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Economic Valuation and Modeling of Multiple Threats to Water and Soil Resources using the WaterWorld Policy Support System in Karkheh National Park - Southwestern Iran

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ABSTRACT

Aims: This study aims to economically value and assess multiple threats to the water and soil resources of the Karkheh National Park and Karkheh Protected Area in the southwest of Iran.

Materials & Methods: Modeling water budget, runoff, soil erosion, and water pollution potential was performed using the WaterWorld Policy Support System (WWPSS), a process-based hydrological model that utilizes remotely sensed and globally available. The economic value has been calculated using the Substitute Cost Method for 2021.

Findings: The result showed that the southern area of the Karkheh River basin experienced the minimum precipitation, which has led to a decrease in vegetation and an increase in runoff generation in the southern areas. The total runoff generated in the river basin is based on the upstream-downstream relationships from the north to the south, estimated at 81000648 $m^3.yr^{-1}$. The soil erosion rate spiked in the southern area with the decline of vegetation, and the intensification of runoff could result in water pollution. Economic valuation represents the actual value of water generation in the whole Karkheh National Park and Protected Area, which was US$ 0.104 million, estimated at US$ 6.63 per hectare. In addition, the soil conservation economic value in the entire Karkheh National Park and Protected Area was US$ 9.3 million and US$ 912.2 per hectare.

Conclusion: This information provides valuable awareness of the economic value of natural resources and can help environmental assessors' in their activities related to conservation planning. It is a valuable tool for emphasizing the economic implications of ecosystem degradation and can help with sustainable management.

Keywords: Economic Valuation; Karkheh National Park; Soil Conservation; Water Budget; Water World Policy Support System.

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Introduction

The watershed functions as a dynamic ecosystem, susceptible to various environmental disruptions that induce alterations in its characteristics. Resource overexploitation has diminished the land's capacity to support populations worldwide, resulting in biodiversity depletion and natural processes' detriment. This has led to various issues affecting watersheds, including flooding, drought, population growth, and air pollution [1, 2]. Preserving environmental health is crucial for the sustained well-being of ecosystems, carrying significant social and economic implications. Decision-makers at multiple management levels recognize its importance as an innovative approach to environmental and watershed management [3,6]. In the literature, initial attention was directed towards addressing the health of aquatic ecosystems, given that the impact of damage in such ecosystems is immediate and conspicuous compared to terrestrial ecosystems. The need to analyze the health of specific components such as soil, air, and water has also been recognized. Consequently, the perspective on ecosystem health issues has evolved in recent years, transitioning from one-dimensional assessments to comprehensive, multi-dimensional evaluations [7, 8].

Various techniques have been proposed for assessing the health of ecosystems and watersheds, encompassing approaches like network analysis, the health distance model, the evaluation of optimal functional conditions, and conceptual models. Hydrological models play a crucial role in water management, possessing synthetic, analytical, and predictive capabilities that enhance the evaluation and optimization of complex management options across various scales and purposes [9]. Recent advancements in watershed pollution mechanism research and geographic information systems have improved data availability and spatial resolution models. Understanding the characteristics and limitations of these models with diverse structures and complexities is essential for selecting appropriate models based on the study area's characteristics [10]. Over the past two decades, hydrological models have evolved to become more complex, explicitly considering spatial heterogeneity and biogeochemical cycles and more integrated, incorporating elements such as vegetation, soil, topography, and atmosphere. The rapid progress of supercomputers, cloud-based storage and computing, remote sensing technology, and Earth information systems in the last ten years enables detailed watershed representations and hydrological modeling at finer scales, ranging from large basins, e.g., RHESSys model [11], WRF-Hydro [12] to the global scale, e.g., WaterWorld [13]. The WaterWorld Policy Support System (WWPSS) www.policysupport.org/waterworld) is a spatially explicit, physically-based, globally applicable model for baseline and scenario water balance. Particularly suitable for heterogeneous environments with limited locally available data, it is delivered through a user-friendly web interface, requiring minimal local capacity. The model generates a hydrological baseline representing the mean water balance, allowing the examination of impacts from population, climate, and land-use changes, as well as land and water management interventions on hydrology [14]. It incorporates scenario tools for climate and land-use changes and policy option/intervention tools for land management, utilizing global data at resolutions of 10 km, 1 km, and 1 ha [15]. Based on evapotranspiration and runoff for 1950–2000 at a monthly resolution, the baseline can be compared to modeled scenario runs to test water resource policies under land-use, land management, and climate change.

WaterWorld evaluates the Human Footprint on Water Quality (HFWQ) as a proxy for water contamination [16]. HFWQ calculates potential water quality, representing the parameter-independent accumulation of upstream influences from point and non-point sources of contamination.

The WWPSS comprises spatial models integrating biophysical and socio-economic processes, offering climate, land-use, and economic change scenarios. It provides a range of interventions (policy options) that can be implemented, and their consequences can be traced through socio-economic and biophysical systems. This model has been widely employed in numerous international studies to simulate and analyze vegetation changes in hydrological conditions, droughts, and climate change [13, 17,21]. Birch et al. [22] utilized the WWPSS model to assess fundamental hydrological conditions and the impacts of land-use change in the Himalayan Jungles in Nepal, employing a 1-hectare resolution. Their focus was mainly on using the model's outputs to identify changes related to soil erosion and sediment load (as indicators of water quality) and the annual water budget (as an indicator of water generation). Van Souesbergen [23] applied the WWPSS model to evaluate the effects of various threats, including climate change, deforestation, population growth, petroleum extraction, and mining, on water security in the Amazon Jungles in Peru.

The assessment was conducted from the perspective of impacts on water quality and quantity. Building on the established correlation between social and economic activities, pollutant discharge, and water quality, it is imperative to propose an advanced cost-benefit system for water pollution control in lake basins. The linear programming method is currently used to formulate and select the optimal scheme [24, 25]. Generally, the approach to water pollution prevention and control has shifted from emphasizing terminal treatment to placing greater emphasis on pollution prevention and comprehensive process control. Implementing pollution prevention and control measures can profoundly alter a watershed's economic structure and developmental trajectory. Simultaneously, changes in the socio-economic landscape will impact the prevention and control of water pollution in the watershed. The interplay between the environmental and economic subsystems will give rise to intricate changes [26].

Ecosystem valuation is essential in understanding and quantifying the economic value of natural resources and ecosystem services. As the world faces rising environmental deterioration and resource depletion, it shows the advantages of assessing and accounting for the value of ecosystems in sustainable management. Ecosystem valuation supplies a structure to evaluate the advantages gained from ecosystems, helping policymakers, economists, and stakeholders create enlightened options concerning environmental management and conservation. By allocating economic values to ecosystem parameters, the method passes over the gap between environmental conservation and economic development. It illustrates the association between good physical condition ecosystems and human health.

The selection of the valuation method is subject to several things, such as the property and nature of the considered results, the availability of essential features, specialist sight, time, and accessible reservoir. The Substitute Cost Method provides various superiority in ecosystem valuation. First, it produces a real and relatable metric for policymakers and economists, as it expresses the utility of ecosystem parameters in financial expressions. This simplifies the differences between ecosystem parameters and other economic features, helping in cost-benefit inspections and decision-making activities. Moreover, the method enables the recognition of trade-offs between natural ecosystems and human-made options, giving awareness of the future advantages and costs of different management choices. In this study, the economic value of water and soil resources was calculated using the Substitute Cost Method after determining the water budget and the amount of soil erosion using the WWPSS model. Since the economic valuation studies of environmental resources estimate the net present value (NPV) of ecosystem goods and services, the value of the ecosystem of the studied area at the time of conducting the study (2021) has been estimated. Then, to determine the value of the desired functions in the future, the economic value for the next 5, 10, 15, and 30 years with discount (compound) rates of 8, 12, and 15% has been calculated.

During the past decades, numerous research studies have been carried out on the physical and utility quality of natural ecosystems, and they have focused attention on their value. Protected areas are established to keep the ecosystem and supply services to the animal and plant species of the ecosystem with community-based points. Protected areas provide a range of ecosystem services, including biodiversity conservation. Protected areas display a severe impression of the human community [27]. These zones protect the natural and ethnic inheritance and guarantee ecological stability. Some of these regions have a high-risk potential owing to their ecological considerations; consequently, the conservation and continuous recording of the variations in the protected areas, considered national natural resources of any country, is required with proper management methods.

Karkheh National Park and Karkheh Protected Area is located southwest of Iran. Karkheh forests are one of the last remaining subtropical forests in the world. With more than 50 years of management history as a protected area, the presence of a rare species of Iranian yellow deer, and the presence of the Karkheh River in this region, the Karkheh region is considered one of the most valuable ecosystems in Iran. Identifying the economic value of the resources of this region and their importance is necessary. A novel standpoint in this research is to utilize a self-parameterizing physically based model, which can supply complete spatial datasets at several ecological scales, such as river basins, for quick quantitative environmental evaluations. Its major novelty includes the studied area's economic value via the Substitute Cost Method. Therefore, our goals include (1) an assessment of the water budget, runoff, soil erosion, and water pollution potential within the Karkheh National Park and Karkheh Protected Area, using the WWPSS model in the year 2021, and (2) economic value of water and soil resources, accomplished through the Substitute Cost Method.

Material & Methods

Study Area

The Karkheh basin is located in the southwest of Iran, between 30° 58′ to 34° 56′ N latitude and 46° 06′ to 49° 10′ E longitude (Figure 1). It covers an area of about 50700 km^2.

The Karkheh River passes through Karkheh National Park and Karkheh Protected Area, located between 31° 36'-32° 57' N latitude and 48° 10'- 48°32'E longitude (Figure 1). Karkheh National Park consists of a northern part (1623 ha) and a southern part (5852 ha), while the Karkheh Protected Area covers an area of 8352 hectares. Tropical forests surrounding the river have grown on both sides of the study area. No significant topographic changes are observed in this area. In addition, no specific and considerable plains are observed either, due to the narrow width of the area that stretches as a narrow strip along the margins of the Karkheh River amidst the vast plain of agricultural lands. The altitude in the area ranges from 24 to 99 m with a total elevation difference of 75 m. Regarding erosion susceptibility, the Karkheh study area is classified as highly sensitive to erosion, with abundant signs of lateral river erosion observed along the margins of the Karkheh river bed .Based on the Amberje climate classification, the study area has a hot mid-latitude desert climate with long summers and short winters. The mean annual temperature and precipitation are 23°C and 243 mm, respectively. Due to the hot climate, the mean annual pan evaporation is 3367 mm.

WaterWorld Policy Support System (WWPSS)

Assessment of the hydrological condition and ecology of the Karkheh River basin (Figure 1) was provided using the WWPSS model. There are five stages to track when operating WWPSS for modeling ecosystem features. The first stage is to clarify the studied area at a resolution of 1 km^2 or 1 ha. The second includes providing the data (www. policysupport. org). The third is to drive the baseline simulation. The last step is to use all the scenario choices to assess possibilities. Finally, the results are interrogated in maps, graphs, or an explanation of the outcomes promoted by the model.

The water budget is determined by calculating the wind-driven precipitation aggregated with fog and then subtracting the real evapotranspiration rate from those two values based on climatic information and data on vegetation obtained from remote sensing. The difference between precipitation and wind-driven precipitation refers to the effect of wind speed on precipitation distribution in an area, as the areas exposed to the wind flow receive further precipitation. Moreover, the effects of snowing and freezing on precipitation and temperature will be simulated in addition to the amount of water resulting from melting snow and ice. Calculating the water budget and runoff (*i.e.*, surface water flow) is one of the main methods of estimating water generation in

Table 1) The key maps of the ecosystem water services as the WWPSS outputs.

Ecosystem Water Service Map	**Description**
Precipitation	The total annual precipitation (wind-driven precipitation) (mm.yr^{-1})
Water Balance	Water balance on a local scale (mm.yr^{-1}) (precipitation + fog + melted snow and ice) – (actual evapotranspiration)
Runoff	Total annual runoff (m^3.yr^{-1}) Runoff is calculated as the water balance accumulated in a downstream area. A cell's negative water balance (AET> precipitation) means the runoff consumed in an upstream area.
Net Erosion Caused by the Hill Slopes	The net erosion is erosion minus the sediment accumulated in the hill slopes (mm.yr^{-1})
Total net erosion	The total net erosion is erosion minus the sediment accumulated in hill slopes and water channels, including streams and rivers (mm.yr^{-1})
Mean Human Footprint in Water Quality (Pollution)	The mean percentage of water that can be polluted (human footprint water quality index)

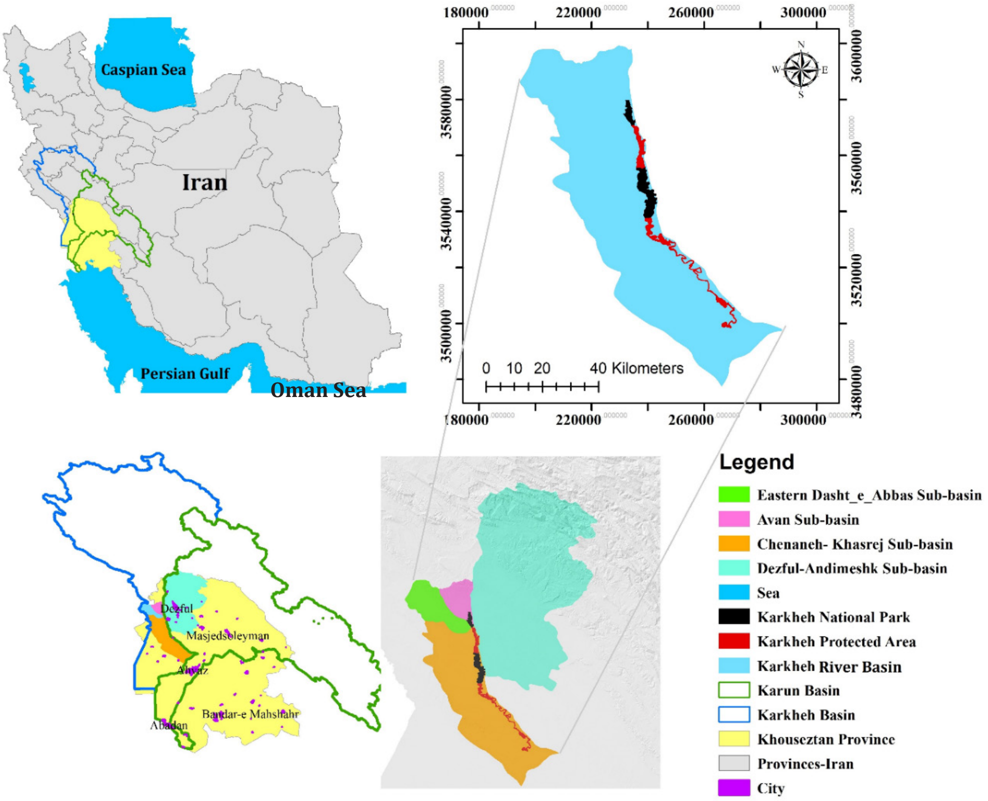

Figure 1) The geographical location of the Karkheh River basin, Karkheh National Park, and Karkheh Protected Area in South Western Iran.

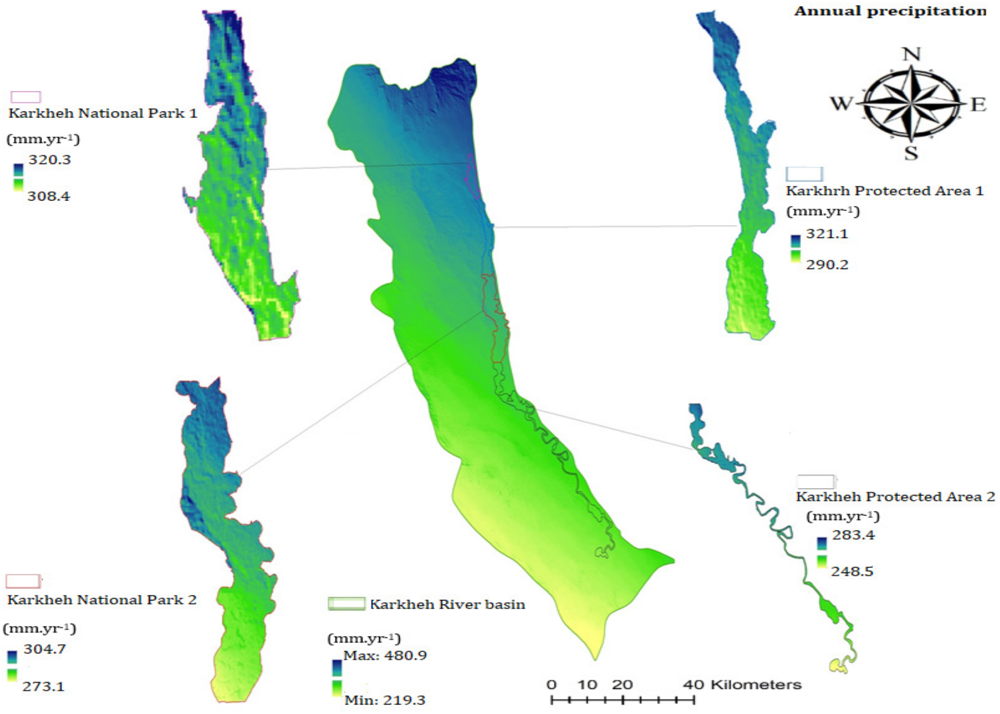

Figure 2) Annual precipitation (mm.yr^{-1}) map of Karkheh River basin, Karkheh National Park, and Karkheh Protected Area based on WWPSS model output.

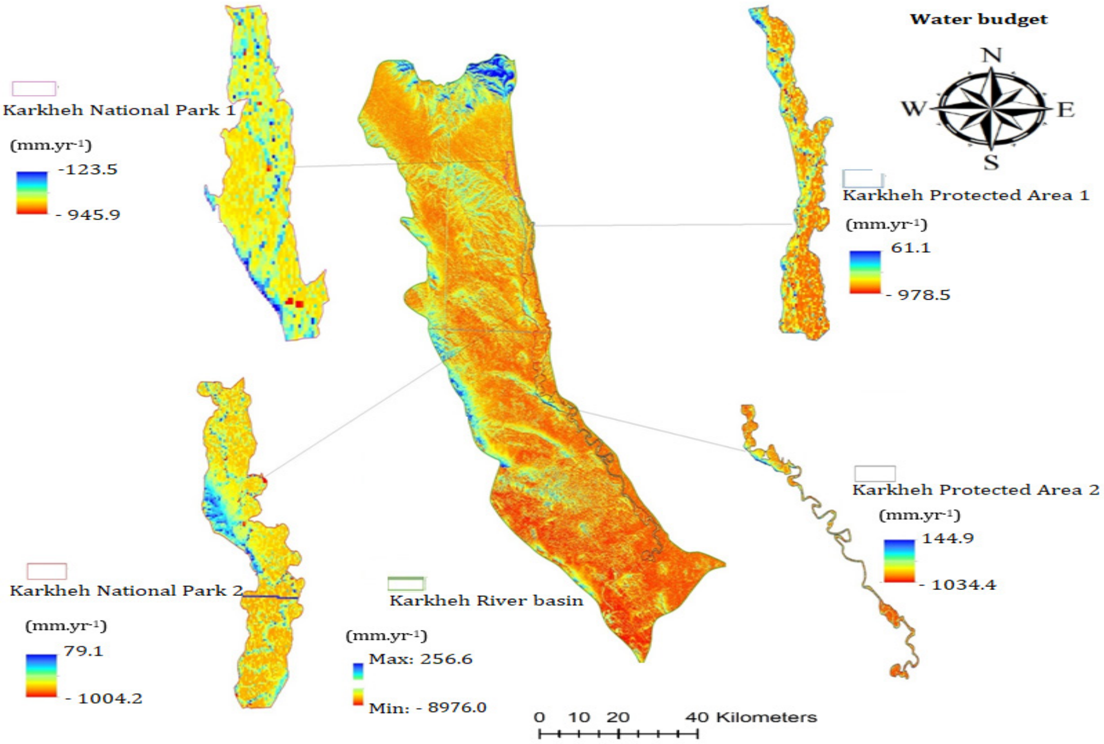

Figure 3) Water budget (mm.yr^{-1}) map of Karkheh River basin, Karkheh National Park, and Karkheh Protected Area based on WWPSS model output.

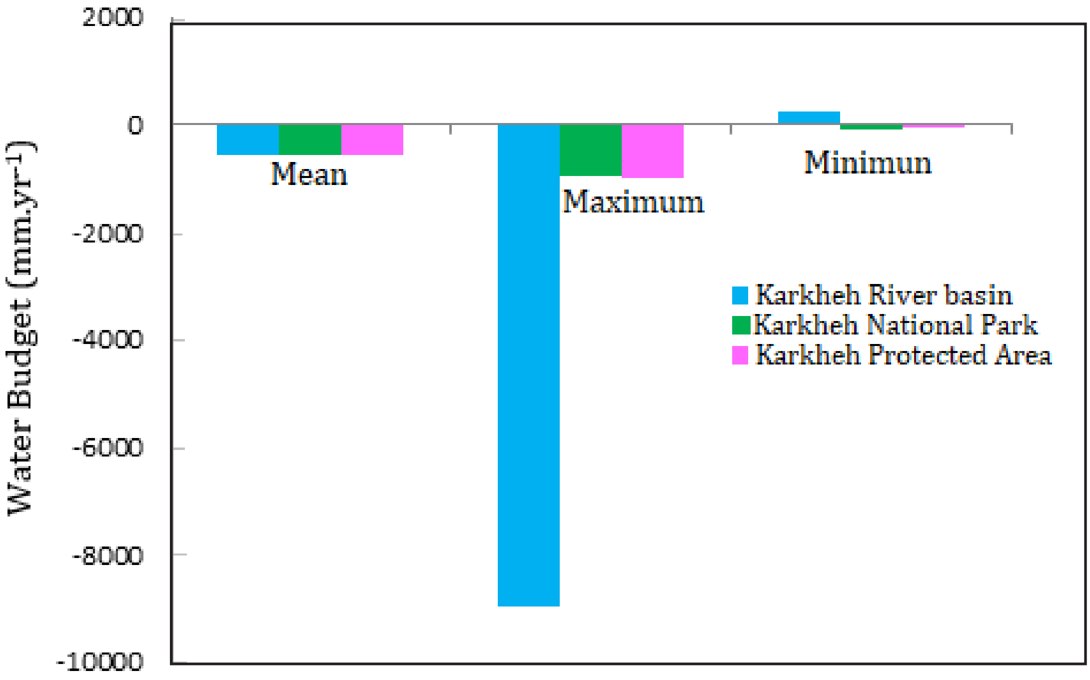

Figure 4) Comparison of mean, maximum, and minimum water budget (mm.yr^{-1}) in Karkheh River basin, Karkheh National Park, and Karkheh Protected Area.

an ecosystem. The water budget comes from a network flow of different height levels from an upstream area to a downstream area. Hence, the WWPSS model simulates the ground components of a water cycle, not its atmospheric components. Accordingly, this model does not aim to simulate precipitation variations based on evapotranspiration change.

Model calculate the annual water product, Y(x), for every pixel in landscape x according Eq. (1):

$$Y(x)=\left(1-\frac{AET(x)}{P(x)}\right).P(x) \qquad \text{Eq. (1)}$$

where AET (x) is the actual annual evapotranspiration for pixel x, and P (x) is the annual precipitation at pixel x. In areas with vegetation, the share of evapotranspiration in the water budget, $\frac{AET(x)}{\mathrm{P}(x)}$, is considered through the Budyko curve [29,30] (Eq. 2):

$$\frac{AET(x)}{P(x)}=1+\frac{PET(x)}{P(x)}-\left[1+(\frac{PET(x)}{P(x)})^{\omega}\right]^{1/\omega}$$

Eq. (2)

where PET (x) is the evapotranspiration potential, and $\omega(x)$ is a nonphysical parameter concerning the climatic-soil features. In detail, the evapotranspiration potential is defined as below (Eq. 3):

$$PET(x)=K_c(\ell_x).ET_0(x) \qquad \text{Eq. (3)}$$

where ET_0 (x) is the reference evapotranspiration in pixel x, $K_c(\ell_x)$ is the coefficient of the plant evapotranspiration (vegetation) about the vegetation/use of ℓ_x in pixel x, and $ET_0(x)$ is the local climatic conditions based on evapotranspiration from vegetation grown on the site. $K_c(\ell_x)$ depends significantly on the vegetation features in the vegetation/use of a pixel. In addition, $\mathrm{K_c}$ moderates or corrects the value of $\mathrm{ET_0}$ for a crop or vegetation type in each vegetation/use map pixel.

The WWPSS model can also evaluate some hydrological functions of quality/regulation concerning water, *e.g.*, impure soil erosion and sediment. This model calculates soil erosion through the Equation of Thornes [31] (Eq. 4).

$$E=kQ^2S^{1.67}e^{-0.07V_c} \qquad \text{Eq. (4)}$$

where *E* is erosion ($\mathrm{mm.h^{-1}}$), and *k* is the soil erodibility coefficient, considered the constant value of 0.2 because its information is unavailable. *Q* is the runoff ($\mathrm{mm.h^{-1}}$) taken from the FIESTA model connected to the WWPSS, S is the tangent of the slope gradient, which is taken from the digital height model of SRTM, and $\mathrm{V_c}$ is the vegetation obtained from the MODIS VCF on images captured by the Landsat (2000–2005).

The sediment transport is determined by the transport capacity ($\mathrm{T_c}$), calculated by the flow power as a function of runoff and slope (Eq. 5).

$$T_cQ^{1.7}sin(S)^{0.001}(1-V_c) \qquad \text{Eq. (5)}$$

Sediment transport (S) is a function of the upstream sediment input plus local erosion, and P is considered when the sediment input and erosion are lower than the transport capacity. Finally, sedimentation occurs in places (areas) where S is greater than or equal to P.

The model yields two key outputs for calculating soil erosion: net soil erosion caused by the hill slopes and net soil erosion (erosion minus sedimentation). Erosion refers to damaged soil, whereas sedimentation refers to the amount of soil accumulated in each cell of the raster network. Net erosion indicates soil volume that enters water flows and rivers as sediment.

Soil erosion, which results from water flows and rivers, indicates the final value of net soil erosion in hills. In this model, the rate of erosion is calculated in mm $m^{-2}.yr^{-1}$. To calculate the weight of the eroded soil, the soil bulk density is considered 1.2 - 1.7 $t.m^{-2}$. To execute the model, the software first defined its geographical limits by matching the boundaries of areas defined for the hydrological unit of the Karkheh on four 1º mosaics (100 km) with a one-hectare resolution. The key maps were then generated (Table 1) through data preparation and simulation, considered the two primary steps in the model implementation process. Traditional validation methods pose significant challenges in the context of validation output data of the WWPSS model. The primary purpose of the WWPSS model is to provide rapid environmental assessment in data-scarce regions with limited technical expertise to conduct hydrological calculations, a cost-effective assessment in cases where data is unavailable for baseline ecosystem conditions. To address this, we employed several alternative validation approaches, compared the model outputs with those from other established hydrological models to check for consistency, consulted with local hydrologists and ecologists to evaluate the plausibility of our model predictions, using field observations and stakeholder feedback provided additional support for the model's predictions.

Economic Valuation Methods

Revealed Preferences

Revealed preference (RP) methods mention various valuation methods promoting that many (non-market) environmental properties and favors are entirely dealt with in markets. This allows RP methods to reveal

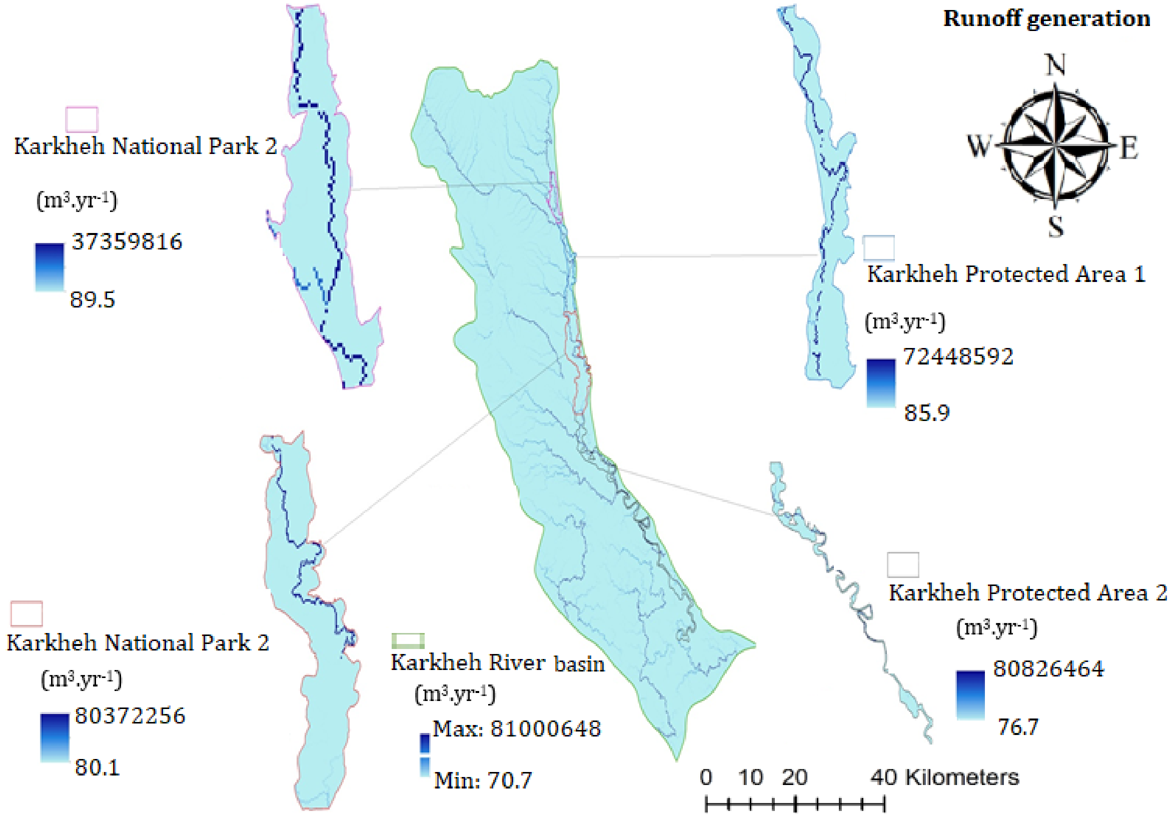

Figure 5) Runoff generation ($m^3.yr^{-1}$) map of Karkheh River basin, Karkheh National Park, and Karkheh Protected Area based on WWPSS model output.

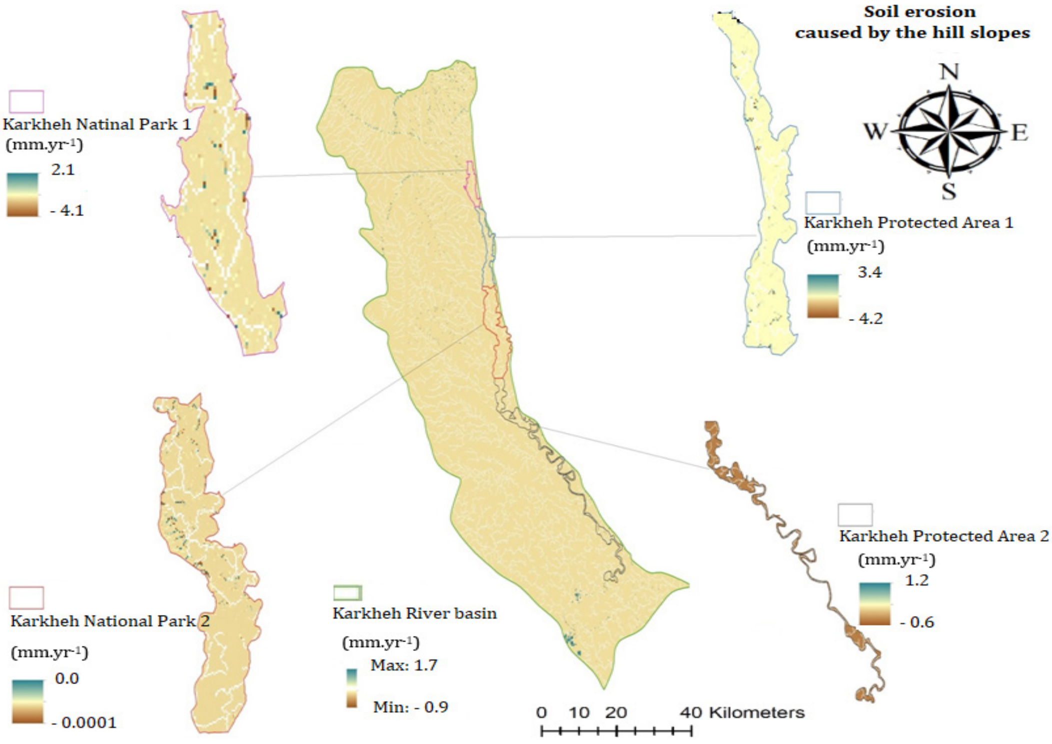

Figure 6) Soil erosion caused by the hill slopes (mm.yr^{-1}) map of Karkheh River basin, Karkheh National Park, and Karkheh Protected Area based on WWPSS model output(negative values indicate that deposition is more than erosion).

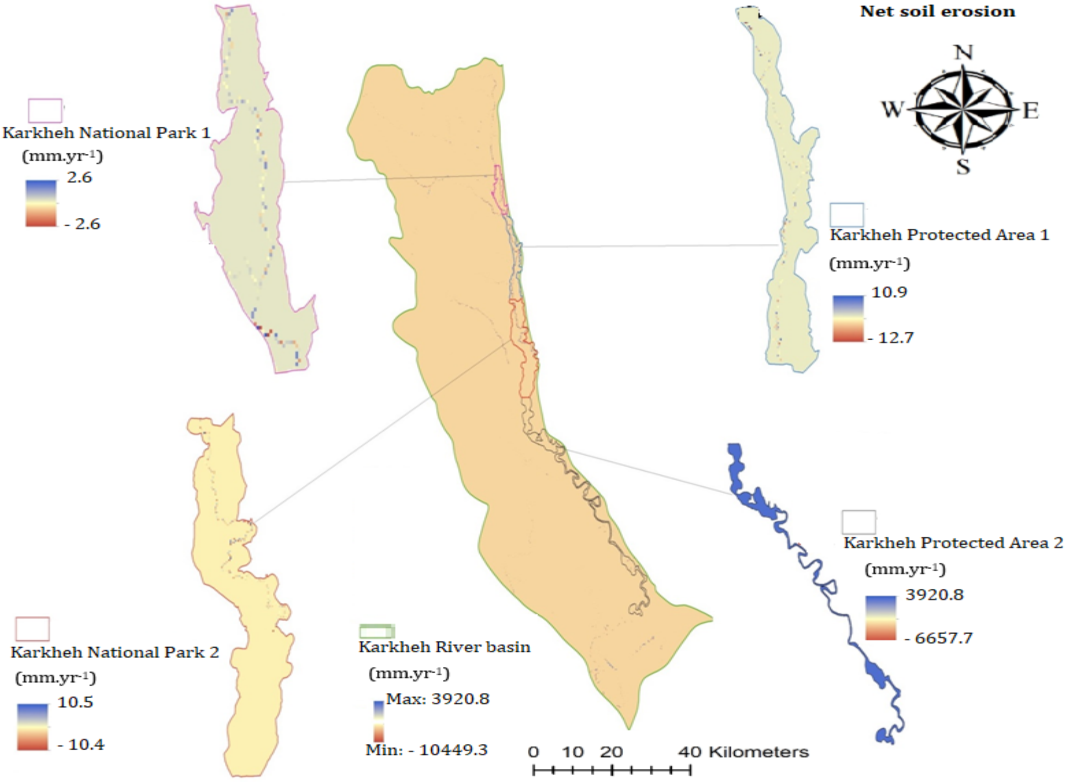

Figure 7) displays the total net soil erosion in existing conditions and its difference (mm.yr^{-1}) in the river basin based on the results from the WWPSS model.

these values differently, depending on the good in question and the market in which it is thoroughly dealt with.

Cost Based Methods

The cost-based methods (damage cost avoided, replacement cost, and substitute cost methods) are relevant methods that estimate values of ecosystem goods and services based on either the costs of avoiding damages due to lost services, the cost of replacing environmental assets, or the cost of providing substitute goods or services. The replacement cost method estimates the value of an ecosystem or its goods and services by using the cost of replacing them. Similarly, the substitute cost method estimates the value of an ecosystem or its goods and services using the cost of providing substitutes.

These methods might be applied to evaluate improved water quality, erosion protection services, water purification services, storm protection services, and habitat and nursery services.

Since economic valuation studies of environmental resources estimate the net present value (NPV) of ecosystem goods and services, the value of the ecosystem of the studied area at the time of the study (2021) has been estimated.

Findings

Modeling Parameters Using WWPSS

Precipitation

The WWPSS outputs indicated that the minimum, maximum, and mean precipitation were 219.3, 409.0, and 274.8 mm.yr^{-1} in the Karkheh River basin, which is slightly greater than Iran's mean annual precipitation (250 mm.yr^{-1}).

According to Figure 2, the southernmost area of the river basin experienced the minimum precipitation. As we move toward the north, the precipitation approaches the mean levels and peaks in the northern area. In total, the precipitation declines over the surfaces of the river basin from north to south. Because of high elevation gradients and the impact of topographic exposure to wind-driven rain, rainfall distribution is notably unequal in mountainous regions.

Water Balance (Water Budget)

Figure 3 demonstrates the water budget status across the Karkheh River basin in existing conditions.

The water balance (water budget) was determined by calculating the difference between precipitation and evapotranspiration. According to the model calculations, the ecosystem minimum, maximum, and mean water budget was -8976.0, 256.6, and -576.7 mm.yr^{-1}, respectively. The negativity of the mean budget means that the entire river basin faces water scarcity due to the high rate of evapotranspiration and the low rate of precipitation. This can lead to water bankruptcy in the long run, meaning water demand invariably exceeds the supply. Since the ecosystem water supply service rate must be determined specifically for the National Park and the Protected Area for economic valuation, the detailed water budget can be seen in Figure 3. According to the model calculations, the minimum, maximum, and mean of the ecosystem water budget for the Northern National Park (1) was -945.9, -123.5, and -577.9 mm.yr^{-1}, respectively. The ecosystem water budget for the Southern National Park (2) was -1004.2, -79.1, and -575.7 mm.yr^{-1} at minimum, maximum, and mean, respectively. Hence, the water budget status of the National Park was worse than that of the river basin. The minimum, maximum, and mean water budgets of the Northern Protected Area (1) were -987.5, 61.1, and -568.6 mm.yr^{-1}, respectively. These values were -1034.4, -144.9, and -561.2 mm.yr^{-1} for the Southern Protected Area (2). Overall,

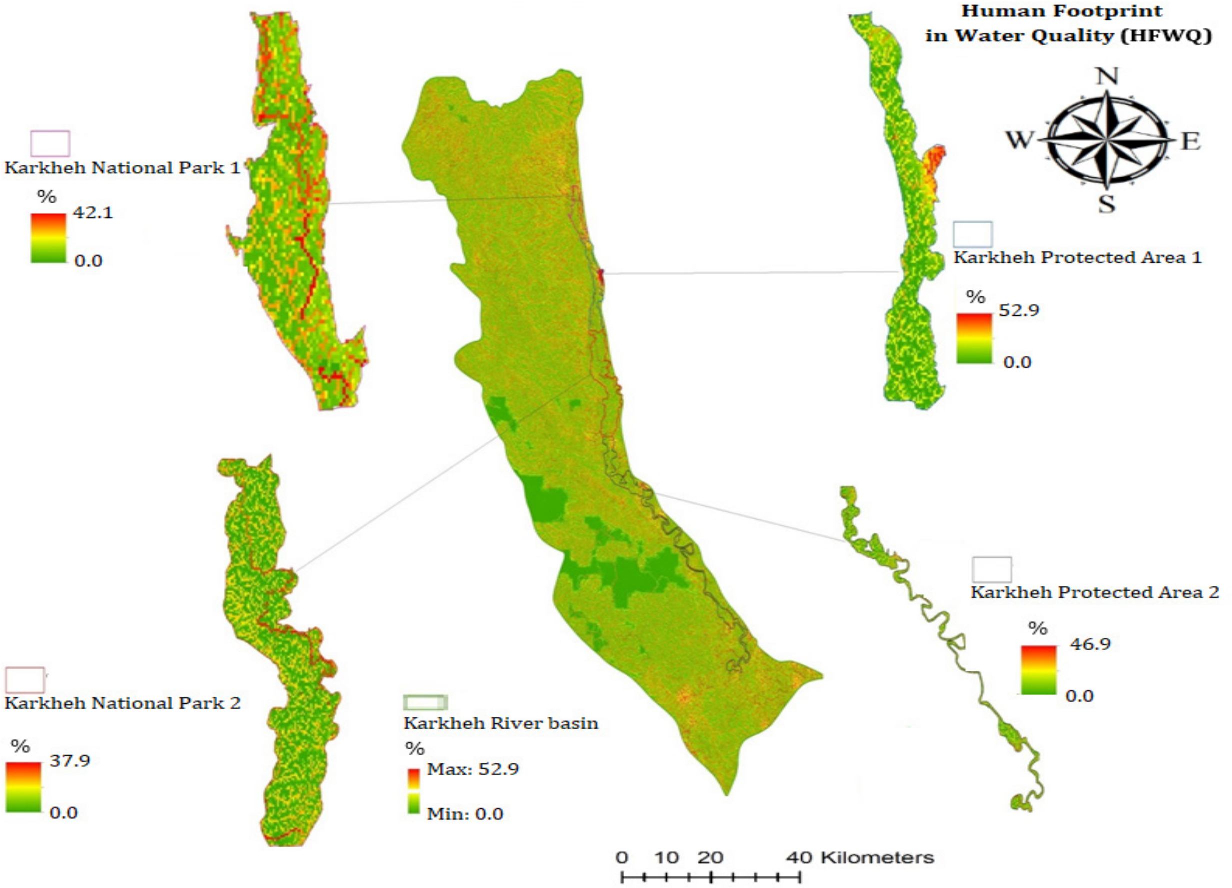

Figure 8) Human Footprint in Water Quality (HFWQ%) map of Karkheh River basin, Karkheh National Park, and Karkheh Protected Area based on WWPSS model output.

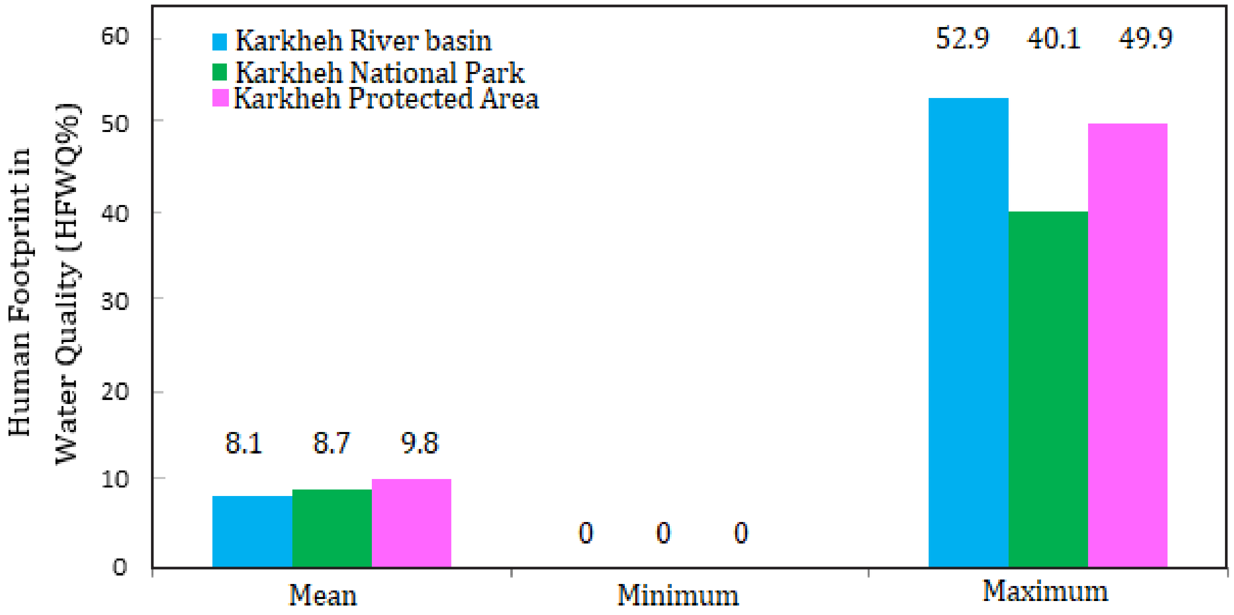

Figure 9) Comparison of mean, maximum, and minimum Human Footprint in Water Quality (HFWQ%) in Karkheh River basin, Karkheh National Park, and Karkheh Protected Area.

the water budgets of the National Park and the Protected Area were lower than that of the Karkheh River basin due to the higher rates of evapotranspiration caused by its vegetation (Figure 4).

Runoff Generation

Figure 5 displays the runoff generation status across the Karkheh River basin in existing conditions. The water generated by the river basin was determined by calculating the runoff as the water budget accumulated in a downstream area. The minimum, maximum, and mean runoff generation rates were estimated at 70.7, 81000648.0, and 300489.4 $m^3.yr^{-1}$ in the Karkheh River basin.

The total runoff generated in the river basin is based on the upstream-downstream relationships from the north to the south. Finally, the sum of water generation in the southernmost area of the protected area can be considered the maximum runoff generated in the river basin. It was estimated at 81000648.0 $m^3.yr^{-1}$.

Estimation of Soil Erosion

Figure 6 depicts the soil erosion status caused by the hill slopes across the Karkheh River basin in existing conditions. The minimum, maximum, and mean rates of the net erosion caused by the hill slopes were estimated at -0.92, 1.71, and 1.87 $mm.yr^{-1}$, respectively.

The minimum, maximum, and mean net soil erosion rates in the existing status of the river basin were -10449.28, 3920.79, and 0.05 $mm.yr^{-1}$, respectively. According to

Table 2) The mean water fee based on the crop type in the study area.

Crop	Yield ($t.ha^{-1}$)	Price of the Harvested Crop ($US\$.kg^{-1}$)	Mean Water Fee* ($US\$.ha^{-1}$)
Sugar Beets	85.4	0.024	20.57
Oil Seeds (Canola, Soybean, and Sunflower)	1.14	0.21	2.46
Rice	4.54	0.23	10.76
Corn	7.36	0.087	6.45
Wheat	4.94	0.105	5.18
Barley	2.69	0.083	2.23
Mean ($US\$.ha^{-1}$)			7.94

* the mean water fee for the conventional method was used and calculated by 1% of production multiplied by the price of a harvested crop

Table 3) Economic value of water generated in the study area (US$ million).

Study Area	Area (a)	Economic Value of Generated Water* (US$ million)
Karkheh River Basin	352943.33	2.9
Karkheh National Park	7475.82	0.06
Karkheh Protected Area	8352.09	0.06
Karkheh National Park + Karkheh Protected Area	15827.91	0.12

*Obtained by multiplying the area by the mean of water fee (7.94 $US\$.ha^{-1}$)

a previous study [32], the soil erosion speed limit in the arid areas of Iran is 0.01 mm yr^{-1}, whereas it is 7.7 $mm.yr^{-1}$ in humid areas. Since the study area is in a semi-arid climate, its mean soil erosion rate is five times higher than the crisis limit. This finding indicates an upward trend beyond the soil erosion limit in the river basin.

The mean soil erosion in the Northern National Park (1) was 0.0006 $mm.yr^{-1}$, whereas it was -0.002 $mm.yr^{-1}$ in the Southern National Park (2). The mean soil erosion in the northern Protected Area (1) was -0.006 $mm.yr^{-1}$, whereas 2.64 $mm.yr^{-1}$ in the northern Protected Area (2). In the WWPSS model, a negative value for soil erosion indicates soil deposition within a specific area, indicating that soil is not being transferred from upstream to downstream areas (negative values indicate that deposition is more than erosion). Therefore, the negative value indicates that due to appropriate vegetation, soil erosion did not have a destructive effect in the area.

Water Pollution Potential

Land-use change, especially vegetation change, significantly affects surface runoff and groundwater resources. Intact vegetation may enhance water quality by stopping sediments. Hence, destroying a region's vegetation can have unbelievable effects on the quantity and quality of water. The WWPSS model can present an index to determine the potential of water pollution level due to human intervention by modeling the water quantity (*i.e.*, the water balance accumulated as runoff in the downstream area). Referred to as the HFWQ, this index determines to what extent downstream water can be affected by upstream pollution due to human intervention that changes natural vegetation.

This index assumes that precipitation on human-occupied ground can lead to the formation of point pollution sources (e.g., mines, petroleum wells, roads, and cities) and non-point pollution sources (e.g., farms and pastures), which will result in polluted

Table 4) The economic value of water generated in Karkheh National Park and Karkheh Protected Area in the next 5, 10, 15, and 30 years (US$ million).

Period (yr)	Discount Rate (%)	Value ($US\$.ha^{-1}$)	Total Net Present Value (NPV) (US$ million)
5	8	9.7	0.15
	12	11.6	0.18
	15	13.3	0.21
10	8	14.2	0.22
	12	20.6	0.32
	15	26.7	0.42
15	8	21.1	0.33
	12	36.2	0.57
	15	54.0	0.85
30	8	66.7	1.05
	12	198.7	3.1
	15	439.3	6.9

wastewater. Therefore, an area's HFWQ (%) index means the share of water that pours down as rain on artificial vegetation; hence, it is considered a potential index of water pollution. Therefore, effects on water quality depend on the extent and distribution of human functions in upstream areas and places with precipitation. Overall, the scientific approach to this model to determine the pollution potential and change the water quality is based on the calculation of the HFWQ. The pollution potential is calculated by calculating the water percentage that can be polluted with the arrival of hydrological pollutants.

Figure 8 displays the pollution potential of surface waters in the Karkheh River basin based on the HFWQ. According to Figure 9, the mean surface water pollution potential in the Protected Area was tangibly higher than in the National Park and the river basin.

Economic Valuating using Substitute Cost Method

Economic Value of Water Sources

The water generated by the river basin in the study area was calculated by determining the runoff as the water budget accumulated in the downstream area. The total runoff generated in this river basin flows through upstream-downstream relationships from the north to the south. Finally, the total water generated in the southernmost area of the Protected Area can be considered the maximum runoff generated in the river basin, estimated at 81000648.0 $m^3.yr^{-1}$.

The water fee announced by the government was used for the valuation of water sources . According to the Law on Stabilization of the Agricultural Water Fee, Iran's currently announced water fee equals 1, 2, or 3% of production multiplied by the price of a harvested crop. In the study area, crops involve sugar beets, oilseeds (canola, soybean, and sunflower), rice, corn, wheat, and barley, which were considered to calculate the farming water fee. The crops produced in the selected counties were extracted from Iran's Statistical Yearbook, and the guaranteed prices for purchasing the crops announced by the Economic Council in 2021 were considered. Since the main irrigation method is conventional in Iran, the mean water fee for the conventional method was applied (Tables 2 and 3).

The estimated value is the nominal value that must be converted into an absolute value through the inflation correction Equation. The estimated values must also be adjusted to the expected changes in price levels over time. Otherwise, the results of the cost-benefit analysis will not be reliable. Two adjustments must be made: 1) determination of the current value, taking into account the opportunity cost of money,

Table 5) Economic value of soil conservation based on the amount of NPK as a major protected nutrient in Karkheh National Park and Karkheh Protected Area.

Amount of Conserved Soil (t)	Amount of Major Protected Nutrient (t)		Economic Value of Major Protected Nutrient (US$ million)
432000	Nitrogen	518.4	0.83
	Phosphorous	1296	2.08
	Potassium	5184	8.3
	Total	6998.4	11.2
	Total (ha^{-1})	0.68	0.001

and 2) inflation adjustment, adjusting for changes in price levels.

The initial estimates of the cost-benefit analysis must also be adjusted for changes in price levels over time. This is called inflation adjustment. Nominal value means the determined value for the present time. The real value refers to the adjusted value by considering the effect of inflation. The Eq. (6) demonstrates the relationship between the nominal value and the actual value:

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

Eq. (6)

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

$$Nominal\,value_{period\ x+t} = Real\,value_{period\ x} \left(1+p\right)$$

Eq. (7)

According to the Central Bank of Iran and the Statistical Center of Iran, the mean inflation rate has been 19.8% over the past 30 years. This inflation rate was then used for inflation correction. The real value of water generation in the entire Karkheh National Park and Protected Area was estimated at US$ 0.104 million after inflation correction in 2021 (Table 3 and Eq. 7). By considering the total area of both Karkheh National Park and Protected Area (Table 4) the actual value of water generation per hectare in the area was estimated at US$ 6.7 after inflation correction. Table 4 reports the economic value of the water generated in the Karkheh National Park and the Protected Area during 5, 10, 15, and 30 years. However, since the value of each function in the study area is unclear during the forgoing periods, all current values are converted into the future timeframe with a composite rate so that their values can be determined in 5, 10, 15, and 30 years. The environmental deterioration rate was considered to be nearly 8% in many international studies. However, given the prioritization of short-

Table 6) The economic value of soil conservation in Karkheh National Park and Karkheh Protected Area in the next 5, 10, 15, and 30 years (US$ million).

Period (yr)	Discount Rate (%)	Value (US$.ha^{-1})	Total Net Present Value (NPV) (US$ million)
5	8	1331.8	13.7
	12	1605.5	16.5
	15	1833.5	18.8
10	8	1961.2	20.1
	12	2837.0	29.2
	15	3685.3	37.9
15	8	2891.7	29.7
	12	10616.1	51.3
	15	7425.4	76.4
30	8	9176.8	94.5
	12	27329.9	281.2
	15	60397.7	621.6

term exploitations over the sustainable use of ecological resources in Iran, this rate is expected to be considered higher. In this study, three discount rate scenarios of 8, 12, and 15% were developed to evaluate the functions of interest.

Economic Valuation of Soil Conservation

Economic valuation of soil conservation was done using the Nutrient Substitute Cost Method. This method is aimed at restoring the eroded soil to its previous status. For this purpose, the cost of purchasing chemical fertilizers required for conservation and restoring soil efficiency should be estimated. In this method, the nutrient substitute costs are estimated directly based on the depletion of significant elements, *e.g.*, nitrogen, phosphorus, and potassium, by considering the food balance and the retail prices of chemical fertilizers.

The amounts of these major elements in the pasture were 0.12, 0.3, and 1.2% of soil for nitrogen, phosphorus, and potassium, respectively. As a result of soil erosion, the amounts of these major elements in the soil will decrease significantly. Considering the NPK fertilizer price at US$1.6 per kg on markets in Iran, the value of soil conservation can be estimated in the study area.

Table 5 shows the amount of NPK elements in protected soil as protected nutrients, calculated in the Karkheh National Park and Protected Area based on the market price of the NPK fertilizer.

The estimated value is the nominal value, which must be converted into the real value through the inflation correction Equation. According to the Central Bank of Iran and the Statistical Center of Iran, the mean inflation rate has been 19.8% over the past 30 years. Therefore, this inflation rate was corrected. The real value of soil conservation in the entire Karkheh National Park and the Protected Area was estimated at US$ 9.3 million after inflation correction in 2021 (Eq. 7). Therefore, the real value of soil conservation per hectare in the study area was estimated at US$ 912.2.

Table 6 reports the economic value of soil conservation in the Karkheh National Park and the protected area during 5, 10, 15, and 30 years with three discount rate scenarios of 8, 12, and 15% to evaluate the functions of interest.

Discussion

The case study emphasizes the economic value of Karkheh National Park and Karkheh Protected Area in the southwest of Iran. The Substitute Cost Method prepared a valuable structure for evaluating ecosystem services by estimating the economic costs of substituting these services through human-made alternatives. This method provides numerous favors, such as its general perspective, market-based standpoint, and applicability in the absence of markets. The data required for economic valuation was obtained by modeling eco-hydrological parameters using the WWPSS model. It allows users to assess the changes in ecosystem parameters. However, this model was previously used in other studies.

Pandeya and Mulligan [35], using the WWPSS model in India, showed that more cropland regions with favorable environments would experience a higher percentage of annual crop actual evapotranspiration (AET) growth. Crop AET would lead to a shortage of water supply. Since some regions have already exploited all available water resources, the additional requirement and increased crop water use in the upland areas may create a severe water crisis in lowland regions. Cacal et al. [36] evaluate rainfall-runoff simulation utilizing GIS techniques in Irawan. They illustrated that multiple physical factors were affected by runoff in the basin. Runoff generation can be substantially influenced by soil type and the land-use/land cover classes. The slope of the basin can also significantly impact how much runoff occurs [37]. Thus, runoff travels to the basin's outlet point more rapidly the steeper it is. As per Zarandian et al. [38], a decline in vegetation density within the basin has led to an approximately 11% mean reduction in evapotranspiration. This, in turn, has resulted in increased runoff. The loss of vegetation causes the sudden release of water stored in aerial and underground tissues and the soil around plant roots. Consequently, this amplifies overall runoff, elevating the risk of food hazards, escalating sedimentation from water erosion on hillslopes and canals, heightening net soil erosion and water turbidity, diminishing water quality, and augmenting sediment load in surface waters within the watershed. The ecological condition of the basin was such that it effectively stabilized the soil. The mean soil erosion was estimated as positive, indicating sediment transport from slopes across the River basin to the canals and waterways. This finding indicates the high potential for low water quality and high pollution in the study area. Net soil erosion means destroying soil and transporting resultant sediment through waterways and rivers from upstream areas to downstream. This situation can lead to major ecological hazards and economic challenges. In the WWPSS model, the net soil erosion is determined by calculating the total amount of eroded soil minus the sediment accumulating in hill slopes and water channels. These values are worthwhile because the northern and southern National Parks and the northern Protected Area are covered by the dense vegetation of desert poplar (*Populus euphratica*) and (*Tamarix*) as the main tree species. Unlike the erosion regimen across the hydrological unit, the soil erosion rates were near completely controlled thresholds. In other words, the National Park and the northern Protected Area were in satisfactory condition to provide ecosystem services for preventing soil erosion (soil conservation). However, the soil erosion rate spiked in the southern Protected Area with the decline of vegetation and the intensification of irrigated and dryland farming activities. Vegetative cover is vital in soil conservation, climate regulation, hydrological processes, carbon cycles, and ecosystem stability [39]. This finding indicates the deterioration of the ecosystem services for soil conservation in this area due to land-use change for farming. To calculate the weight of eroded soil, the soil bulk density was considered to be 1.6 $g.m^{-3}$ in the study area. The annual eroded soil in the downstream area of the protected area was estimated at 42 $t.ha^{-1}$, which indicates its very severe and dangerous erosion regimen. Considering the area of the southern Protected Area, which is 5513.6 ha, its annual eroded soil will be 231571.2 t. Regarding this matter, it is essential to highlight that the annual soil erosion rate in various regions of Iran ranges from 7 to 70 t, with a mean of 16.5 $t.ha^{-1}$ [32]. Another study [40] using the RUSLE model for Asia found a mean erosion rate of 12 t $ha^{-1}.yr^{-1}$.

To determine the importance of ecosystem services on soil conservation, the difference of the annual eroded soil (t) across the National Park and the northern Protected Area compared with that of the southern Protected Area. This argument is based on the hypothesis that if the desert poplar (*Populus euphratica*) and (*Tamarix*) vegetation had been absent in the National Park and the northern protected area, their soil erosion rates could have equaled that of the southern Protected Area due to their ecological similarities. The difference is nearly equal to the calculated weight of eroded soil (42 $t.ha^{-1}.yr^{-1}$). Since the total area of the National Park and the northern Protected Area was 10296.3 ha, their ecosystem service functions can prevent the erosion of nearly 4320 t.yr^{-1}. In other words, desert poplar (*Populus euphratica*) and (*Tamarix*) vegetation in these areas can prevent the erosion of 42 t.ha^{-1}.

Soil erosion is due to changing the eco-hydrological properties of the ecosystem and the decline of vegetation's effect on water quality. According to our results, the surface water pollution potential in the protected area was greater than that of the national park and the river basin. This finding is due to non-point-point pollutants, especially in irrigated cropland and rainfed lands. Indeed, agricultural lands contribute significantly to non-point on-point pollution, often falling water quality below human consumption standards [41]. The decline in water quality can be attributed to deforestation, where forest is converted to pasture and agricultural land, which increases erosion . This implies that an increase in the percentage of forested areas (> 15% and 20%) may be essential for enhancing water quality in sub-basins [43]. However, the reduction in the percentage of forest cover is sufficient to degrade water quality in most sub-basins. Similar trends, as indicated by the HFWQ index by WaterWorld, were also observed by other researchers [22, 40].

Conclusion

River basin management implements scientific soil and water conservation practices to enhance biomass production. This study presents an overview of the importance of water and resource management in the Karkheh River basin, contributing to understanding the economic value of ecosystem services using the WWPSS model. One of the advantages of using the WWPSS model is the potential to compare and evaluate several parameters. Second, with the global datasets given in the model, it is feasible to simulate further variations. The study demonstrates that this model effectively addresses such challenges, leveraging diverse international databases for reliable results. Our findings indicate a decline in water quality and a reduction in water quantity within the southern sections of the basin, characterized by lower vegetation cover. Ultimately, the study underscores the crucial role of vegetation in providing hydrological ecosystem services (manifested as virtual water) to consumers within and beyond the basin.

While these methods facilitate the validation, we suggest that future work emphasize collecting more field data, leveraging recently developed remote sensing technologies for further validation, and exploring the socio-economic impacts of improved water management strategies on local communities. Additionally, we have proposed policy recommendations based on our findings, implementing integrated river basin management plans that consider both upstream and downstream impacts and encouraging stakeholder participation in the decision-making process to ensure sustainable water resource management.

Declaration

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Authors' contributions

This work was carried out in collaboration between all authors. All authors contributed equally to the study conception and design of this paper. All authors read and approved the final manuscript.

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