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ORIGINAL ARTICLE

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Valuation of ecosystem services benefits from a ravine watershed in south-eastern Rajasthan

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ABSTRACT

Evaluating ecosystem services has become an essential area of study, highlighting the vital benefits that natural environments provide to human societies. This research focuses on the economic benefits of ecosystem services generated through watershed development interventions in the Badakhera Ravine Watershed in Bundi district, Rajasthan. Spanning 682.5 ha, the watershed underwent treatment between 1997 and 2003, employing various soil and water conservation measures such as land leveling, bunding, and water resource development. The economic valuation of ecosystem services utilized primary and secondary data, applying the market price method. The impact of watershed interventions was measured by comparing the enhanced ecosystem services against baseline ecosystem service values. The results indicate that, based on the soybean grain equivalent prices for 2019-20, these interventions significantly increased agricultural productivity, yielding additional returns of ₹ 60,000 per hectare per year from crop production. Furthermore, the interventions contributed ₹ 917 $ha^{-1}yr^{-1}$ from fodder production and ₹3,989 $ha^{-1}yr^{-1}$ from livestock production. Fuelwood generated from community and agroforestry trees added approximately ₹ 6,864 $ha^{-1}yr^{-1}$, while employment opportunities increased by 62 man-days $ha^{-1}yr^{-1}$, valued at ₹ 12,404. Regulating and cultural services from the watershed were also quantified, including an additional harvest of 24.93 cubic m ha^{-1} of surface water, valued at ₹ 374, and improvements in groundwater recharge, estimated at ₹ 9,007 $ha^{-1}yr^{-1}$. Nutrient loss due to erosion was valued at ₹ 117 $ha^{-1}yr^{-1}$. Average carbon sequestration across various land uses was estimated at ₹ 36,392 $ha^{-1}yr^{-1}$, and the demonstration value for education and training was calculated at ₹ 70.80 $ha^{-1}yr^{-1}$. This comprehensive valuation underscores the critical role of ecosystem services in sustainable watershed management and development policy.

Key words:

Carbon sequestration
Ecosystem services
Regulated services
Valuation
Watershed

HIGHLIGHTS

- The enhanced ecosystem services to baseline values were quantified due to the impact of watershed interventions.
- Watershed interventions increased agricultural productivity by an additional ₹ 60,000 $ha^{-1}yr^{-1}$ from crops, contributed ₹ 917 ha^{-1} from fodder, ₹ 3,989 from livestock, and ₹ 6,864 from fuelwood.
- Employment opportunities rose by 62 man-days ha^{-1} annually, valued at ₹12,404.
- An additional 24.93 cubic meters of surface water per hectare (valued at ₹ 374) and improvements in groundwater recharge are estimated at ₹ 9,007 $ha^{-1}yr^{-1}$.
- Soil and nutrient loss reduction due to watershed interventions was valued at ₹117 ha^{-1}, while carbon sequestration averaged ₹ 36,392 ha^{-1}.
- The skill development facilitation was valued at ₹ 70.80 ha^{-1}.

1 | INTRODUCTION

Ecologists and economists have long explained how human societies depend on natural environments. In recent years, more explicit language and data have enhanced understanding of how natural and economic processes benefit society. These ideas, called "ecosystem services" or something else, are crucial to future environmental policy. The concepts have been globally accepted by organizations such as the World Bank, World Resources Institute, UN Millennium Ecosystem Assessment (2005), Goldman Sachs, and the Heinz Foundation.

These organizations have chosen ecosystem-based management because other frameworks fail to effectively integrate economics and ecology while communicating their benefits to broader audiences. The concept emphasizes the connection between environmental management and human well-being. However, increasing human activity and rapid urbanization have led to the over-exploitation of natural resources, affecting achieving sustainable development goals (SDGs). In recent decades, policymakers and academics have had considerable interest in estimating the monetary value of ecosystem services (ES). This valuation can highlight their impact on human welfare and support their integration into public decision-making processes (Constanza *et al.,* 1997). Sharda *et al.* (2019) assessed the economic cost of soil erosion in India using the replacement cost principle, which calculates the cost of replacing nutrients lost due to erosion. The energy expended in producing fertilizers to replenish these nutrients was also estimated. Economic valuation of ecosystem services assists in decision-making regarding trade-offs between production and environmental conservation. It quantifies the benefits ecosystems offer and the impact of changes on human comfort. Therefore, monetary values should be considered when making economic decisions. Proponents argue that ecosystem service valuations can (i) enhance understanding of challenges and solutions, (ii) provide a basis for precise decision-making, (iii) illustrate profit allocation and support cost-sharing, and (iv) promote innovative organizational and market mechanisms for sustainable ecosystem management.

The primary aim of valuation studies is to inform decision-makers of the importance of ES for human well-being. These estimates may encourage policymakers to consider ES data when making land-use decisions prioritizing environmental sustainability (Kieslich and Salles, 2021). Several studies have focused on the challenges of valuing ES (Costanza *et al.,* 1997) and the complexity of understanding interactions between ecological functions and human use (Polasky *et al.,* 2011). These challenges stem from the indirect and spatially displaced effects of environmental change on human health, making them difficult to grasp (Bogardi *et al.,* 2020). Though ES valuation methods have improved, a lack of understanding of ecosystem dynamics, human needs, and technical issues in the valuation process still leads to uncertainty, particularly in stated preference methods. Market imperfections and policy failures can distort expected monetary values when using such methods. High-quality transaction data, large datasets, and sophisticated statistical analysis are essential for accurate valuations. However, stated preference approaches can be both expensive and time-consuming.

Market valuation methods, which primarily rely on production or cost data, are easier to apply but are limited in assessing ES due to the lack of or distorted markets. Consequently, these methods can produce skewed values, offering unreliable data for policy decisions (Muthee *et al.,* 2017). Various efforts have been made to value natural resources, especially forest-based resources and recreational / ecotourism (Chopra, 1998), water supply, and wetlands (Bhatta *et al.,* 2016). Scholars have valued soil conservation functions in a watershed context, but many other supporting, regulating, and cultural services affected by natural resource interventions remain under studied. This calls for a complex biophysical and socio-economic data set to value watershed interventions properly.

Since the 1970s, Watershed Development (WSD) has been integral to India's efforts to improve agricultural productivity and alleviate poverty in rainfed regions. These programs aim to rehabilitate degraded watersheds to enhance rainwater harvesting, prevent soil erosion, and increase soil nutrient and carbon content, improving crop productivity and rural livelihoods. Most of India's rural poor live in these areas, relying on natural resources for subsistence. Improved agricultural yields enhance both human welfare and national food security. However, despite significant attention and funding from the government, the success of WSD programs in achieving food security and reducing hunger remains unclear. This is partly due to inconsistent data collection and evaluation efforts across implementing agencies. Most reviews focus on changes in key indicators and anecdotal project outcomes, lacking a comprehensive understanding of the economic, social, and environmental benefits for beneficiaries. Studies like Verma's (2007) research on Uttarakhand's forest ecosystems demonstrate the need for more rigorous data to evaluate the benefits of watershed services, especially regarding water flow monitoring. A recent meta-analysis by Meena *et al.* (2022) on 221 watersheds across five agro-climatic zones in India revealed watershed ecosystem services worth ₹ 34,113 ha^{-1}. Due to the scarcity of studies on watershed-based ecosystem services, none have attempted to value these services in the degraded ravine areas of the region. This research seeks to comprehensively examine the ecosystem services of a particular ravine watershed, evaluating its ecological, economic, and social significance. This study aims to quantify the advantages of the rehabilitated degraded ravine watershed by utilizing an interdisciplinary method that combines ecological, economic, and social sciences while underscoring the necessity for ravine area development and sustainable management through a watershed framework. Comprehending the significance of ecosystem services in ravine watersheds can enhance policy formulation, direct conservation initiatives, and elevate public consciousness regarding safeguarding these habitats. This research enhances the existing knowledge on ecosystem service valuation and provides practical insights for stakeholders engaged in watershed management, environmental planning, and sustainable development.

2 | MATERIALS AND METHODS

2.1 | Study Area

The Badakhera Watershed, located in Rajasthan's Bundi district (Fig. 1), was selected for this study due to the availability of extensive data. Badakhera is a rain-fed ravine watershed at a latitude of 25°36' N and a longitude of 76° 15'E. The watershed spans 682.5 ha and drains into the Mej river near its confluence with the Chambal river. The elevation varies from 150 to 172.5 meters above sea level. The Mukundara range of the Vindhyan Hills flanks the watershed to the north and south. Approximately 20% of the watershed comprises tablelands that gradually transition into slopes ranging from 2% to 10% as they approach the extensive network of gullies, which cover about 80% of the downstream area. The ravenous slopes range from 20% to 30%. The highest stream order within the watershed is 4, and the drainage density was calculated at 14.86 km km^{-2}. The multidirectional slopes of adjacent cultivated fields and subsistence farming with low productivity provide a significant opportunity to demonstrate and evaluate recommended agricultural practices.

The Badakhera watershed covers a total area of 682.5 ha, of which 378.9 ha are privately owned agricultural land and 303.6 ha are community-owned. Work on the watershed began in 1997-98 and concluded in March 2003, with a total project cost of ₹ 27.3 lakhs. Several conservation measures were implemented on arable lands as part of the development activities. These included land leveling between bunds, constructing masonry, gabion, or loose boulder spillways for safely disposing of excess runoff, and building graded and peripheral bunds reinforced with grasses. Drainage lines were treated with stabilization methods such as straight-drop masonry or gabion spillways at gully heads, check dams, gully plugs, and live hedge barriers to flatten and stabilize the gully beds. Depending on the runoff-generating area, either masonry (>5 ha), gabion (1-5 ha), or loose boulders (<1 ha) were constructed. Rectangular waste weirs were provided at the lowest portion of the graded

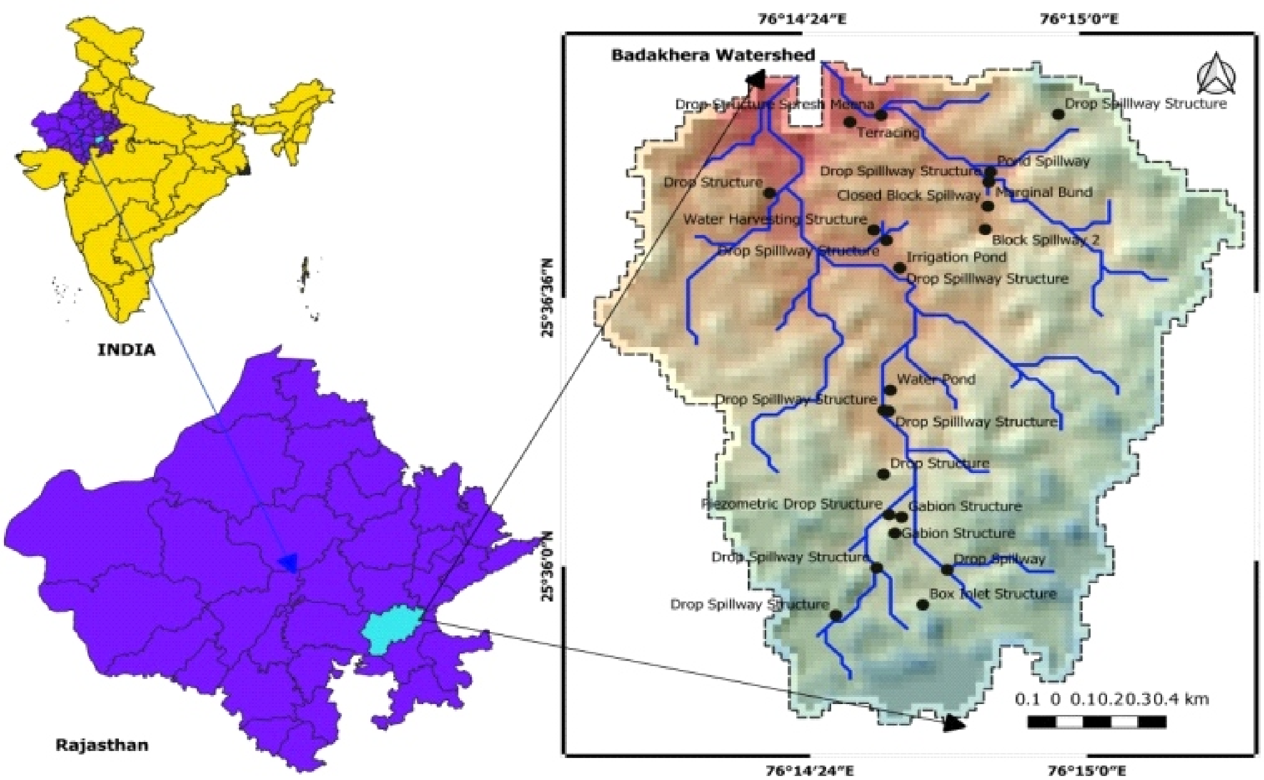

FIGURE 1 Location and interventions map of selected watershed

bund. The crest of the waste weir was kept 15 cm above ground level. In some places, a shoulder bund perpendicular to the graded bund was provided to trap the silt in continuation of the waste weir. These measures were employed either individually or in combination, depending on the problem to be addressed. Additionally, two agricultural ponds with capacities of 1.6 and 0.6 ha-m were constructed, and crop demonstrations of improved practices were introduced.

2.2 | Data and Valuation Methods

The study adopts a "before and after" project approach, comparing benchmark data from 1997-98, when the project was initiated, with data collected in 2013-14, 10 years after the project was completed. The considerable duration of 10 years was necessitated by the understanding that soil and water conservation methods require extended periods to realize their full potential and necessitate adequate time for the complete stabilization of the watershed ecoregion. Data on specific ecosystem services such as soil organic carbon (SOC) and carbon sequestration related to cultural ecosystem services were collected from field observations and secondary sources such as reports and official records for 2019-20. The impact of integrated watershed management (IWM) and soil and water conservation interventions on ecosystem services (ES) was measured using the Pande *et al.* (2023) approach.

$$ESWM = IWMES_1 - IWMES_0$$

Where, ESWM = Ecosystem Service change due to IWM; $IWMES_0$ = ES before IWM intervention (baseline); $IWMES_1$ = ES after IWM intervention.

This protocol was applied as a matrix for each ecosystem service supported by integrated watershed management. The yields of different crops are converted into crop equivalent yields (CEY) of any one crop (in the present case, Soybean) based on the price of the produce.

$$CEY = Cy + C1y * \frac{P_{c1}}{P_c} + C2y * \frac{P_{c2}}{P_c} + ------- -$$

CEY is the crop equivalent yield; Cy is the yield of the main crop, the yield of other crops converted to its equivalent, and Pc is its respective price; C1y, C2y .... are yields of intercrops / other crops which are to be converted to the equivalent of main crop yield and Pc1 and Pc2 are their respective prices. (Rana and Kumar, 2014).

2.3 | Ecosystem Services Categorization

Based on the Millennium Ecosystem Assessment, over 20 ecosystem services (ES) have been classified into four main categories: provisioning, regulating, supporting, and cultural services. Based on available data, a comprehensive list of ecosystem services resulting from watershed management interventions was identified and valued at 2019-20 prices, as detailed in Table 1.

3 | RESULT AND DISCUSSION

3.1 | Provisioning Services

Watershed development provisioning of ecosystem services refers to the provision of commodities and resources by ecosystems, especially those located within watersheds, directly to the activities of humans. Services of this nature are crucial for the welfare of communities and may encompass the following

3.1.1 | Crop Production: For annual crop production, yields were analyzed based on the area under cultivation before and after watershed interventions. Depending on availability, these yields were converted into major crop equivalents using either the Minimum Support Price or the market price. The by-products and pure fodder crop output were also converted into grain equivalent terms using farm harvest prices and local prices of by-products and green fodder (Table 2). This provided a comprehensive view of total productivity, comparing pre- and post-NRM (Natural Resource Management) interventions. It was found that the watershed interventions generated an additional return of approximately ₹ 41,491,159 from crop production when expressed in major crop grain equivalents (soybean). This corresponds to an additional return of approximately ₹ 60,000 $ha^{-1}yr^{-1}$. The significant rise in the value of provisioning ecosystem services was mainly due to changes in farming practices and the increased land usage after the interventions. Enhanced productivity was further supported by improved irrigation systems made possible through groundwater recharge and soil and water conservation measures that helped retain moisture in the soil. A study by Kumar *et al.* (2024) conducted in the Kokriguda watershed, Odisha, found that provisioning ecosystem services increased to $ 392.9 ha^{-1} in crop production at 2020-2021 prices. The analysis by Dhayani *et al.* (2020) of 38 years of data in the Bhaintan participatory integrated watershed management project, located in the Indian North Western Himalayas (INWH), also demonstrated a steady improvement in all provisioning ecosystem services (ES) indicators compared to the pre-project period.

3.1.2 | Livestock Production: Livestock is vital in providing ecosystem services and is a fundamental component of many agroecosystems. It contributes by converting non-edible feed into nutritious food and valuable products (e.g., converting grass into milk or meat), interacting with ecosystems through grazing and trampling, and producing dung and urine.

Additionally, livestock mobility allows them to respond to resource and climate fluctuations. The impact of watershed interventions was assessed by evaluating additional income

TABLE 1 Ecosystem services and methods used for valuation

Ecosystem services	Indicator	Methodology	Data use
Provisioning services			
- Food	Crop production	Change in crop production due to integrated Watershed Management (IWM) before and after intervention.	Crop-wise area, yield, the market price of the crop (MSP/Farm harvest price)
- Fodder	Fodder production	Change in fodder production due to IWM intervention	Area under fodder crop, yield, local market price
- Forest	Timber / fuel wood / grass production	Change in tree / grass biomass production due to IWM intervention	Area under tree/ grass species, number, height, DBH of tree, grass yield, local market price of fuelwood, grass, stumpage price of timber
- Livestock	Livestock production	Change in milk and dung production due to IWM intervention	Number of cattle in lactation, milk production, dung production, local market price of milk and dung
- Water	Fresh water for household use	Change in surface water storage due to IWM intervention	Surface water harvest from different water bodies, watershed area, cost of municipal water supply
- Livelihood support	Employment generation	Change in employment generated in the watershed due to IWM intervention	Number of days employed (casual and regular) in different activities, local wage (MGNREGA) rate
Regulating services			
- Water flow regulation	Groundwater recharge	Change in annual groundwater recharge due to IWM intervention	Watershed area, average annual water level fluctuation, watersheds specific yield, cost of municipal water supply
- Atmosphere temperature regulation	Carbon sequestration	Change in carbon stock in soil and vegetation due to IWM intervention	Carbon stock in soil and vegetation in different land uses, area under land uses, Certified Emission Reduction (CER) price
Cultural services	Awareness creation / education service (demonstration)	Value of acquiring knowledge about natural resource management due to IWM intervention	Number of people acquiring knowledge, the average expenditure on the watershed visit by the trainees or visitors

TABLE 2 Changes in provisioning ecosystem Value of crop production with watershed interventions in Badakhera watershed

Agricultural crop products on arable land	Total Production (q) in Soybean grain* equivalent	Value in (₹ Lakh)
Pre-project		
i) Crop -main (grain)	2844.84	105.54
Crop by-products -cob	0.444	0.02
Stalk	26.61	0.99
ii) Fodder production	103.70	3.85
Post project		
i) Crop main (grain)	13859.5	514.19
Crop by-products-cob	0.528	0.02
Stalk	290.29	10.77
ii) Fodder production	272.300	10.10
Change as a result of IWM [(b) - (a)]		
I) Crop main (Grain)	11014.66	408.64
Crop by-products-cob	0.084	0.00
Stalk	263.6	0.01
ii) Fodder production	168.59	6.25
Additional return total return from watershed	--------	414.91
Return $ha^{-1}yr^{-1}$		0.61

**Soybean price 3710 q^{-1}*

from milk and dung production (Table 3). Results indicate that additional income post-intervention was estimated at ₹ 3,552 ha^{-1}yr^{-1} from milk and ₹ 436 ha^{-1}yr^{-1} from dung.

3.1.3 | Fuel wood Availability: Firewood and timber yield were considered based on the area under tree plantations within the watershed. Forest productivity was calculated by summing the total biomass (yield multiplied by area) of all forest trees in the watershed and dividing this by the total plantation area. The Badakhera watershed covers 682.5 ha, with 378.9 ha of arable land and 303 ha of degraded land. The community land, covering 432 ha, is mainly used for grazing and is dominated by *P. juliflora* and mixed vegetation, including medicinal and non-timber forest products (NTFP) species. Fuelwood sourced from *P. juliflora* is the village's major household fuel for cooking. Hence, the value of fuel wood provided by the watershed was assessed accordingly, and it was found that an additional return of ₹ 6864 ha^{-1} was generated by fuel wood in the watershed.

3.1.4 | Employment Generation: The watershed development program positively impacted employment opportunities. During 2013-14, the program generated 56,333 man-days of crop and livestock production employment, compared to 23,957 man-days before the project (Table 4). Additionally, 10,167 man-days were created during the project's implementation phase. In monetary terms, this translated to an additional ₹ 12,404 ha^{-1}yr^{-1} in employment. Increased cropping intensity due to improved irrigation facilities was a major factor in this employment growth.

3.2 | Regulatory Ecosystem Services

The regulation of ecosystem services from watershed growth focuses on the advantages that ecosystems offer by controlling environmental processes. These services contribute to preserving ecological equilibrium and assure the long-term viability of natural resources. The listed regulatory services have been examined:

3.2.1 | Water Storage and Groundwater Recharge: Soil and water conservation measures were instrumental in enhancing groundwater recharge and water storage through reduced surface runoff, increased infiltration, and improved soil moisture retention. Techniques such as contour farming, terracing, and planting cover crops slowed water flow, mitigated soil erosion, and improved water absorption. These practices helped maintain groundwater levels and ensured a steady water supply during droughts. The study estimated that watershed interventions resulted in an additional harvest of 24.93 m^3 ha^{-1} of surface water by reducing runoff (Table 5). Groundwater storage increased by 409,500 m^3, valued at ₹ 374 for surface water and ₹ 9,007 for groundwater using a replacement cost approach. A similar study by Esen *et al.* (2023) in Turkey's Southern Aegean Region estimated the value of groundwater recharge at approximately € 40.4 million yr^{-1}, or around € 35 ha^{-1}yr^{-1}.

TABLE 3 Valuation of ecosystem services of animal husbandry in watershed

Particulars	Pre-project	Post project	Net Change
Total nos of milch animals (SAU*)	104	187.2	83.2
Milk production(lit) / yr^{-1}	71740	149791	78051
Dung production (t) yr^{-1}	743.4	872.07	128.67
Milk Productivity (lit) animal^{-1}yr^{-1}	689.8	744.25	54.45
Milk productivity (lit) ha^{-1}yr^{-1}	105.11	217.6	112.49
Dung production(t) ha^{-1}yr^{-1}	1..08	1.27	0.19
Gross value (₹) of Milk yr^{-1}	2331010.5	4755455	2424445
The gross value of dung (₹) yr^{-1}	728500.5	1026344	297843
Value of milk (₹) ha^{-1}	3415.4	6967.7	3552.3
Value of dung (₹) ha^{-1}	1067.4	1503.8	436.4

**1 SAU = 1 buffalo, 0.7 cow, 0.08 goat,0.09 sheep*

TABLE 4 Valuation of Employment created by the watershed interventions

Activity	Pre-project			Post project			Net change value ₹ lakh ha^{-1}
	Employment generated (man days)	Gross value (₹ in lakh)	Value ₹ lakh ha^{-1}	Employment generated (man days)	Gross value (₹)	Value ₹ lakh ha^{-1}	
Crop production	9837.3	19.58	0.03	30778	61.25	0.09	0.06
Livestock production	14120	28.10	0.04	25555	50.85	0.07	0.03
Casual employment (Project activities)	----	-----	-----	10167	20.23	0.03	0.03
Total	23957.3	47.67	0.07	66500	132.34	0.19	0.12

Valuation of employment generation was done using the MGNERGA rate in Rajasthan state @199 Rs during 2019-20

3.2.2 | Carbon Sequestration: Carbon sequestration is a critical ecological process that regulates atmospheric carbon dioxide levels, helping mitigate climate change. Watershed interventions, such as soil and water conservation measures, enhance this process by improving soil and vegetation quality. Carbon inventories were assessed using soil and vegetation sampling, and carbon was converted into CO_2 equivalents, which were then valued based on the market price of certified emission reductions (carbon credits) (Table 6). The carbon sequestration value for the Badakhera watershed was calculated at ₹ 36,392 $ha^{-1}yr^{-1}$, mainly due to the extensive coverage of *Prosopis juliflora* and other mixed vegetation in the area. Pande *et al.* (2012) also found an incremental soil carbon buildup of ₹ 41,000 ha^{-1} in bamboo plantations with recommended harvest practices.

3.2.3 | Erosion Control: Soil conservation structures, such as check dams, contour bunds, and vegetative barriers, play a key role in storing silt and minimizing nutrient loss. These structures help reduce soil erosion, capture sediment, and prevent nutrient-rich topsoil from being washed away. Nutrients retained in the soil were valued using the market price of nitrogen, phosphorus, and potash, applying the replacement cost technique. Data about silt retention and nutrient loss collected from different reach of the watershed are given in Table 7. The study found that the annual value of nutrients lost through erosion was ₹ 79,931 annually (₹ 117 $ha^{-1}yr^{-1}$). A study by Lemma *et al.* (2017) estimated that soil nutrient loss due to rill erosion in a 768.8 ha watershed amounted to $ 1,341 annually.

3.3 | Cultural Ecosystem Services

Cultural ecosystem services resulting from watershed development pertain to the intangible advantages individu-

TABLE 5 Valuation of Groundwater recharge and water harvesting

Particulars	Pre-project	Post-project
A. *Groundwater storage*		
Average water level fluctuation (m)	1.25	2.25
Specific yield	0.06	0.06
Storage volume (m^3)	511875	921375
Change in groundwater storage due to watershed intervention (m^3)		409500
Value in ₹ ha^{-1}		9007
B. *Surface water harvested*		
Surface (water storage m^3)	5000	22000
Surface water storage per unit area (m^3ha^{-1})	7.2	32.25
Addition in surface water harvested due to watershed intervention (m^3ha^{-1})		24.93
Value in ₹ ha^{-1}		374

TABLE 7 Nutrient value from silt retention as a result of soil and water conservation measures in Badakhera Watershed

Location	Silt retention (tones)	Nutrient retained (kg)		
		N	P	K
			Upper reach	
WUR 1	1500.2	112.7	4.2	274.9
WUR 2	1243.2	92.3	3.1	251.7
WUR 3	1981.2	148.0	4.8	3698.0
WUR 4	673.3	50.6	1.9	123.3
WUR 5	611.9	38.2	1.6	115.3
WUR 6	2668.9	197.8	6.6	514.4
WUR 7	668.4	45.9	1.9	140.8
			Middle reach	
WMR 1	583.7	43.9	1.4	112.4
WMR 2	1200.5	85.5	2.7	171.6
WMR 3	807.5	55.3	1.7	155.6
			Lower reach	
WLR 1	739.5	49.0	1.8	147.9
WLR 2	855.1	54.1	1.9	161.8
Total		973.6	31.7	2376.5
Annual value of nutrients lost using replacement cost (₹)*				79931.4
Cost per ha^{-1} yr^{-1}				117

**Prices of UREA = ₹ 5.36 kg^{-1}, SSP ₹ 7.24 kg and MOP = ₹ 15.7 kg^{-1} https://agritech.tnau.ac.in/*

TABLE 6 Impact of Watershed interventions on Carbon sequestration values

Particulars	Arable lands		Non arable lands	
	Pre-project	Post- project	Pre-project	Post-project
Above ground biomass Carbon stock (t ha^{-1})	14.15	31.7	29.45	52.55
Below ground biomass carbon stock (t ha^{-1})	3.16	6.34	5.21	7.65
Soil carbon stock (t ha^{-1})	2.76	3.34	3.74	6.2
Total Carbon stock (t ha^{-1})	20.07	41.38	38.4	66.4
CO_2 eqv in Mg m t^{-1}	73.68	153.89	140.93	243.69
Area covered in watershed (ha)	36	36	303	303
Total carbon seq. potential Mg (matric tonne) year	2652.48	5540.04	42701.8	73838
Total value of carbon sequestration for treated area @ US $ 10 t^{-1}	26524.8	55400.4	427017.8	738380.8
Change in value due to watershed interventions in US $	-	28875.6	-	311363
Average carbon sequestration value in INR* $ha^{-1}yr^{-1}$ (1 US$ = INR 73)	-	-	-	36392

The carbon credit price in the agricultural sector was US$10.38 in 2020 and US$8.81 in 2021; hence, US$10 was used for computations. Source: www.forest Trends.com als derive from the ecosystems within the watershed. These services foster human well-being by providing education or skill development facilitation, offering recreational activities, and facilitating aesthetic experiences.

3.3.1 | Skill Development: One of the cultural services ecosystems provide to societies is the valuation of training the IISWC provides to watershed implementing agency personnel, watershed committee members, farmers, and engineering students through field exercises and exposure visits. While we have developed valuation methods for several ecosystem services, we have not given much attention to training / education as an ecosystem service. The classification of ecosystem services classifies education as a cultural service. The critical criterion for including the activity as an education service is the direct association of the educational activity with the natural ecosystem. The scope includes institutionally organized watershed education through capacity building and training. One can assess the monetary value of a watershed training ecosystem service, which does not produce a market product, through expenditures or stated preferences associated with the service. Unlike other ecosystem services, the distinctive feature of training services is that the financial costs of providing a training service are relatively well-defined and can be expressed as a specific amount of money. In our case, the sponsor agency or training institution finances the trips for trainees who visit watersheds for educational purposes, eliminating individual expenditures. The valuation of training services was based on the total expenditure for training trips to the watershed, valued at ₹ 483,200 or ₹ 70.8 $ha^{-1}yr^{-1}$ over the past decade (Table 8). Muniyandi Balasubramanian (2021) also estimated the economic value of recreational ecosystem services at sites like Nandi Hills and Nagarhole National Park using a similar approach.

4 | CONCLUSIONS

The study of the Badakhera Ravine Watershed indicates that watershed development initiatives significantly enhance agricultural productivity, livestock production, water storage, groundwater recharge, carbon sequestration, and soil conservation. These initiatives create socio-economic benefits, such as employment opportunities and improved livelihoods for rural communities. The research highlights the crucial role of watershed management in promoting environmental sustainability, economic development, and climate resilience. However, data limitations often hinder the accurate valuation of ecosystem services, underscoring the need for further research to understand their importance fully. The study stresses prioritizing watershed improvement initiatives in ravine ecosystems nationwide. Policymakers can enhance ecosystem services - such as increased agricultural output, groundwater recharge, and carbon sequestration - by implementing soil and water conservation measures, including bunding, land leveling, mechanical structures, and water resource development. This strategy bolsters environmental sustainability and provides socio-economic benefits, such as higher farmer incomes and job creation, ultimately improving rural livelihoods and enhancing national food security. Furthermore, integrating watershed management with agroforestry and livestock rearing can increase the resilience and multifunctionality of these ecosystems, highlighting the essential role of policy in promoting comprehensive and sustainable resource management.

TABLE 8 Watershed training ecosystem service value (₹)

Parameter	Value
a. average travel costs for one trainee (₹). Calculated based on average bus rental price (₹ 667 hr^{-1}), average rental duration (12 hrs), typical trainee group size (25)	667*12/25 = 320.16
b. Total numbers of trainees visited the watershed	1510
c. Watershed training ecosystem service value (₹)	4,83,200
d. Watershed training ecosystem service value ₹ $ha^{-1}yr^{-1}$	70.80

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DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available with the corresponding author.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR'S CONTRIBUTION

AK: Conceptualization, data compilation, methodology, writing original draft, review and editing of manuscript, RKS: Conceptualization, Supervision and editing, IR: Data collection, analysis, review, and editing; SK: Data collection, analysis, review, and editing. KK: Review and editing. GLM: Data collection and Map preparation. AKS: Data compilation. SA: Supervision and editing.

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