosystem structure, function, and local conditions can enhance ecological conservation and restoration, thereby increasing carbon storage (15,16). The quantity and distribution of ecological sources, corridors, and nodes have changed as a result of ecological conservation and restoration, affecting ecosystem services such as habitat preservation, forest and soil conservation, and so on (17,18).

A global climate shift has resulted from the escalating carbon emissions induced by human activities and changes in land use and land cover (19). This has garnered international attention.

Land-use change is considered the second most important source of carbon emissions into the atmosphere, after fossil fuels. Therefore, it is clear that land-use change driven by mismanagement is one of the main reasons for the emergence of the greenhouse effect and global warming in recent decades (20). To alleviate environmental burdens and facilitate policy development, it is advantageous to approximate the changes in ecosystem services resulting from LULC change (21,22). Huq et al (23), for instance, examined the dynamics of land use, tradeoffs between ecological services, and changes in economic values in the rapidly developing South of Bangladesh between 1973 and 2014. Rimal et al (24) evaluated how LULC change will affect ecosystem services, accounting for food production and biogeochemical carbon cycles. Ma et al (25) conducted a statistical analysis of land-use conversion in Central Asian inland lake wetlands from 2000 to 2015, illuminating the impact of LULC change on wetland ecosystems.

Scientists have developed several models to assess the ecosystem services (ES) of different land-use and land-cover (LULC) types. Among these, the most recent and sophisticated is the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model (26-28). This model potentially captures the dynamic relationship between alterations in the distribution of carbon storage and human activities (29,30). In order to evaluate carbon storage at the following spatial-temporal scales: global (31), national (32), provincial and municipal (33), and county and district (34), model analysis has already grown in importance over the last several years. The InVEST model has been widely used to evaluate how land-use changes in a given area affect carbon storage in ecosystems (35,36). Based on changes in land use in the Roman Province and the Morrissey area in central Italy, Sallustio et al (37) evaluated carbon stocks between 1990 and 2008. Eigenbrod et al's (38) simulation of land-use changes driven by urbanization in the UK enabled them to examine spatiotemporal changes in carbon stocks. The findings suggested that, over a given research period, carbon stocks in the UK will decline to varying degrees. Using the InVEST model, Muhammad Imran et al. (35) evaluated carbon stocks in mountain forests in the Karakoram Mountains' Bagrot Valley. Piyathilake et al (36) assessed land-use carbon stocks in the Kalu River Basin of Sri Lanka in 2020. They examined the contributions of various land uses to carbon stocks using the InVEST model. Chuai et al (39) assessed how land-use changes affected Jiangsu Province's carbon inventories using a holistic ecosystem approach to examine the impacts of different ecosystem components on carbon inventories. These studies show that the InVEST model provides a compelling regional perspective for characterizing carbon stocks (40,41).

Failure to consider and account for the valuation of ecosystem services, including carbon sequestration, in sustainable development management plans has led to various environmental harms, such as distortions in the carbon cycle, which can release even more greenhouse gases into the atmosphere. It is thus more crucial than ever to quantify these services and activities and assess their financial value. The lives of nearby populations may also be adversely affected by soil erosion, deteriorating water quality, and increased susceptibility to natural disasters resulting from the removal of plant cover (20).

Protected areas have been established around the world for a variety of reasons, with very different objectives and criteria (42), including the conservation of natural habitats and the preservation of biodiversity within them (43). They have been established to protect ecosystems, provide ecosystem services to animal and plant species, and serve social and cultural purposes (44). In defining protected areas, lands with high conservation value can be designated to preserve and restore natural and wildlife habitats (45).

The protected areas of Karkheh were officially recognized in 1970, and their key areas were designated as a national park under the management of the Environmental

Protection Organization in 2010. Karkhe National Park, or Karkhe Forest, is located in southwestern Iran. This park comprises three parts: South Karkhe National Park and North Karkhe National Park, with an area of 7476 hectares, and Karkhe Protected Land, totalling 8352 hectares (46). Our objectives are to (1) provide a comprehensive assessment of the carbon storage within Karkheh National Park and Karkheh Protected Area by employing the InVEST model in the year 2021, and (2) evaluate the cost efficiency of forest carbon storage, which was carried out through the replacement cost method.

Material and methods

Study area

The Karkheh River is located between 31°36' and 32°57' N latitude and 48°10' and 48°32'E longitude in southwestern Iran. The river flows through Karkheh National Park and Karkheh Protected Area. Karkheh National Park covers an area of 7739 ha, of which 1623 ha is located in the northern part and 6,116 ha in the southern part. The area of Karkheh Protected Area is 8352 ha (46). Figure 1 shows the location of the studied area.

The vegetation in the area is tropical forest, visible on both sides of the river. The area's topography is relatively uniform and changes little. The minimum altitude of the area is 24 meters, and its maximum is 99 meters, for a total altitude difference of 75 meters. From the perspective of soil conservation and soil erosion sensitivity, the study area is highly sensitive. Numerous signs of lateral river erosion along the Karkheh river bed indicate severe erosion in the area (47).

According to the Amberge climate classification, the Karkheh area has a hot mid-latitude desert climate with lengthy summers and short winters. The average annual temperature in the region is 23 °C and the average annual rainfall is 243 mm. The hot climate has caused intense evaporation in the region, with the basin's average annual pan evaporation at 3367 mm (47).

The vegetation in the Karkheh area consists of several types of trees, shrubs, and herbaceous plants, with desert poplar (*Populus euphratica*) and (*Tamarix*) as the principal tree species (46).

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model

The InVEST model uses maps such as land-use and various types of land-cover maps (48). It also incorporates data related to timber harvesting rates, postharvest waste

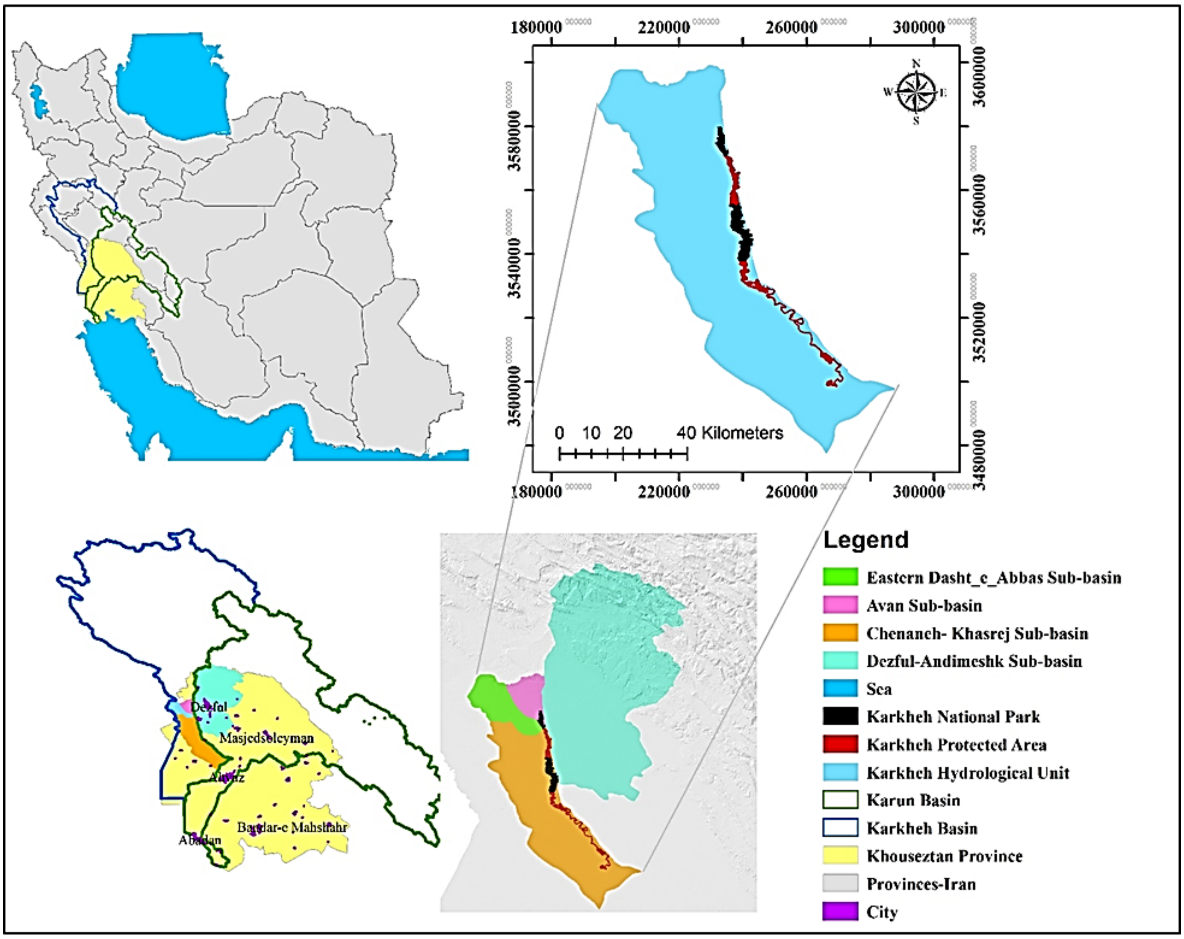

Figure 1. The location of Karkheh National Park and Karkheh Protected Area on the border of Karun and Karkheh watersheds

of crops, and carbon pools in the four leading sinks (aboveground biomass [AGB], below-ground biomass [BGB], soil, and dead organic matter) to estimate the amount of carbon stored in a landscape under current conditions and/or sequestered by that landscape over time.

This model calculates the net stored carbon in each land parcel over time by using LULC maps and the quantities of carbon stored in the carbon sinks. In addition, it calculates the total biomass removed from the harvesting areas in each parcel, as well as the market and social values of the sequestered carbon. The model is implemented on the network map, which is called the raster format in GIS. For each LULC type, the model requires the quantity of carbon stored in at least one of the four leading carbon sinks. The more data on a larger number of carbon sinks are provided to the user, the more complete the modelling results will be. The model also calculates the total biomass and wood volume removed from each parcel for the corresponding year. The total quantity of carbon in each raster cell, and hence in the entire area, is determined by summing up the quantities of carbon in all four carbon sinks. The model outputs are expressed in tons (Mg) of carbon per pixel (49).

Carbon stored in aboveground biomass (AGB)

The AGB consists of all living plants on the soil (bark, branches, trunk, and leaves). Few studies have been conducted in Iran to estimate biomass in scattered *Populus euphratica* and *Tamarix* forests. Most similar studies have focused on forests in the northern and western parts of the country. Zhang et al (50) used remote sensing data to estimate the biomass of *Populus euphratica* forest stands in China. Considering the volumetric mass of *Populus euphratica* trees in this country (0.74 t/m^3), the AGB (in aerial organs) of the trees was estimated to be in the 250–350 t/ha range (300 t/ha on average). In Iran, Calegari et al (51) estimated the mean annual diameter increment for desert poplar trees in Shushtar and Gotvand Counties, which are very close to the study area in the present research, to be 9.63 and 9.54 mm, respectively, and their approximate ages to be 35 and 36 years, respectively. In addition, the volumetric mass of *Populus euphratica* and *Tamarix* trees, the dominant species in the northern part of Karkheh National Park and Protected Area, has been reported in domestic research to be 0.35 t/m^3, which is almost half that reported in foreign research. Given the hot, dry climate of the study area and the year-round effect of water scarcity on diameter growth in these trees, the biomass of *Populus euphratica* and *Tamarix* in Iran is estimated to be considerably lower than in countries such as China.

If data and statistics are not available in studies on carbon sequestration, it is recommended that the public sources in reports published by the Intergovernmental Panel on Climate Change be used (52) as they are valid international references for this purpose. Forest stand volumes for the various types of natural forests across the ecological zones of different climatic regions are provided in the *2006 IPCC Report*. According to this report, the estimated forest stand volume in hot and dry forest systems (which experience winter precipitation but are dry in summer) in subtropical Asia is 130 t/ha on average (minimum 100 t/ha and maximum 160 t/ha). Given the above explanations and considering the climatic conditions in Iran, these values are close to the actual ones. Of course, these biomass values depend on the type of forest trees. As *Populus euphratica* and *Tamarix* are the dominant species in the study area, the provided values must be corrected using their volumetric mass factors. Since the reported values for the volumetric mass of *Populus euphratica* and *Tamarix* trees are 0.35 t/ha and 0.7 t/ha, respectively, the mean volumetric mass for them (0.52 t/ha) was multiplied by their forest stand volumes.

Carbon stored in below-ground biomass (BGB)

The BGB includes plant roots. In many studies, the quantity of BGB for various LULC classes is calculated as a ratio of BGB to AGB (the root/shoot ratio). In these studies, the BGB volume is typically taken to be one-fifth that of the AGB. Therefore, after calculating the AGB, 20% of it is considered to be the BGB (49).

Carbon stored as soil organic carbon in mineral layers

Soil organic matter includes the organic components of soil that are the indicator of the most significant carbon sink on land. In most studies on carbon, soil carbon is limited to soil organic carbon (SOC) in the mineral horizon. Of course, SOC in its organic horizon is also calculated separately by estimating carbon in litter and dead organic matter. In this regard, information and data have been obtained from previous studies conducted in the region (49).

Carbon stored in dead organic matter

The dead organic matter includes plant wastes and the remains of biomass constituents scattered as deadwood in landscapes (49). Dead organic matter mainly consists of litter and deadwood on forest trees. Based on available international references and the *IPCC Report* (52), the amount of stored carbon in forest litter in subtropical regions is about 3 t/ha. In addition, based on the studies by Delaney et al (53), the amount of deadwood on forest trees can usually be considered one-tenth of the AGB. The carbon stock in dead organic matter for non-forest and non-woody land cover types is considered to be zero (49).

Model database

The LULC map of the hydrological unit, Karkheh

National Park, and Karkheh Protected Area, and the data on carbon quantities in the carbon sinks were prepared as input for the model to estimate carbon storage and sequestration in the study area (49,53).

Economic Valuation

The replacement cost method, which uses the cost of preparing replacements for an ecosystem or its services to estimate the value of an ecosystem or its services, was used to estimate the value of the stocked carbon function.

For the cost-benefit analysis results to be reliable, the estimated values need to be adjusted for forecasted future price changes. This adjustment is done at two levels (54): 1) determining the present value: taking into account the opportunity cost of money, and 2) adjusting for inflation: adjusting for changes in price levels.

It is also necessary to correct the initial estimates of the cost-benefit analysis for changes in the price level over time, known as inflation adjustment. To adjust the current value of the dollar for expected future inflation, it must be converted to its nominal value at the desired time.

Nominal value means the determined value for the present time. The real value is the adjusted value that accounts for inflation. The following formula demonstrates the relationship between the nominal value and the real value (54):

$$Nominal\ value_{period\ x+1} = Real\ value_{period\ x} \times (1+p) \qquad (1)$$

where p is the inflation rate between time x and time $x+1$. If longer periods are desired, the formula will be in the following form:

$$Nominal\ value_{period\ x+t} = Real\ value_{period\ x} (1+p)^t \qquad (2)$$

The nominal value can be converted into the real value by inverting Equation 2:

$$Real\ value_{period\ x} = \frac{Nominal\ value_{period\ x+t}}{(1+p)^t} \qquad (3)$$

The nominal value of carbon sequestration in the study area can be converted into its real value using Equation 3. Then, the inflation adjustment is made. According to statistics published by the Central Bank of Iran and the Statistical Centre of Iran, the average inflation rate over the past 30 years was 19.8%. Since we intend to discount the estimated value over the next 30 years, we use the mean inflation rate over the past 30 years to make the inflation adjustment.

The net present value (NPV) depends on the net profit turnover in the base year (t) and the next year (ct), the period 0 of the studied discount (T), and the discount rate (r) as presented in the following formula (54):

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^1} = C_0 + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \frac{C_3}{(1+3)^3} + \ldots \qquad (4)$$

Results

LULC map

Figure 2 presents the LULC map of the Karkheh hydrological unit (55). Based on this map, a table of natural wealth and resources was prepared, showing the various LULC classes in the study area (Table 1) and the area of each LULC class (ha) along with its percentage distribution.

The information derived from the LULC map indicates that the main ecosystem structure in the study area comprises poor rangelands, rainfed lands, irrigated croplands, and middle-class rangelands, covering 21.97, 21.77, 14.13, and 14.02% of the study area, respectively. In addition, 10.06%, 6.29%, and 5.49% of the study area is covered by dune land, brushlands, and barren land, respectively. Only about 3.5% of the study area is covered with *Populus euphratica* and *Tamarix* trees, wetlands (0.43%), and water bodies (0.09%).

Quantities of carbon in the four leading carbon sinks

The estimated AGB obtained for the desert poplar forests in the study area was 67.6 t/ha (and 20% less, or 54 t/ha, for the brushlands). In converting metric ton AGB per hectare to metric ton carbon per hectare, many studies assume that 50% of the biomass dry weight equals the carbon content. In this research, the 0.46 factor, which is considered for hot and dry forests, was used. Therefore, the calculated AGB per hectare of *Populus euphratica* and *Tamarix* trees was 31 t/ha (and 24 t/ha for the brushlands).

The other agricultural lands in the study area are mainly used for growing alfalfa, clover, and corn, which are annual, herbaceous (non-woody) plants. The biomass in this non-woody vegetation is relatively transient, decomposing annually or every few years and being reproduced. Therefore, the emissions resulting from its decomposition are offset by vegetation regrowth, and the net carbon content remains constant in the long run. Hence, the AGB in this type of land use was not calculated. Similarly, it was not necessary to estimate biomass in the rangelands within the study area, as they consisted of annual herbaceous vegetation.

For forest cover classes in arid and semi-arid regions with above-ground biomass exceeding 20 tons per hectare, the ratio of BGB to AGB (root-to-shoot ratio) was considered to be 0.28. Therefore, the estimated BGB for the *Populus euphratica* and *Tamarix* forests in the study area was 19 t/ha. Hence, applying the 0.46 factor for converting the BGB to carbon (Mt/ha) in the mentioned forest cover, the estimated BGB was 9 t/ha (for brushlands, the estimated biomass was 15 t/ha, and the estimated carbon was 7 Mt/ha)

Stored organic carbon has been reported, and the effects of various land-use types on SOC in soils have been investigated in previous studies in Khuzestan Province (56). The quantity of organic carbon of soil at 0–15 cm

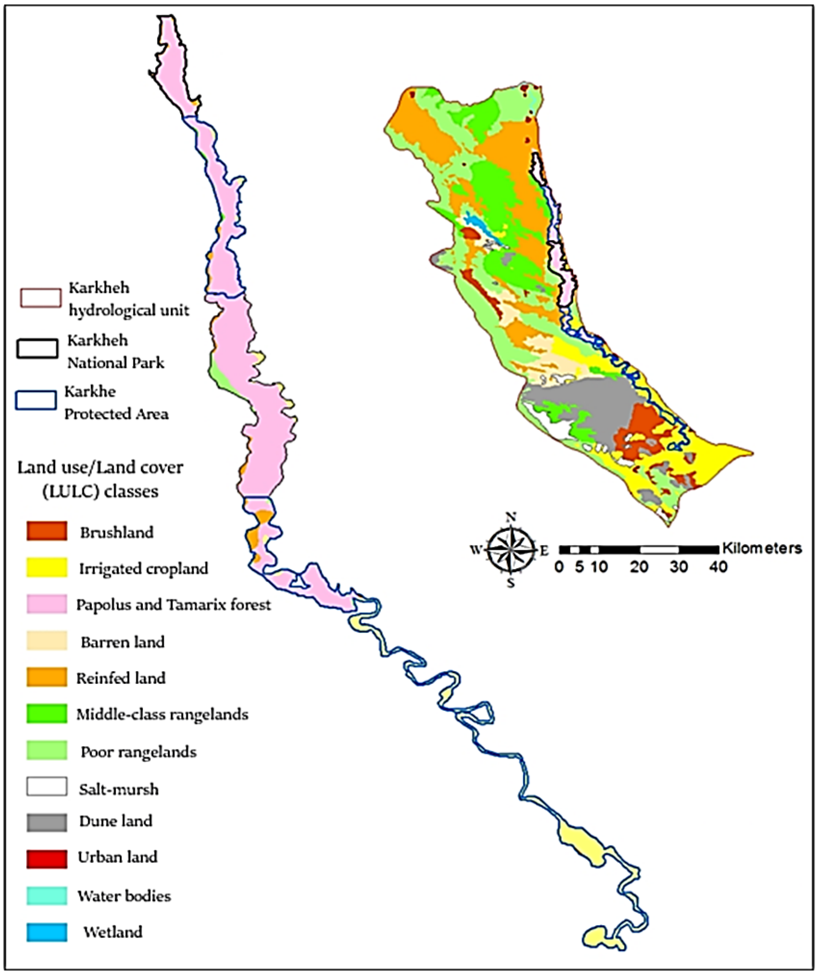

Figure 2. The land use/land cover (LULC) map of the Karkheh hydrological unit, National Park and Protected Area

depth in rangelands, shrublands, and croplands was about 30 t/ha (30 t/ha in medium rangelands and 20 t/ha in poor rangelands), 25 t/ha, and 20 t/ha, respectively (56). That data was also used in the study area in the present research. These data were also used in calculating carbon sequestration in the study area of the present research.

Consequently, the estimated quantity of biomass in dead organic matter (litter and deadwood) in *Populus euphratica* and *Tamarix* trees in the Karkheh region is about 7 t/ha. Its estimated stored carbon, considering the 0.46 factor for converting biomass into carbon, is 3 Mt/ha (for brushlands, the estimated amount of biomass is 1.5 t/ha and its carbon content is 0.69 Mt/ha).

Total carbon stored in the hydrological unit

Based on the prepared maps and the model's output data, the total carbon currently stored in Karkheh hydrological unit is 743,393,861 t. Because of the spatial distribution of stored carbon per hectare, it is in the 0–6 t range. The mean quantity of stored carbon throughout the hydrological unit is 1.89 t/ha. The study area was classified into seven classes based on carbon storage capacity to allow economic valuation of carbon sequestration, reflecting spatial differences in this capacity within the hydrological unit. The results are presented in Figure 3.

The mean amounts of stored carbon per hectare were 2.9 t/ha in Karkheh Protected Area and 3.5 t/ha in Karkheh National Park. The southern part of Karkheh Protected Area had a lower carbon sequestration capacity than the other three parts due to lower forest cover density. To perform an economic valuation of carbon sequestration based on spatial differences in carbon sequestration capacity within Karkheh Protected Area and Karkheh National Park, the study area was classified into seven classes based on their carbon storage capacity. The results are shown in Figure 4.

Economic valuation of carbon sequestration in the hydrological unit

The research results concerning the total amount of carbon stored in the hydrological unit are shown in Table 2. These findings indicate that the estimated total economic value of carbon sequestration in Karkheh hydrological unit was US$63.5 million (or US$179 per ha).

Economic value of carbon sequestration in Karkheh National Park and Karkheh Protected Area

Based on the research findings, the estimated total

Table 1. Various land-use/land-cover (LULC) classes in the Karkheh hydrological unit, Karkheh National Park and Karkheh Protected Area

land-use/land-cover (LULC)	Area (ha)	Area (%)
Karkheh hydrological unit		
Brushland	22233.04	6.29
Irrigated cropland	49378.14	14.13
Populus euphratica and *Tamarix* forest	12173.23	3.44
Baren land	19394.22	5.49
Rainfed land	76859.75	21.77
Middle-class rangeland	49490.71	14.02
Poor rangeland	75827.77	21.97
Salt-marsh	8660.39	2.45
Dune land	35525.46	10.06
Urban land	1033.85	0.29
Water bodies	341.11	0.09
Wetland	1525.66	0.43
Total	352943.33	100
Karkheh National Park		
Irrigated cropland	217.37	2.90
Populus euphratica and *Tamarix* forest	6773.76	90.63
Reinfed land	197.01	2.63
Middle-class rangeland	5.52	0.07
Poor rangeland	282.14	3.77
Total	7475.82	100
Karkheh Protected Area		
Brushland	26.089	0.31
Irrigated cropland	3325.25	39.83
Populus euphratica and *Tamarix* forest	4492.59	53.79
Reinfed land	398.85	4.77
Middle-class rangeland	60.30	0.72
Poor rangeland	38.51	0.46
Urban land	10.47	0.12
Total	8352.059	100

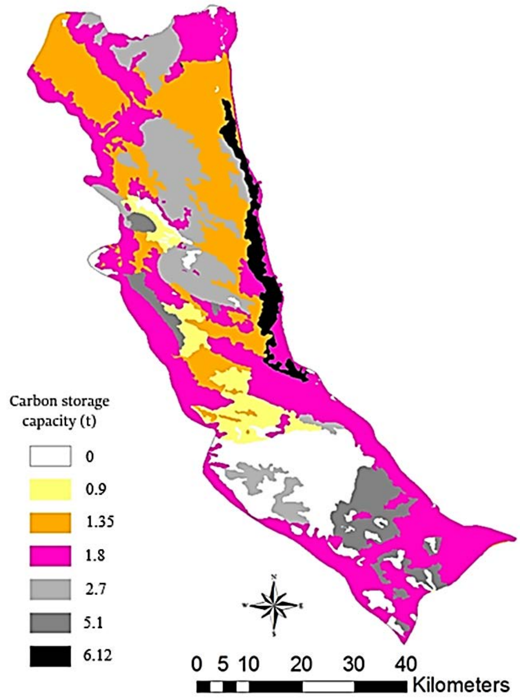

Figure 3. Carbon storage capacity (t) in Karkheh hydrological unit

amount of sequestered carbon for Karkheh National Park and Karkheh Protected Area is listed in Table 3. It shows that the estimated total economic value of carbon sequestration in Karkheh National Park was US$4.04 million (or US$541 per ha). The estimated total economic value of carbon sequestration in Karkheh Protected Area was US$3.26 million (or US$391 per ha) (Table 3). The estimated total value of the ecosystem service of carbon sequestration in Karkheh National Park and Protected Area was US$7.3 million.

The estimated real value of carbon sequestration in the entire Karkheh National Park and Karkheh Protected Area in 2019 was US$63.5 million. The estimated mean real value of carbon sequestration per hectare in the study area after inflation adjustment was US$387.5 (Table 4).

Table 5 presents the economic value of carbon sequestration in Karkheh National Park and Karkheh Protected Area in the next 5, 10, 15, and 30 years. Of course, since the values of each function in the study area for the mentioned future years are unknown, all current values are converted to future values for the next 5, 10, 15, and 30 years using the combination rate. The environmental discount rate in many international studies is 8%. However, given the prioritization of short-term exploitation of ecological resources over their sustainable use in Iran, it is expected that a higher rate will be adopted. Therefore, three scenarios with combination discount rates of 8, 12, and 16% were used to determine the values of the desired functions.

Given the forest's role in sequestering a significant portion of atmospheric carbon, estimating carbon sequestration capacity and its value can be an important step toward understanding the role of these functions in the country's economy and environment, and for familiarizing authorities and people with their importance.

Discussion

Carbon storage

As *Populus euphratica* and *Tamarix* forests are the dominant LULC in Karkheh National Park and Karkheh Protected Area, the highest carbon storage capacity in these areas was determined based on modelling outputs. According to Hu et al (57), the total change in carbon sequestration differs significantly among LULC types. Among the LULC types, forest land converted from cropland contributes the most to changes in carbon storage in their study area.

Previous research has shown a higher carbon density

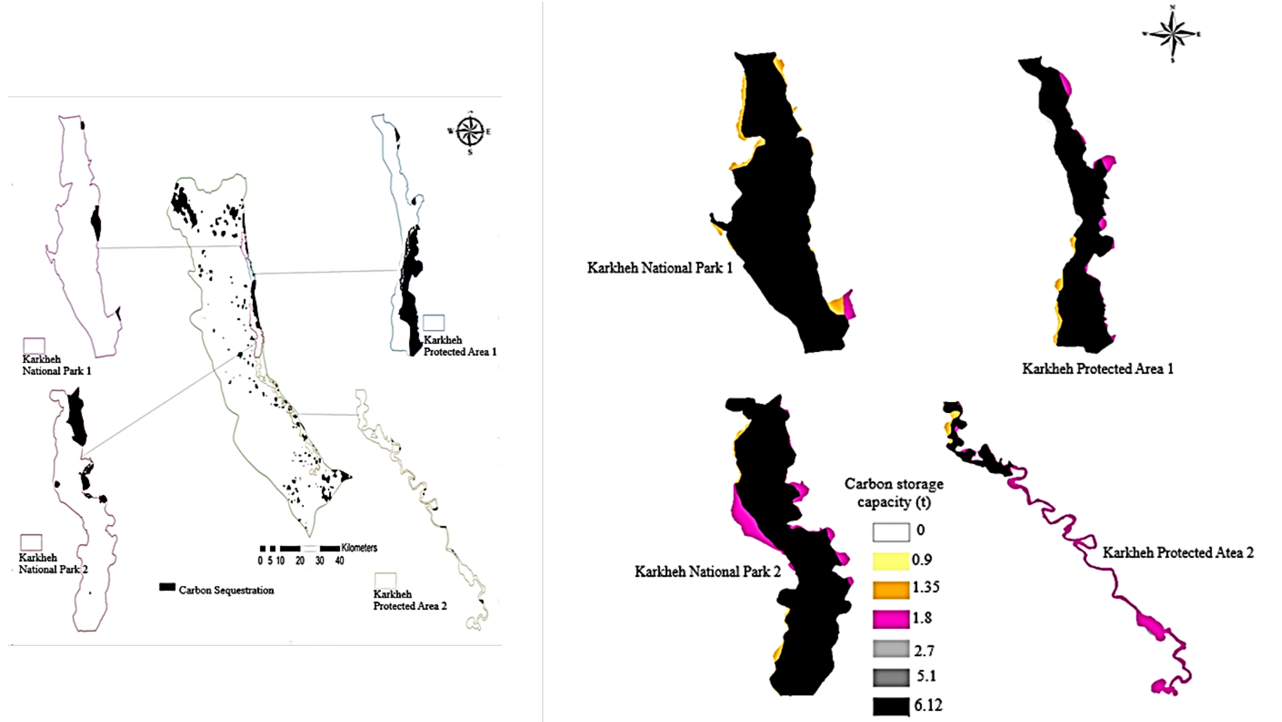

Figure 4. Carbon storage capacity (t) in Karkheh National Park and Karkheh Protected Area

Table 2. Total carbon (t/ha) stored in Karkheh hydrological unit

Carbon (t/ha)	Area (ha)	Total carbon (t)
0	47082.87	0
<0.9	19392.02	17452.82
0.9–1.35	76860.51	103761.69
1.35–1.8	125706.10	226270.98
1.8–2.7	49485.44	133610.69
2.7–5.1	22236.64	113406.86
5.1–6.12	12172.59	74496.25
Total		668998.6

Table 3. Total carbon (t/ha) stored in Karkheh National Park and Karkheh Protected Area

Carbon (t/ha)	Area (ha)	Total carbon (t)
Karkheh National Park		
<1.35	196.84	265.76
1.35–1.8	499.00	898.2
1.8–2.7	5.56	15.01
2.7–6.12	6773.33	41452.78
Total		42631.72
Karkheh Protected Area		
0	10.60	0
<1.35	397.52	536.65
1.35–1.8	3361.94	6051.5
1.8–2.7	59.48	160.6
2.7–5.1	26.52	135.25
5.1–6.12	4494.58	27506.83
Total	34390.83	

in highly vegetated regions, consistent with the current results (58-61). Additionally, this result is consistent with that of Islam et al (62), who found that the loss of hilly plant cover in Chittagong decreased the region's potential to sequester carbon. According to analyses of changes in carbon storage, the ability to absorb carbon was reduced by the loss of plant cover and by the expansion of built-up and agricultural land. According to Rasul (63), the CHT area of Bangladesh is losing ecosystem services, including carbon sequestration, scenic beauty, water conservation, and biodiversity preservation, due to agricultural land-use practices. It is important to use sustainable farming methods to lessen the negative impact of LULC changes on carbon sequestration.

Deforestation, driven by factors including logging, infrastructure development, and agricultural expansion, is one potential explanation for the decrease in carbon storage in vegetated regions (3). Loss of plant cover and hence a decrease in the ability to store carbon may also be caused by logging for wood and other forest products. Increased carbon emissions from built-up regions may result from infrastructure development, such as road building and urbanization, which can worsen the loss of vegetated areas.

Furthermore, the increased frequency and intensity of extreme weather events, such as storms, floods, and landslides, may destroy vegetation and reduce the amount of carbon stored in the atmosphere (3). Nogueira et al (64) observed that deforestation caused a 2.3% reduction

Table 4. The value of the annual flow of carbon sequestration in Karkheh National Park and Karkheh Protected Area (2021)

Nominal value of the entire area* (US$ million)	The real value of the entire area** (US$ million)	Mean real value per hectare (US$ million)
7.3	7.3 ÷ (1 + 0.198) = 6.1	0.38

*Total estimated value of carbon sequestration for Karkheh National Park and Karkheh Protected Area
**Adjusted for inflation based on Equation 3

Table 5. The economic value of carbon sequestration in Karkheh National Park and Karkheh Protected Area in the next 5, 10, 15 and 30 years (US$ million)

Period (year)	Discount rate (%)	Value per hectare (US$)	Total net present value (NPV) (US$ million)
5	8	566.6	8.9
	12	683.3	10.7
	15	779.1	12.2
10	8	833.3	13.1
	12	1208.3	18.9
	15	1570.8	24.6
15	8	1229.1	19.3
	12	2125.0	33.3
	15	3162.5	49.6
30	8	3912.5	61.3
	12	11650	182.7
	15	25750	403.9

in carbon stocks in 2014, despite being contained within protected areas in the Brazilian Amazon. Consequently, the establishment of conservation units ought to be complemented by enhanced inspection effectiveness by the governing bodies.

Economic valuation

High-benefit target regions are identified by comparing benefit-to-cost ratios between protected and unprotected lands in benefit-targeting studies (65-68). This method implicitly assumes that the costs of creating protected zones are comparable. The need to combine establishment costs and benefits when choosing places to target for protection is shown by the significant cost variance across potential protected zones (69-73). Carbon sequestration is likely more valuable than other ecosystem services, since Brander et al (74) reported median worldwide ecosystem values of \$150 ha^{-1} yr^{-1} or \$200 ha^{-1} yr^{-1} in North America (without carbon sequestration) (75). Costanza et al (76) have demonstrated that ecosystems are economically valuable not only for the environmental goods they produce and trade (such as timber), but also for the services they provide that directly and indirectly improve human well-being, including flood control, soil formation, carbon sequestration, and water provisioning. The *Millennium Ecosystem Assessment* (77) shows that the total economic value of sustainable ecosystem management is much greater than the income generated from converting natural ecosystems to agriculture or other intensive uses. Costanza et al (76) have indicated that the total economic value of ecosystem services provided by existing ecosystems worldwide could exceed the global gross domestic product. The average carbon stocks in the Caatinga biome in 1997 were valued at US$20.4 billion (ranging from US$11.9 billion to US$34.8 billion), according to Ricke et al's (78) estimate of the social cost of carbon for Brazil. Fernandes et al (79) claim that the biome with the highest carbon stocks per hectare (80) was the Atlantic Forest. It was the only one to show increases in carbon stocks, with values ranging from US$1.0 billion to US$3.0 billion in 2017 (minimum of US$965.1 million and maximum of US$2.8 billion) and from US$1.7 billion to US$2.8 billion in 1997 (minimum of US$965.1 million and maximum of US$2.8 billion). Even though there is little native flora in the investigated region, the ecosystem services associated with carbon stocks have increased annually by around US$100 million. Saraiva Farinha et al (81) demonstrated that there are two ways to assess the economic value of natural capital and ecosystem services, which may help policymakers create LULC plans and policies: opportunity costs and societal knowledge. Data from economic valuation might encourage the adoption of novel environmental policy instruments and help formulate policies better suited to the research location (82). However, the advantages and disadvantages of paying for carbon storage in forests may both lead to confusion. For instance, climate change and meteorological patterns can influence forest biomass development, thereby impacting carbon sinks (83). The dynamics of carbon sequestration raise concerns about permanence, as carbon sinks may be vulnerable to risks such as natural disasters, human intervention, and contractually constrained payment terms (84).

Conclusion

Carbon stocks have decreased due to the loss of natural areas and forest cover over the last two decades. Adding additional conservation units would be an alternative to the LULC alterations and decreased forest cover that are causing the Karkheh National Park to lose carbon stock.

The mean amounts of stored carbon per hectare in the Karkheh Protected Area and Karkheh National Park were 2.9 and 3.5 t/ha, respectively. The total economic values of carbon sequestration in Karkheh National Park and Karkheh Protected Area were US$4.04 million and US$3.26 million, respectively. Furthermore, the estimated total value of the ecosystem service of carbon sequestration in Karkheh National Park and Protected

Area was US$7.3 million.

Creating and implementing focused policies and management plans that support sustainable land-use practices, preserve and restore vegetated areas, and enhance Karkheh National Park's capacity to store carbon dioxide are essential to addressing these issues. This might include creating protected areas, encouraging agroforestry systems, and afforestation and reforestation initiatives. Moreover, promoting the significance of CSs and their role in mitigating the effects of climate change might help gain support for conservation and restoration initiatives.

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Authors' contributions

Conceptualization: Jalil Badamfirooz, Ardavan Zarandian, and Hajar Merrikhpour
Data curation: Hajar Merrikhpour and Jalil Badamfirooz
Formal Analysis: Ardavan Zarandian and Roya Mousazadeh
Funding acquisition: Jalil Badamfirooz
Investigation: Jalil Badamfirooz, Ardavan Zarandian, Hajar Merrikhpour, and Roya Mousazadeh
Methodology: Ardavan Zarandian and Hajar Merrikhpour
Project administration: Jalil Badamfirooz
Resources: Hajar Merrikhpour and Roya Mousazadeh
Software: Ardavan Zarandian
Supervision: Jalil Badamfirooz
Validation: Ardavan Zarandian and Roya Mousazadeh
Visualization: Ardavan Zarandian and Hajar Merrikhpour
Writing – original draft: Jalil Badamfirooz
Writing – review & editing: Hajar Merrikhpour

Competing interests

The authors reported no potential conflict of interest.

Ethical issues

Ethical approval was not required for the present study.

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