

Estimation of ecological products in the Yellow River Basin

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Abstract

The Yellow River Basin, a vital ecological and economic region in China, plays a key role in the country's sustainable development. Substantial economic contributions from water conservation, sediment reduction, carbon sequestration, and greening can be estimated. For example, initial estimates suggested that in 2023, the total economic value of water resources was approximately 55.976 billion CNY, while the value of carbon sequestration reached approximately 312.542 billion CNY. Greening products and soil conservation were valued at 83.301 and 5.177 billion CNY, respectively. These valuations underscore the importance of incorporating ecological products into gross domestic product accounting, in line with President Xi Jinping's vision of ecological civilization and the "Two Mountains Theory". By promoting a balanced integration of ecological protection and economic development, the Yellow River Basin can serve as a model for sustainable development in China and beyond.

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1 Introduction

In August 2005, during an inspection in Anji County, Zhejiang Province, Xi Jinping, the then Secretary of the Communist Party of China Zhejiang Provincial Committee, first expressed the insightful principle that "lucid waters and lush mountains are invaluable assets". Since the 18th National Congress of the Communist Party of China, the "Two Mountains Theory" has been continuously refined and expanded, developing into a major theoretical innovation and a key driver of China's sustainable development and social progress. It holds profound practical and historical significance.

The concept that "lucid waters and lush mountains are invaluable assets" creates a bridge between ecological and economic value. For these waters and mountains to generate economic benefits, the value of green products must be realized, reflecting the value of ecological products. This economic value has two aspects: the intrinsic value of ecological products and the consumable value derived from them. Integrating the economic value of ecological products into gross domestic

product (GDP) accounting represents an important step in applying Xi Jinping's thought on ecological civilization and putting the "Two Mountains Theory" into practice.

2 Overview of the natural and social conditions in the Yellow River Basin

2.1 Hydrology and sediment

Figure 1 shows the annual runoff and sediment inflow data for Tongguan Station from 1919 to 2023. Over the past century, both water and sediment entering the Yellow River Basin have declined considerably, with sediment showing a more pronounced decrease. Although the water-sediment relationship has improved considerably, the long-term challenges of water scarcity and excessive sediment remain unresolved.

2.2 Socioeconomic overview

Figure 2 shows the population and GDP changes from 1950 to 2023 across the nine provinces along the Yellow River. Popu-

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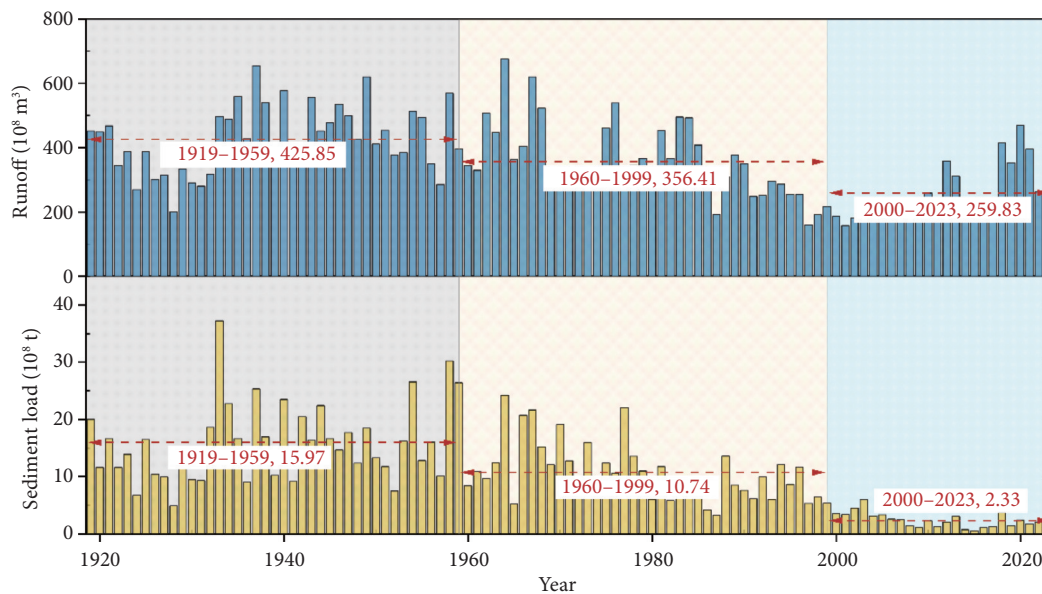


Fig. 1 Annual variations in runoff and sediment load at the Tongguan Hydrological Station from 1919 to 2023.

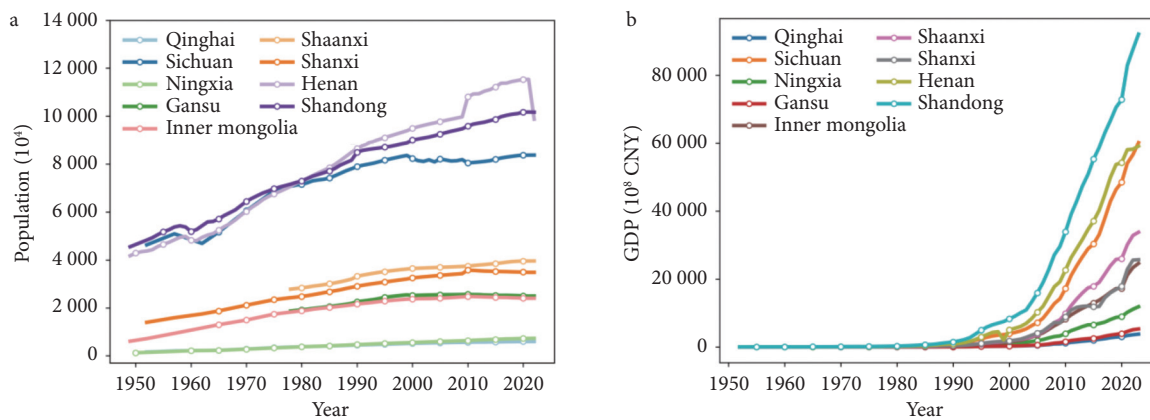


Fig. 2 Population (a) and GDP (b) changes in the nine provinces along the Yellow River.

lation growth has been slow and linear over the past 70 years, stabilizing in recent years, whereas GDP has experienced rapid, nonlinear growth since the economic reform and opening-up period.

The Yellow River Basin is a key national energy base. Table 1 presents the energy reserves in the nine provinces along the river, Table 2 shows their energy production, and Table 3 details their power generation capacity.

2.3 Ecological environment

The estimated carbon emissions of the nine provinces along the Yellow River in 2019 are presented in Table 4.

Figure 3 shows that annual vegetation coverage in the Yellow River Basin has been steadily increasing, driven by reforestation and afforestation projects. This trend has considerably enhanced the region's carbon sink capacity.

The estimated carbon sink for the nine provinces along the Yellow River are presented in Table 5.

Table 1 Energy resources in the nine provinces along the Yellow River.

Province	Coal (10^8 t)	Oil (10^4 t)	Natural gas (10^8 m ³)
Qinghai	12.39	8252.3	1354.44
Sichuan	53.21	623.4	13191.61
Ningxia	37.45	2432.4	274.44
Inner Mongolia	510.27	8381.3	9630.49
Gansu	27.32	28261.7	318.03
Shaanxi	162.93	38375.6	7802.5
Shanxi	916.19	/	413.75
Henan	85.58	4427	74.77
Shandong	77.22	32627.4	348.35

Table 2 Energy production in the nine provinces along the Yellow River.

Province	Coke (10 ⁴ t)	Crude oil (10 ⁴ t)	Gasoline (10 ⁴ t)	Kerosene (10 ⁴ t)	Diesel (10 ⁴ t)	Fuel oil (10 ⁴ t)	Natural gas (10 ⁸ m ³)
Qinghai	182.57	228.5	53.27	0.7	66.9	2.66	64.01
Sichuan	1074.23	7.9	232.3	97.78	216.84	14.95	463.34
Ningxia	920.81	0	168.64	14.44	200.89	25.57	0
Inner Mongolia	4222.53	13.6	167.02	16.55	168.4	7.68	25.55
Gansu	516.84	968.7	450.78	86.52	542.53	2.21	3.9
Shaanxi	4896.51	2693.7	652.11	73.81	689.53	147.68	527.38
Shanxi	10493.7	/	/	/	15	/	85.93
Henan	1847.84	239.9	226.56	56.19	230.19	3.6	2.9
Shandong	3162.55	2219.2	2042.49	187.63	2897.33	954.81	5.77

Table 3 Installed power generation capacity in the nine provinces along the Yellow River.

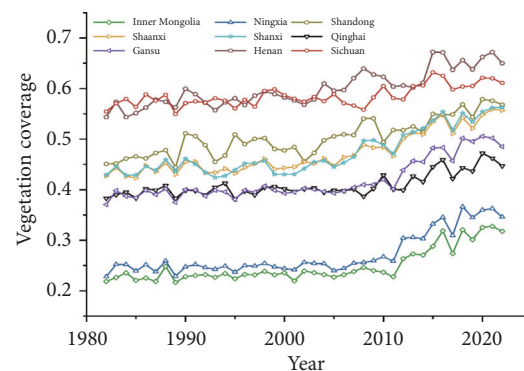
Province	Coal power (10 ⁴ kW)	Hydropower (10 ⁴ kW)	Wind power (10 ⁴ kW)	Solar power (10 ⁴ kW)
Qinghai	389	1305	1185	2561
Sichuan	1844.64	10198.85	770.06	573.57
Ningxia	3313.43	42.62	1463.61	2136.57
Inner Mongolia	10764	238	4773	1556
Gansu	2524.62	971.82	2614.1	2539.78
Shaanxi	5675.76	353.36	1285.33	2292.06
Shanxi	8010.72	225.11	2499.67	2490.45
Henan	7401.96	534.9	2177.92	3731.36
Shandong	11797.68	407.41	2591.13	5692.51

Table 4 Estimated carbon emissions in the nine provinces along the Yellow River in 2019.

Province	Carbon emissions (10 ⁴ t)
Qinghai	1982
Sichuan	10384
Ningxia	8727
Inner Mongolia	29879
Gansu	6358
Shaanxi	15257
Shanxi	30130
Henan	15862
Shandong	43797

2.4 Soil erosion in the Yellow River Basin

The main forms of soil erosion in the Yellow River Basin are water erosion and wind erosion. According to the *Yellow River Basin Soil and Water Conservation Bulletin*, the total area affected by soil erosion in 2023 was 251,100 km², with water erosion covering 181,200 km² and wind erosion accounting for 69,900 km². Based on the *Standards for classification and gradation of soil erosion* (SL190-2007), soil erosion is categorized into five levels: mild, moderate, strong, very strong, and

**Fig. 3** Annual variations in vegetation coverage across the nine provinces along the Yellow River.

extreme. **Table 6** presents the areas and intensity levels of soil erosion in the Yellow River Basin.

2.5 Soil and water conservation measures

Soil and water conservation measures in the Yellow River Basin mainly include engineering, vegetation, and farming interventions. By 2020, these efforts had led to the creation of 6.08 million ha of terraced fields and 58,100 sediment control dams, covering a total area of 85,898 ha. **Table 7** summarizes the construction of sediment control dams in the Loess Plateau region of the Yellow River Basin by province.

Additionally, Fig. 4 shows the forest and grassland areas with varying canopy coverage levels in the primary sediment-producing regions of the Yellow River Basin in 2020.

3 Valuation of ecological products in the Yellow River Basin

Ecological products in the Yellow River Basin refer to ecological services with economic value generated through human

activities. Broadly, these products can be classified into four categories: water conservation, sediment reduction, carbon sequestration, and greening.

The first category, water conservation, is represented by available water resources. The second, sediment reduction, can be quantified by the decrease in sediment achieved through soil and water conservation measures. The third, carbon sequestration, is reflected in the basin's carbon sink values. The fourth, greening, includes improvements in vegetation cover-

Table 5 Estimated carbon sink in the nine provinces along the Yellow River.

Province	Forests (10 ⁴ t)	Crops (10 ⁴ t)	Grasslands (10 ⁴ t)	Total (10 ⁴ t)
Qinghai	2660	41	13311	16013
Sichuan	93670	1687	7459	102816
Ningxia	522	167	1103	1793
Inner Mongolia	78992	927	28842	108762
Gansu	13490	566	6553	20609
Shaanxi	24225	634	1905	26764
Shanxi	7030	458	1666	9154
Henan	12635	2849	1623	17107
Shandong	6175	2750	600	9524

Table 6 Soil erosion area and intensity in the Yellow River Basin (2023).

Erosion type	Total area	Mild	Moderate	Strong	Very strong	Extreme
Soil erosion area	Area (10 ⁴ km ²)	25.11	16.97	5.33	1.77	0.84
	Proportion (%)	100.00	67.58	21.23	7.05	3.34
Water erosion	Area (10 ⁴ km ²)	18.12	11.07	4.55	1.58	0.77
	Proportion (%)	100.00	61.09	25.11	8.72	4.25
Wind erosion	Area (10 ⁴ km ²)	6.99	5.90	0.78	0.19	0.07
	Proportion (%)	100.00	84.41	11.16	2.72	0.99

Table 7 Sediment control dam construction in the Loess Plateau region of the Yellow River Basin (2020).

Province	Silt dams				Area covered (ha)
	Total dams	Large dams	Medium dams	Small dams	
Qinghai	674	173	128	373	212
Ningxia	1104	338	372	394	912
Inner Mongolia	2241	844	673	724	5715
Gansu	1600	560	450	590	2977
Shaanxi	34008	2645	9361	22002	57333
Shanxi	18161	1191	844	16126	18162
Henan	341	107	168	66	587
Total	58129	5858	11996	40275	85898

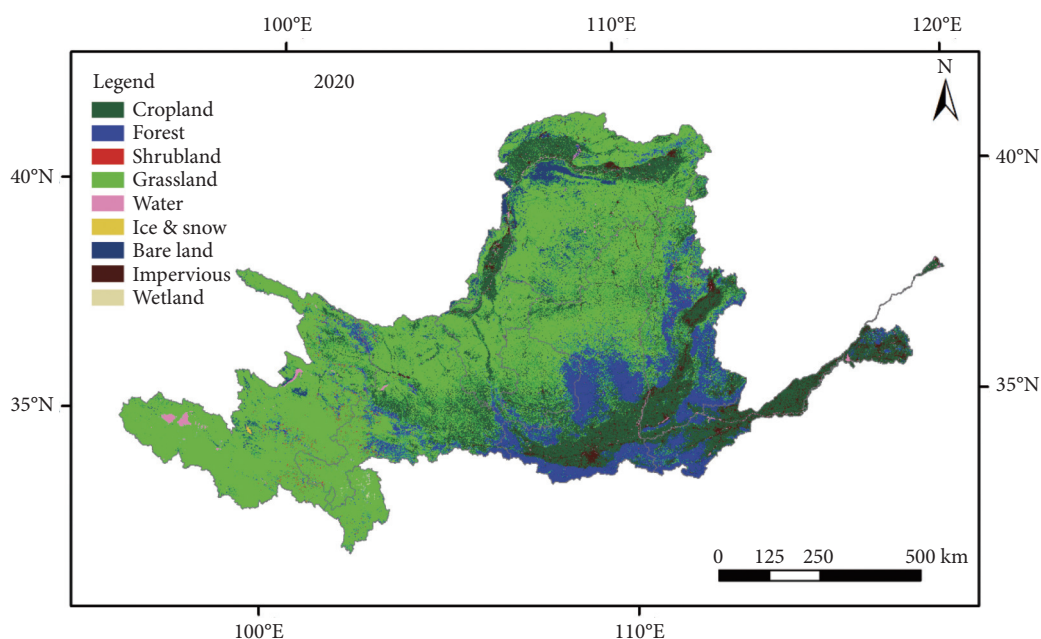


Fig. 4 Forest and grassland areas by canopy coverage level in the main sediment-producing regions of the Yellow River Basin (2020).

age resulting from initiatives such as the Three-North Shelterbelt Project, soil and water conservation on the Loess Plateau, and urban greening efforts.

In November 2023, Ningxia purchased 15 million m^3 of Yellow River water rights from Sichuan for three years at a total price of 18 million CNY, marking the first interprovincial water rights transaction in the Yellow River Basin. The agreed price of 1.2 CNY/ m^3 was determined based on factors including the local water prices for residential and industrial use in Aba Prefecture, Sichuan, and the average water rights transaction price in Ningxia.

In the carbon sink market, Zhejiang Province conducted its first batch of forest carbon sink transactions in December 2022, selling 3,602 t of forestry carbon sinks at a unit price of 100 CNY/t, for a total transaction value of 360,187 CNY. Similarly, in April 2023, Hainan Province completed its first carbon sink transaction from the Xiaohai mangrove ecological restoration project, selling 220 t of carbon sinks at 110 CNY/t. In addition, in December 2023, the first soil conservation carbon sink project was successfully traded in Changting County, Fujian Province, with a total transaction value of 1.8 million CNY.

Regarding greening, the total planned investment for the Three-North Shelterbelt Project is approximately 90 billion CNY, covering an afforestation area of 35.08 million ha, which corresponds to a cost of approximately 257,000 CNY/ km^2 .

In the field of soil and water conservation, the first national transaction of soil conservation ecological products was completed in March 2024 in Anji County, Zhejiang Province. Zhejiang Green Group Longshanyuan Tourism Development Co., Ltd. acquired a six-year development and operational right for eco-tourism resources in the Shimenkeng clean small water-

shed for 33.28 million CNY. The Shimenkeng watershed, covering approximately 57 km^2 , was evaluated to have a current ecological product value of approximately 103 million CNY, equivalent to 1.807 million CNY/ km^2 .

In summary, transactions involving water resources, carbon sinks, soil and water conservation, and other ecological products have been increasing, providing reference points for pricing ecological products in the Yellow River Basin. Based on these benchmarks, this study made preliminary estimates using the following transaction prices: 1.2 CNY/ m^3 for water resources in water rights transactions, 100 CNY/t for carbon sinks in carbon trading, 200,000 CNY/ km^2 for greening products (slightly below cost), and 1.807 million CNY/ km^2 for soil conservation ecological products. Using these values, the economic value of the basin's ecological products in 2023 was preliminarily calculated. The results, detailed in Tables 8–11, present water resources, carbon sequestration, greening, and soil conservation values by province.

4 Pathways for realizing the value of ecological products in the Yellow River Basin

To realize the transformation of ecological value into economic value in the Yellow River Basin, additional approaches are encouraged, including institutional innovation, market mechanisms, and supportive policies.

4.1 Institutional mechanisms

Establishing clear property rights for ecological resources is a prerequisite for realizing their economic value. This requires defining ownership and usage rights for water resources, for-

Table 8 Provincial water supply and associated economic value in the Yellow River Basin.

Province	Water supply (10 ⁸ m ³)	Unit price (CNY/t)	Value (10 ⁸ CNY)
Qinghai	12.83	1.2	15.396
Sichuan	0.27	1.2	0.324
Ningxia	64.79	1.2	77.748
Inner Mongolia	104.03	1.2	124.836
Gansu	40.87	1.2	49.044
Shaanxi	67.84	1.2	81.408
Shanxi	49.34	1.2	59.208
Henan	55.99	1.2	67.188
Shandong	70.51	1.2	84.612
Total	466.47	1.2	559.764

Table 9 Carbon sink values for the Yellow River Basin (2023).

Province	Carbon sink (10 ⁸ t)	Unit price (CNY/t)	Value (10 ⁸ CNY)
Qinghai	1.601	100	160.125
Sichuan	10.282	100	1028.164
Ningxia	0.179	100	17.930
Inner Mongolia	10.876	100	1087.624
Gansu	2.061	100	206.086
Shaanxi	2.676	100	267.645
Shanxi	0.915	100	91.543
Henan	1.711	100	171.065
Shandong	0.952	100	95.241
Total	31.253	100	3125.423

est lands, and other ecological assets. For instance, in water resource management, cross-provincial water rights transactions, such as those between Ningxia and Sichuan, can serve as a model. Likewise, creating a legal framework for carbon sink transactions can help ensure the legitimacy and fairness of such trades.

4.2 Market-based transactions

Expanding market-based mechanisms is essential for efficiently realizing the value of ecological products. Carbon markets and water rights trading platforms should be further developed to facilitate the exchange of ecological resources. Additionally, promoting green financial instruments—such as ecological bonds, green credit, and insurance for ecological resources—can attract private capital to support ecological protection and restoration projects.

Table 10 Greening product values in the Yellow River Basin (2023).

Province	Grassland (10 ⁴ ha)	Forest (10 ⁴ ha)	Unit Price (10 ⁴ CNY/km ²)	Value (10 ⁸ CNY)
Qinghai	5.262	15.103	20	4.073
Sichuan	163.263	4.353	20	33.523
Ningxia	347.209	8.562	20	71.154
Inner Mongolia	1004.173	17.395	20	204.313
Gansu	934.923	149.988	20	216.982
Shaanxi	506.846	342.544	20	169.878
Shanxi	272.285	267.698	20	169.878
Henan	5.517	99.577	20	21.019
Shandong	5.262	15.103	20	4.073
Total	3244.740	920.323	20	833.012

Table 11 Soil conservation values in the Yellow River Basin (2023).

Province	Soil erosion control area (km ²)	Unit price (10 ⁴ CNY/km ²)	Value (10 ⁸ CNY)
Qinghai	480.00	180.7	8.674
Sichuan	26.35	180.7	0.479
Ningxia	363.54	180.7	6.678
Inner Mongolia	520.00	180.7	9.604
Gansu	495.60	180.7	9.055
Shaanxi	293.25	180.7	5.475
Shanxi	459.78	180.7	8.538
Henan	80.63	180.7	1.513
Shandong	92.90	180.7	1.753
Total	2812.05	180.7	51.769

4.3 Policy support

Government policies play a crucial role in enabling and sustaining the transformation of ecological products into economic value. Policies should incentivize ecological conservation and restoration through subsidies, tax exemptions, or direct investments. For example, implementing payment for ecosystem services schemes can reward regions or communities that contribute to ecological protection, such as through afforestation projects or soil conservation efforts. Moreover, regional coordination mechanisms should be strengthened to ensure an equitable distribution of benefits and responsibilities among the provinces along the Yellow River.

4.4 Public awareness and participation

Raising public awareness of the importance of ecological products and encouraging active participation from individuals and communities are essential for sustaining ecological protection efforts. Educational campaigns, community-based programs, and public-private partnerships can foster collective responsibility and promote innovative solutions for ecological sustainability.

4.5 Technological advancements

Adopting advanced technologies can improve the efficiency and effectiveness of ecological product valuation and management. Remote sensing and geographic information systems can provide accurate, real-time data on ecological resources, while big data analytics can support forecasting and decision-making. Furthermore, advancements in carbon sequestration technologies and eco-friendly agricultural practices can further strengthen the ecological benefits of the Yellow River Basin.

5 Conclusion

The Yellow River Basin is a region of critical ecological and economic significance. Evaluating and realizing the value of its ecological products represents an important step in implementing Xi Jinping's ecological civilization thought and the "Two Mountains Theory."

The economic value of water conservation, sediment reduction, carbon sequestration, and greening of the Yellow River Basin offers insights into the basin's ecological and economic contributions. Achieving the economic transformation of these ecological products requires a comprehensive approach, encompassing institutional innovations, market mechanisms, policy support, public participation, and technological ad-

vancements. By establishing a robust system that integrates ecological protection with economic development, the Yellow River Basin can serve as a model for sustainable development in China and beyond.

In conclusion, incorporating ecological products into GDP calculations not only strengthens the scientific basis for decision-making but also highlights the intrinsic value of nature. It provides a practical pathway to balance ecological protection with economic growth, ultimately contributing to the long-term well-being of the Yellow River Basin and its communities.

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Not applicable.

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