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A surface water resource asset accounting method based on multi-source remote sensing data

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Water resource asset (WRA) accounting holds great importance in ecological civilization construction. Existing WRA accounting methods heavily rely on statistical data, resulting in issues such as missing and inaccessible data. Moreover, they only consider the value brought by the physical resources, such as water quantity and quality, while neglecting the value brought by the ecological functions. Therefore, by fully exploiting the rapid, objective, and efficient advantages of remote sensing (RS) in monitoring surface objects, this article develops a surface WRA (SWRA) accounting method based on multi-source RS data. First, a representation model is innovatively proposed, with full consideration of the ecological service functions offered by water resources. Specifically, the SWRAs are represented by two parts: tangible and intangible assets. The tangible asset refers to the quantifiable stock of water resources. Surface water volume is adopted as the indicator for tangible assets in this article. The intangible asset, which primarily embodies the ecological service functions provided by water resources, encompasses five major categories: flood regulation, carbon fixation, oxygen release, water purification, and water conservation. Furthermore, due to different units, the total amounts cannot be summed or compared directly. Therefore, this article utilizes price tools to convert SWRAs into price value, ultimately achieving SWRA accounting. The established method was tested in Miyun, Beijing, China, from 2013 to 2023. The findings demonstrate that the SWRA value reached its peak in 2023, amounting to 56,9368.6 $\times 10^4$ yuan, while it had its lowest point in 2014, standing at 14,7402.7 $\times 10^4$ yuan. The experimental results indicate that the proposed method can quickly provide the SWRA values for many years, offering a methodological foundation for SWRA asset auditing and enhancing the timeliness of the auditing work.

KEYWORDS
surface water resource, asset accounting, remote sensing, tangible assets, intangible assets

1 Introduction

As the foundation of sustainable development, natural resource asset accounting is of great significance to national decision-making, ecological protection, and social equity. In recent years, governments worldwide have introduced a series of policies, such as compiling natural resource balance sheets and establishing a system for auditing outgoing leaders' management of natural resources to advance ecological civilization, conserve resources, and safeguard the ecological environment (Tang et al., 2020). Surface water resources are a vital part of natural resources and play a critical role in human existence and development. With the rapid socio-economic development and profound changes in the environment and climate, concerns regarding surface water resources have become more noticeable, posing a significant constraint to economic development and people's livelihoods (Guan and Hubacek, 2008; Aznar-SÃ¡nchez et al., 2018). Therefore, it is necessary to investigate an effective surface water resource asset (SWRA) accounting method.

Natural resource asset accounting has been studied in recent years (Li and Yin, 2016; Hu et al., 2018; Fang and Ji, 2021). However, the methods described in those articles cannot be directly applied to WRA and fail to comprehensively consider various aspects of WRAs. Consequently, a few studies have begun to separate water resources from natural resources and focus on the WRA accounting. Dee et al. initiated the first research on the WRA accounting index system (Dee et al., 1973), based on which Vilanova et al. developed a new system incorporating economic and social benefits (Vilanova et al., 2015). Lu et al. devised an accounting index system based on the water resource balance sheet, conducting a system to assess the performance of water resource management and protection in Gansu, China, from 2014 to 2016 (Lu et al., 2019). Wang et al. established an accounting index system based on the Drive-Pressure-State-Impact-Response (DPSIR) model (Wang and Yang, 2017) that covers five key aspects: drive, pressure, state, impact, and response. In order to consider the social and economic factors, Yang et al. applied a fuzzy mathematical model of water resource value, taking into account resources, the environment, society, and efficiency (Yang et al., 2017). Furthermore, Chen et al. constructed an accounting index system for the WRA outgoing audit evaluation system from four dimensions: resource, environment, society, and economy (Chen et al., 2023). The article utilized the analytic hierarchy process (AHP) and the initial comparison scoring method to comprehensively assess the water resource management performance of a certain city during 2018–2020. Although the techniques mentioned above establish a comprehensive accounting system for natural resources, they encounter several practical problems and are difficult to apply. One major challenge is that these methodologies heavily rely on regional statistical and survey data, which frequently suffer from issues that include missing or incomplete data and challenges in data acquisition. This reliance restricts the promptness and geographical specificity of the accounting, hence impacting the practical effectiveness of the accounting system. In addition, the current methodologies only evaluate the water resource based on measurable physical factors like quantity and quality without considering the ecological functions offered by natural resources. Hence, it is imperative to research effective and viable accounting approaches for SWRA.

This study proposes an SWRA accounting method based on multi-source RS data that takes full advantage of the rapid, objective, and efficient benefits of remote sensing (RS) technology to greatly enhance the feasibility of accounting operations. The main contributions are:

- This study develops a comprehensive model for representing SWRAs based on the ideas of water resource availability, regulation, and cultural services for gross ecosystem product (GEP) accounting outlined in Zhiyun et al. (2021). The model categorizes SWRAs into two categories: tangible and intangible assets. Surface water volume serves as the tangible asset that includes five primary kinds of ecological services as intangible assets: flood regulation, carbon fixation, oxygen release, water purification, and water conservation.
- The tangible and intangible assets are determined by employing multi-source RS data. Subsequently, through the utilization of price tools, the various assets of surface water are converted into economic values and expressed in monetary terms, thereby establishing a water resource asset accounting table.

The article is organized as follows. Section 2 introduces the materials and the proposed methods, and Section 3 experiments the proposed methods in the Miyun District based on multi-source RS data. The results are discussed in Section 4. The conclusions are given in Section 5.

2 Materials and methods

2.1 Research area and data sources

Miyun District is located in the northeastern region of Beijing, between N 40°13′7″ and 40°47′57″, and E 116°39′33″ and 117°30′25″. It stretches 69 km from east to west and spans 64 km from north to south, covering an area of 2229.45 km^2, making it the largest district in Beijing, as shown in Figure 1. Miyun serves as a crucial reservoir of drinking water source in Beijing, with over two-thirds of its land designated as water protection zones. The district boasts 123 rivers that converge into Miyun Reservoir, providing a continuous drinking water supply for Beijing. Standing in the center of the region, Miyun Reservoir is the largest artificial lake in North China, and it is the only source of drinking water in Beijing.

The RS data used in this article include Landsat Collection 2 Level-2 (LC2L2), Moderate-Resolution Imaging Spectroradiometer (MODIS) MOD16A2, and Global Land Surface Satellite (GLASS) products. Rainfall data are provided by the Beijing Miyun Reservoir Management Office and the China Meteorological Data Service Centre (CMDC). All data are collected from the period of 2013–2023.

2.2 Surface water resource asset accounting method

Figure 2 shows the proposed novel SWRA accounting method, which consists of three major phases. First, the SWRAs are modeled as tangible and intangible assets. Then, SWRAs are calculated based on multi-source RS data. Afterward, the SWRA value is accounted for using price tools. More details are explained as follows.

2.2.1 SWRA model

This section provides a detailed description of the proposed SWRA model. By considering the ecological service function, the

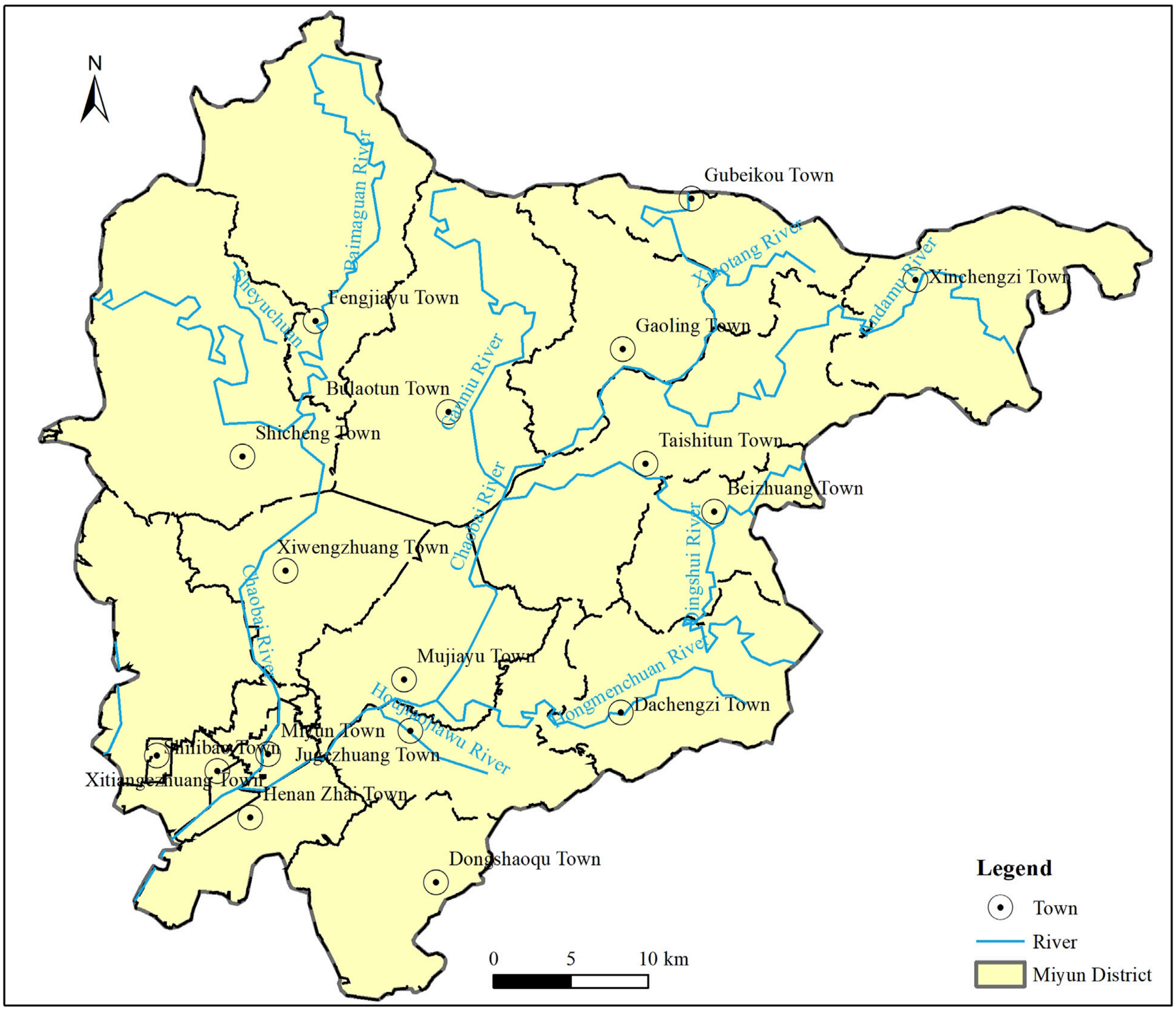

FIGURE 1
Location map of Miyun District, Beijing.

SWRAs are represented as two components: **tangible** and **intangible assets**. Tangible assets refer to physical entities that can be seen and touched, such as water area and volume. This article uses surface water volume as the tangible asset indicator, denoted by Q_v. Intangible assets refer to non-physical entities that offer ecological services. The intangible assets are represented by five indexes: flood regulation, carbon fixation, oxygen release, water purification, and water conservation, and are detailed as follows:

- ***Flood regulation*** (Q_{fr}) is a unique characteristic of natural ecosystems, enabling them to effectively absorb large amounts of precipitation and transit water. This function not only helps accumulate water during peak floods but also reduces and delays the occurrence of flood peaks, thereby significantly mitigating the potential threats and losses caused by flood peaks during the flood season. In principle, the value of flood regulation is only calculated for regions with annual precipitation exceeding 400 mm.
- ***Carbon fixation*** (Q_{ws}) refers to the ability of natural ecosystems to effectively absorb carbon dioxide from the atmosphere and convert it into organic matter, thereby fixing carbon elements within plants or soil. This process not only significantly reduces the concentration of carbon dioxide in the atmosphere but also effectively mitigates the greenhouse effect, playing a crucial role in maintaining the stability of the Earth's climate.
- ***Oxygen release*** (Q_{or}) primarily stems from the process of plants releasing oxygen during photosynthesis. This process not only helps maintain a stable level of oxygen in the atmosphere, ensuring the balance and health of ecosystems, but also has significant implications for improving human living environments and safeguarding the respiratory needs of humans and animals.
- ***Water purification*** (Q_{wp}) achieves the effect of purifying the aquatic environment primarily through the adsorption, degradation, and transformation of pollutants present in the water.
- ***Water conservation*** (Q_{wc}) is an important means for ecosystems to maintain water balance and enhance water

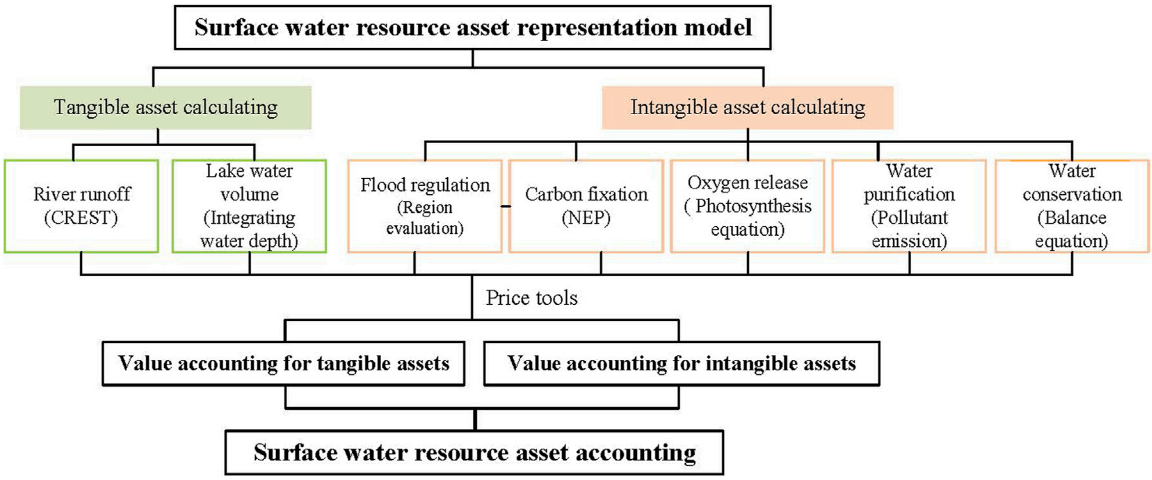

FIGURE 2
Flowchart of the proposed method.

availability. It encompasses functions such as intercepting and retaining precipitation, as well as regulating runoff generated by heavy precipitation. Areas with large water conservation capacity not only meet the water demands of production and living within the accounting region but also continuously provide water resources to areas outside the region.

Due to different accounting units, the total amount cannot be summed and compared. The price tool is applied to convert the assets into price values, hence achieving the SWRA accounting. The ultimate SWRA value is indicated by P and can be expressed as Equation 1.

$$P = f_0(Q_v) + f_1(Q_{wc}) + f_2(Q_{fr}) + f_3(Q_{ws}) + f_4(Q_{or}) + f_5(Q_{wp}), \tag{1}$$

where $f_i(\cdot)$ (i = 0,1, . . . ,5) represents the specific price tool.

2.2.2 Calculating SWRA based on multi-source RS data

As previously stated, most current methods rely on statistical data, which suffer from limitations such as coarse time resolution and significant regional bias. To address these limitations, this study computes the SWRAs, that is, tangible and intangible assets, using multi-source RS data.

2.2.2.1 Tangible asset calculating

According to Section 2.2, this article considers water volume as a tangible asset. The evaluation objects for surface water resources include rivers, lakes, reservoirs, and ponds. The calculation methods for water volume vary between rivers and lakes/reservoirs. Therefore, the surface water volume is determined from two aspects: river runoff and lake water volume. The latter aspect is applicable to reservoirs and ponds.

- **River runoff.** River runoff is estimated by multiplying the length of the runoff by the flow rate of the cross-section, which is defined as Equation 2.

$$Q_v = L \times S_{cs}, \tag{2}$$

where L (m) is the length of the runoff and S_{cs} (m^2) is the flow rate of the cross-section. More precisely, the length of the runoff is calculated by the water area. In addition, the flow rate of the cross-section is determined by the distributed hydrological model, that is, coupled routing and excess storage (CREST) (Wang et al., 2011).

- **Lake water volume.** The calculation of lake water volume is achieved by integrating water depth within the water range, which is defined as Equation 3.

$$Q_v = \int_S H dh, \tag{3}$$

where S (m^2) is the water area. H (m^2) is the water depth, which is calculated by the established model between optical imagery and water depth in Ren et al. (2023).

2.2.2.2 Intangible asset calculating

As discussed in Section 2.2, the intangible assets are represented by five indexes: water conservation, flood regulation, carbon fixation, oxygen release, and water purification.

- **Flood regulation.** The GEP guideline categorizes China into five regions based on the substantial variations in climatic conditions: the Eastern Plain, the Mongolian-Xinjiang Plateau, the Yunnan–Guizhou Plateau, the Tibetan Plateau, and the Northeast Plain and Mountains. A distinct evaluation model for flood regulation is established for each region: Q_{fr} (10^{4}m^3/a),

$$Q_{fr} = \alpha e^{\beta} S^{\gamma}. \tag{4}$$

The specific values of α, β and γ in different regions are listed in Table 1 and can be obtained from Zhiyun et al. (2021).

- **Carbon fixation.** This article adopts the net ecosystem production (NEP) method to quantify carbon fixation. NEP is a crucial

TABLE 1 Parameters for flood regulation evaluation in different regions.

Region	α	β	γ
Eastern Plain	3.19	4.924	1.128
Mongolian-Xinjiang Plateau	0.26	5.653	0.680
Yunnan–Guizhou Plateau	0.36	4.904	0.927
Tibetan Plateau	0.14	6.636	0.678
Northeast Plain and Mountains	0.98	5.808	0.866

scientific indicator used to quantitatively analyze the carbon source/sink of ecosystems and measure the carbon fixation. Carbon fixation Q_{cf} (tCO^2/a) can be described as Equation 5.

$$Q_{cf} = \text{NEP}\frac{M_{CO_2}}{M_C}, \tag{5}$$

where $\frac{M_{CO_2}}{M_C} = \frac{44}{12}$ is the conversion factor from carbon to carbon dioxide. NEP (tC/a) is derived by

$$\text{NEP} = \alpha\text{NPP}\frac{M_{C_6}}{M_{C_6H_10O_5}}, \tag{6}$$

where α is the conversion coefficient between NEP and net primary productivity (NPP) (t dry matter/a). $\frac{M_{C_6}}{M_{C_6H_10O_5}}$ represents the coefficient for converting dry matter into carbon elements. NPP can be derived by using the vertically generalized productivity model (VGPM), the inputs of which include chlorophyll-a concentration, suspended matter concentration, water surface temperature products, and processed photosynthetically active radiation intensity. All the VGPM parameters can be obtained by traditional RS quantitative methods based on the commonly used optical RS images, such as Landsat, SPOT, and MODIS.

- **Oxygen release.** The chemical equation of photosynthesis reveals that for every 1 mol of carbon dioxide absorbed, plants release 1 mol of oxygen during photosynthesis. Therefore, the oxygen release Q_{or} (t oxygen/a) can be derived using the following equation:

$$Q_{or} = Q_{cf}\frac{M_{O_2}}{M_{CO_2}}, \tag{7}$$

where $\frac{M_{O_2}}{M_{CO_2}} = \frac{32}{44}$ is the conversion factor from carbon dioxide to oxygen.

- **Water purification.** This section adopts the pollutant emission accounting method to compute the water purification Q_{wp} (kg/a), which is defined as Equation 8.

$$Q_{wp} = \sum_{i=1}^{n} p_i, \tag{8}$$

where p_i represents the amount of the i-th emission (kg/a).

- **Water conservation.** The water conservation is quantified by the water balance equation. The equation defines that the water conservation Q_{wc} (m^3/a) is equal to the precipitation minus the storm runoff and the water consumption by the ecosystem itself, which can be defined as

$$Q_{wc} = \sum S\frac{R - Q_v - \text{ET}}{1000}, \tag{9}$$

where ET (mm/a) is the evapotranspiration, usually provided by the MODIS MOD16A2. R (mm/a) is the precipitation coming from local weather bureaus.

2.2.3 SWRA value accounting by price tools

This section uses price tools to unify the accounting units, assess the economic value of the SWRAs acquired earlier and present that value in monetary terms.

2.2.3.1 Value accounting for tangible assets

The calculation of volume value is based on the market value method, that is, as Equation 10.

$$V_v = Q_v P_v, \tag{10}$$

where P_v represents the surface water resource fee according to the local collection standards and calculation methods of water resource fees.

2.2.3.2 Value accounting for intangible assets

- **Flood regulation.** The substitution cost method (i.e., the construction cost of a reservoir) is applied to calculate the value of flood regulation V_{fr}, which is defined by the following Equation 11.

$$V_{fr} = Q_{fr} P_{cm}, \tag{11}$$

in which P_{cm} (yuan/m^3) represents the construction and maintenance cost per unit capacity of a reservoir.

- **Value of carbon fixation.** The value of carbon fixation V_{cf} (yuan/a) is estimated by the market value method as Equation 12.

$$V_{cf} = Q_{cf} P_C, \tag{12}$$

where P_C is the carbon price (yuan/t). For this study, the Swedish carbon tax price is used, which is approximately 919.7 yuan/t.

- **Oxygen release.** This study adopts the market value method (i.e., the price of oxygen production) to calculate the value of oxygen provided by the ecosystem. The value of oxygen release V_{or} (yuan/a) is shown as Equation 13.

$$V_{or} = Q_{or} P_O, \tag{13}$$

where P_O (yuan/t) is industrial oxygen price. In the case of the water-electrolytic oxygen-making method, the cost of industrial electricity is approximately 0.7 yuan/kW·h. In addition, the electrolysis to obtain 1 t oxygen consumes 4110 kW·h of electricity, which translates to approximately 2877 yuan needed to electrolyze water to obtain 1 t oxygen. Hence, the price of industrial oxygen production is 2877 yuan/t.

- **Water purification.** This study adopts the substitution cost approach to estimate the value of the water purification V_{wp} (yuan/a). Specifically, by multiplying the amounts of water purification by the unit cost of pollutant treatment, V_{wp} are defined as Equation 14.

$$V_{wp} = \sum_{i=1}^{n} Q_{wp(i)} P_{(i)}, \tag{14}$$

where $Q_{wp(i)}$ is the purification amount of the i-th $(i = 1, 2, ..., n)$ water pollutant (t/a). $P_{(i)}$ is the unit treatment cost of the i-th water pollutant (yuan/t).

- **Water purification.** The unit treatment costs of pollutants such as total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD) are determined by the *Pollution Charge Collection Standards and Calculation Methods* published by the National Development and Reform Commission. The billing unit is pollution equivalent. The levy standard per equivalent is 0.7 yuan. The pollution equivalent of a pollutant is the ratio of the emission amount (kg) of that pollutant to its pollution equivalent value (kg).
- **Water conservation.** The value of water conservation is primarily manifested in the economic value of water storage and retention. This study employs the shadow engineering method, which aims to quantify the economic value of water conservation by simulating the construction of water conservancy facilities that match the actual water conservation in the ecosystem. This method reflects the value of the ecosystem's water conservation function by estimating the cost of constructing such a water conservancy facility. The value of water conservation V_{wc} (yuan/a) is calculated as follows Equation 15.

$$V_{wc} = Q_{wc} P_{mp}, \tag{15}$$

in which P_{mp} is the trading market price of water resources. When a trading market is not established, the construction and maintenance costs of a reservoir P_{cm} or the shadow prices of water resources can be used.

3 Results

In order to analyze the effectiveness of the proposed accounting method in this article, we select Miyun City, Beijing, as a research area to realize its SWRA assessment over a period of 10 years, from 2013 to 2023.

3.1 Using the proposed method to calculate the value of the tangible assets

The evaluation objects for surface water in Miyun include rivers, reservoirs, and ponds. The section runoff for rivers is calculated by the trained CREST model in Wang et al. (2011), and the river length is calculated by ArcMap. We determine the water depth for reservoirs and ponds using the inversion model in Behrenfeld and Falkowski (1997). The water volume can be calculated by combining the surface water area in Miyun following Kang et al. (2023).

China is divided into six regions based on the collection standards for water resource fees. The average collection standard for surface water resource fees in Beijing and Tianjin is 1.6 yuan/m^3. The average collection standard in Shanxi and Inner Mongolia is 0.5 yuan/m^3. The standard in Hebei, Shandong, and Henan is 0.4 yuan/m^3, and the standard in Liaoning, Jilin, Heilongjiang, Ningxia, and Shaanxi is 0.3 yuan/m^3. The standard in Jiangsu, Zhejiang, Guangdong, Yunnan, Gansu, and Xinjiang is 0.2 yuan/m^3. The standard in the remaining regions is 0.1 yuan/m^3. The average collection standard for surface water fees in Miyun is aligned with the standard set for Beijing and Tianjin, which is 1.6 yuan/m^3.

3.2 Using the proposed methodintangible assets

3.2.1 Flood regulation

Because Miyun belongs to the eastern plain region, the flood regulation is calculated by $Q_{fr} = 3.19e^{4.924}S^{0.866}$, according to Equation 4 and Table 1. The total storage capacity of Miyun Reservoir is 4.375×10^9 m^3, and its total construction cost is 680×10^6 yuan, resulting in a unit storage capacity construction cost of approximately 0.1554 yuan/m^3. The maintenance cost is 2% of the construction cost.

3.2.2 Carbon fixation

The carbon fixation is derived by Equation 4, and the NEP is calculated by Equation 6. The conversion coefficient between NEP and NPP is 0.086 in Beijing. The NPP is calculated using the VGPM model trained in Behrenfeld and Falkowski (1997). The inputs of VGPM are the maximum photosynthesis rate of the water body, photosynthetically active radiation intensity, Zeu (euphotic depth), and illumination period. The maximum photosynthesis rate of a water body is the function of temperature. Photosynthetically active radiation intensity can be obtained by GLASS. Zeu can be calculated by suspended matter concentration and chlorophyll concentration, which can be inferred based on LC2L2. The illumination period is calculated by the average sunrise and sunset times.

3.2.3 Oxygen release

After acquiring the carbon fixation, the oxygen release can be derived according to Equation 7.

3.2.4 Water purification

In these experiments, three emissions, including total nitrogen, total phosphorus, and COD, are chosen. The TP, TN, and COD are calculated by models in Li et al. (2017), Duan (2006), and Peng (2022), respectively. All models take LC2L2 SR data as inputs. The pollution equivalents for TN, TP, and COD are 0.8, 0.25, and 1, respectively.

3.2.5 Water conservation

The evapotranspiration in Equation 9 comes from MODIS MOD16A2. The rainfall data are obtained from the Miyun precipitation station. The surface water area in Miyun is obtained by Kang et al. (2023).

4 Discussion

The numerical values of the individual SWRAs are listed in Table 2, and their economic values are listed in Table 3. As can be seen clearly, the water resources in Miyun decreased significantly from 2013 to 2015, with notable reductions in various aspects.

TABLE 2 The numerical values of water storage and five SWRAs in Miyun from 2013 to 2023.

Year	Water volume (10^8m^3)	Flood regulation ($10^6m^3/a$)	Carbon fixation (tCO^2/a)	Oxygen release (tCO^2/a)	Water purification (kg)	Water conservation ($10^6m^3/a$)
2013	12.43	784.21	3014.15	2192.11	44,201.87	12.5
2014	8.41	743.48	2877.41	2092.66	42,629.99	16.52
2015	10.35	583.75	2261.72	1644.89	333,896.34	15.98
2016	16.47	736.19	2461.05	1789.86	41,540.07	22.48
2017	20.31	962.26	4239.67	3083.40	52,384.47	38.72
2018	25.74	1177.14	5230.48	3803.99	62,917.14	43.37
2019	24.98	1325.93	5540.94	4029.77	69,822.25	42.20
2020	24.75	1193.36	4797.39	3489.01	62,951.37	35.64
2021	33.43	1285.1	4533.36	3296.99	67,392.14	140.20
2022	29.96	1457.7	6173.92	4490.13	75,069.79	25.41
2023	34.14	1329.28	5121.01	3724.37	70,183.48	32.19

TABLE 3 Economic values for water storage and five SWRAs (10^4yuan) in Miyun from 2013 to 2023.

Year	Water volume	Flood regulation	Carbon fixation	Oxygen release	Water purification	Water conservation
2013	198,852.89	12,430.39	277.21	630.67	5.16	198.11
2014	134,484.35	11,784.81	264.64	602.06	5.03	261.83
2015	165,590.83	9252.91	208.01	473.23	3.91	253.32
2016	263,495.25	11,669.25	226.34	514.94	4.8	356.39
2017	324,967.72	15,252.61	389.92	887.09	5.99	613.69
2018	411,894.15	18,658.741	481.05	31,094.41	7.25	687.38
2019	399,694.32	21,017.1	509.6	1159.37	8.02	668.91
2020	396,007.68	18,915.76	441.22	1003.79	7.11	564.97
2021	534,953.31	20,369.96	416.93	948.54	7.66	2222.33
2022	479,311.75	23,106.41	567.82	1291.81	8.48	402.72
2023	546,237.68	21,070.1	470.98	1071.5	8.09	510.28

The data presented in Table 2 clearly show that the water gradually dried up from 2013 to 2015. However, it has seen a large-scale and sustained increase since 2015, stabilizing by 2019. This outcome demonstrates the effectiveness of the South-to-North Water Diversion Project, which was put into operation at the end of 2014. It opened up a new water source for Beijing. Over 70% of the water supply in urban Beijing now comes from the Middle Route, effectively alleviating the city's water shortage and allowing Miyun Reservoir to recover and replenish. In 2020, due to maintenance work on the Beijing section of the Middle Route, the water supply decreased, resulting in a slight drop in water volume. By 2023, over 200×10^6 m^2 of water from the Middle Route had been stored in Miyun Reservoir, leading to a continuous increase in its water storage capacity.

As indicated in Table 3, Beijing's SWRA values have steadily increased since 2015. This positive change is not only attributed to the implementation of the *South-to-North Water Diversion Project* but is also inseparable from the strategic deployment of the local government, such as the *Miyun "5+2" water conservation system*. These projects prioritize water resource protection, spare no effort in safeguarding water sources, strengthen ecological construction, and pursue the path of green development. Note that the value of water conservation reached an abnormal maximum in 2021. This is because Beijing experienced an extraordinarily long flood season lasting 122 days, with 79 rainfall events occurring from June 1st to September 30th in 2021. Of these, 10 rainfall events reached or exceeded the intensity of heavy rain, including two instances of torrential rain. In addition, overall climate conditions were poor in Beijing in 2022, featuring a marked warm and dry climate, with precipitation being the lowest since 2012. Therefore, there was a notable decrease in the value of water conservation in 2022.

5 Conclusion

In response to the deficiencies of existing water resource accounting methods, this article proposes a novel approach to water resource asset accounting based on multi-source remote sensing data. This method considers the ecological service functions of water resources, encompassing both tangible and intangible assets. It further realizes the valuation of assets through pricing tools, providing a more accurate and efficient methodological foundation for water resource asset auditing. Taking Miyun, Beijing, as an example, this article utilizes the proposed method to conduct a rapid SWRA accounting in Miyun District from 2013 to 2023. The results indicate that the value of SWRA is the highest in 2023, reaching 97454×10^4 yuan, while it was the lowest in 2014, at 25206×10^4 yuan.

Data availability statement

Publicly available datasets were analyzed in this study. These data can be found here: https://geocloud.cgs.gov.cn/#/home.

Author contributions

HK: data curation, formal analysis, methodology, writing–original draft, and writing–review and editing. WD: conceptualization, project administration, and writing–review and editing. LC: investigation, methodology, resources, writing–review and editing, and funding acquisition. LH: methodology, software, and writing–review and editing. XS: funding acquisition, supervision, writing–review and editing, and resources. ZD: visualization, writing–review and editing, and formal analysis.

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Conflict of interest

Author HK was employed by China Mobile Communications Group Beijing Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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