Environment, Development and Sustainability (2024) 26:7735–7756
https://doi.org/10.1007/s10668-023-03030-5

Pricing of water rights transactions for major water transfer projects considering water quantity and quality

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Received: 30 August 2022 / Accepted: 9 February 2023 / Published online: 25 February 2023

Abstract
Water rights transactions are an important way for countries to use market mechanisms to optimize the allocation of water resources. Taking the South-North Water Transfer East Project (SNWDP-ER) in China as an example, a full cost pricing model (FCPM) is used to construct an accounting framework for water rights transactions. Water quality factors are innovatively introduced into the model to carry out a study on water rights trading pricing (WRTP) from the perspective of combining water quantity and quality. The results show that: (1) the actual WRTP (1.25 yuan/m^3) for the first phase of the SNWDP-ER was low and in fact not sufficient to cover the corresponding costs. (2) By calculating the ability of water users to pay, and comparing this situation with advanced overseas cases, the conclusion was reached that the FCPM of WRTP (1.63 yuan/m^3) is reasonable. (3) The method of accounting for the WRTP for major projects that take into account water quantity and quality and that are conducive to strengthening ecological protection in river basins is generally feasible. Reasonable WRTP for major projects can promote water market reform by bringing user fees, improving the competition mechanism in the water market, and reducing the financial payments pressure.

Keywords South-to-North water diversion project · Water rights trading pricing · Water quality · Water quantity · Ecological compensation

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1 Introduction

Water is a fundamental natural resource that sustains societies, economies, and ecosystems (Ahmed et al., 2021; Gleick, 2003); water is also one of the basic elements of production. Currently, the conflict between water supply and demand has become a global issue, severely limiting rapid socio-economic development (Murdock et al., 1991). In this context, the international community is now attaching great importance to the rational allocation of water resources. Market and economic instruments are used with a view to improving the efficiency of water use and promoting sustainable economic development (Bhave et al., 2018; Di et al., 2020). On the basis of their national and water conditions, different countries have proposed a series of plans for water resources management and have actively explored corresponding water rights systems to resolve inter-regional water conflicts (Null & Prudencio, 2016; Philpot et al., 2016).

Water scarcity and uneven spatial distribution are also fundamental to China's national situation. This is especially the case in the arid northern regions where water resources are overexploited and ecological degradation is more serious (Berrittella et al., 2006). For many years, China has been increasing capital investment in the construction of various water conservancy projects, and a number of major water transfer projects (MWTP) have been launched. Examples include the South-to-North Water Diversion Project, the Luanhe-Tianjin Water Diversion Project, and the project of water diversion from the Yellow River into Qingdao (Chen et al., 2013). However, as one of the basic elements of production, water resources have not been given sufficient attention with regard to their economic attributes. In fact, the price of water rights has been at a low level for a long time, resulting in the inefficient allocation of water resources.

In 2012, the 18th National People's Congress of the Communist Party of China clearly proposed to actively carry out pilot water rights trading. In 2017, the "Several Opinions of the Central Committee of the Communist Party of China and the State Council on Deepening the Structural Reform of the Agricultural Supply Side and Accelerating the Cultivation of New Momentum for Agricultural and Rural Development" emphasized accelerating the construction of water rights and water markets, as well as promoting the confirmation and entry of water resources use rights. In 2020, the 14th Five-Year Plan called for promoting the market-based trading of water rights. The policies at the national level fully reflect China's strategic need to strengthen water rights management. Water rights trading pricing (WRTP) can solve the contradiction between the static nature of the initial allocation of water rights and the dynamics of social and economic development (Wang et al., 2017). Importantly, however, the transaction price will play a key role in the smooth realization of water rights transactions. A transaction price that is too low not only damages the interests of the water rights transferor, but also is not conducive to the conservation and protection of water resources. A transaction price that is too high may increase the water rights transferee's water cost, making it difficult to achieve the transaction. Therefore, determining the transaction price of water rights is not only conducive to creating an effective water rights market, but is also conducive to solving the contradiction between the spatial and temporal distribution of water resources and promoting the optimal allocation of water resources (Wang et al., 2017).

The WRTP directly affects the smooth implementation of the water rights trading system. As such, how to reasonably determine the WRTP has become a key topic of discussion in academic circles. Scholars have mostly studied the WRTP from the perspectives of both influencing factors and theoretical models. In terms of influencing factors, Murdock et al. (1991) suggested that the pricing of water rights transactions should consider social, economic, demographic, natural environment, and other factors. Michelsen et al. (2000) argued that changes in the WRTP are mainly influenced by the reliability of supply, location of supply, and type of use. Bjornlund and Mckay (2002) found that the cost of the water rights market includes the cost of the system and the cost of water conservancy facilities. Brewer et al. (2008) studied the impact of the extent, nature, and timing of water transfers on the WRTP. Payne and Smith (2013) analyzed the impact of the number of transactions, year, location, new use of water rights, and whether the transaction occurred in a dry year on the price of water. Li et al. (2018) analyzed the important role of the ecological environment in water rights transaction prices from the perspectives of river runoff, groundwater, ecological flow, and water ecosystem. The study emphasized the importance of ecological environmental effects. Wu et al. (2021) argued that water scarcity directly affects the transaction price. In addition, for MWTP, the cost of new construction and expansion, as well as the cost of normal operation, management, and maintenance of such projects and the depreciation of fixed assets are also key concerns.

In terms of the WRTP methods, commonly used methods include the shadow price approach, linear programming (Mosha et al., 2016), econometric models (Pullen & Colby, 2008), neural network analysis (Khan et al., 2010), and game theory methods (Sechi et al., 2011). However, these methods have the following common shortcomings: (i) The resources and economic data required for the model are not readily available and in any event are not applicable to the market characteristics of China's water rights trading market at its initial stage of development. (ii) It is difficult to make the constraints that express the human and economic benefits of water resources projects visible during the construction of the model. (iii) The resulting price only reflects the scarcity of the resource and cannot replace the cost value of the resource itself.

The burgeoning theory and practice of WRTP have led to more researchers advocating the use of water markets to address watershed ecosystems (Bakker, 2014; Kuwayama & Brozović, 2013). However, only a few studies have focused on water quality trading in water markets (Jamshidi et al., 2014); the pricing models in these studies also fail to adequately reflect the value of water resources well. Accordingly, based on the characteristics of China's water rights market, this paper uses the full cost method to construct a water rights transaction price model that considers water quality and quantity. The South-North Water Transfer Project in China provides an example of this research. This is the largest inter-basin water transfer project in human history, affecting the largest number of people (Pohlner, 2016). In the case of the South-North Water Transfer, for example, the characteristics of an MWTP can be more fully integrated to establish a pricing methodology for water rights trading that is consistent with an MWTP.

Empirically, this paper adds a limited study of the WRTP for MWTP (Svensson et al., 2021), takes into account the impact of resource scarcity and water quality scarcity on water prices, and revises the current resource water price model. The aim is to provide new empirical evidence for the study of limited water markets in the context of inter-basin transfers (Pérez-Blanco et al., 2020). The incremental contributions of this paper mainly include three points. First, the water quality factor is innovatively introduced into the WRTP model. This study fully considers the impact of water quality on the transaction price of water rights, promotes the practical development of using the water market to solve ecological problems in the basin, and ensures the fairness of water rights transactions. The second is to innovatively introduce ecological compensation factors into the MWTP. This opens up new channels for the source of funds for ecological compensation in water source areas, and changes passive "blood transfusion" into active "hematopoiesis." This will improve the

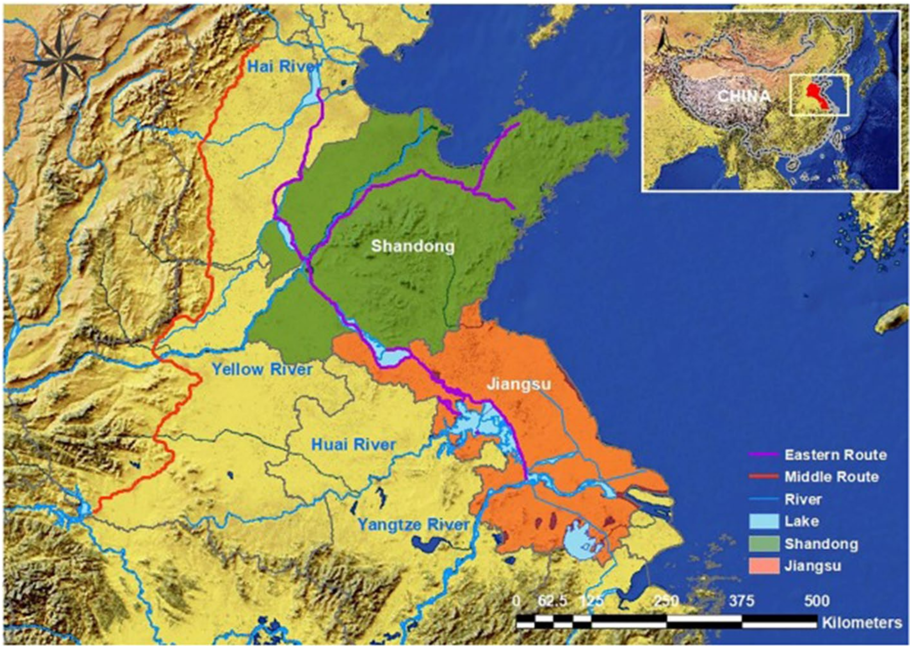

Fig. 1 China's South-North Water Transfer East Project

enthusiasm for water rights trading. Third, the FCPM is adopted to calculate the WRTP, which fully considers the direct cost of water resources utilization and the hidden cost of water environment governance, so as to improve the rationality of WRTP.

2 Materials and methods

2.1 Study area

The South-North Water Diversion Project draws Yangtze River water from Jiangdu, Yangzhou, downstream of the Yangtze River, and uses the Beijing-Hangzhou Grand Canal and its parallel rivers to transport water northward. Also, Hongze Lake, Luoma Lake, Nansi Lake, and Dongping Lake are used to transfer water, and the water is then distributed water in two ways after leaving Dongping Lake. One way is to the north, to Tianjin. The other way is to the east and economic south to Yantai and Weihai. Figure 1 is referenced from *Water quality and incentive coordination in water markets: The eastern route of China's South-North Water Transfer Project* (Sheng et al., 2022).

The total length of the main water transfer line for the first phase of the South-North Water Transfer East Project (SNWDP-ER) is 1466.50 km. That total is comprised of 735.70 km from the Yangtze River to Nansi Lake, 309.70 km from Nansi Lake to Dongping Lake, 173.50 km north of the Yellow River, 239.80 km of the Jiao Dong water transfer main line, and 7.90 km through the Yellow River section. The first phase of the SNWDP-ER has been in operation since November 2013 and by 2020 had completed the transfer

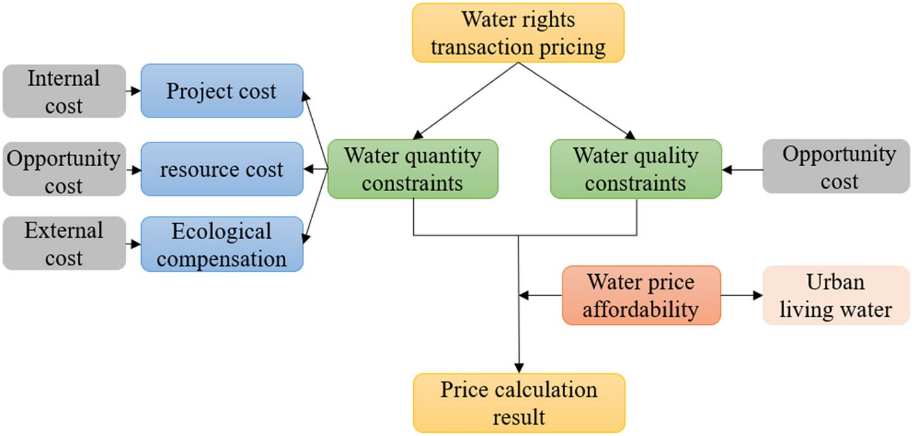

Fig. 2 Flow chart of FCPM for MWTP

of 52.97 billion cubic meters (m^3) of water to Shandong Province (Fig. 2). Water is transferred from the lower reaches of the Yangtze River to the Shandong Peninsula and northern Lu, supplementing urban domestic, industrial, and environmental water use in Shandong, Jiangsu, and Anhui along the water transfer route. Agriculture, shipping, and other water use are also taken into account. On the basis of the full implementation of the East Line pollution control unit project, the water quality of the main water conveyance lines in the planned level year basically reaches the Class III standard for surface water.

2.2 Methods

The FCPM is a model based on economic theory. At present, the global consensus is that full-cost water prices can highlight the commodity property of water resources (Ortega et al., 2005). Full-cost prices reflect the capital cost, operating cost, and environmental cost of water, rather than only considering the direct cost of water resources, construction, and maintenance of its development and utilization project. Full-cost prices also take into account the hidden costs of water environment governance and protection, which can better reflect the value of water resources (Bhojwani et al., 2019).

The FCPM is based on all the costs incurred during the social cycle of water resources (Reznik et al., 2016). This cycle includes the whole process of water resource extraction, purification treatment, distribution, transportation, utilization, etc. The sum of all costs in this process is the full cost, also known as the social cost. This is the real cost paid by the whole of society for the utilization of water resources.

From the perspective of economics, the FCPM consists of three parts: opportunity cost, internal cost, and external cost.

The quantity and quality of water are the key factors affecting the pricing of water rights in MWTP. In terms of the WRTP of MWTP that is based on water quantity, this mainly includes three parts: project cost, resource cost, and ecological compensation (Bhojwani et al., 2019). Among the three components, project cost mainly refers to the investment in the construction, operation, and maintenance of water conservancy projects. These factors represent is the internal cost of water resources (Bjornlund & Mckay, 2002). The resource cost refers to the value of the actual water resources, because the water provider can use this element of the water resources to achieve income. This is also known as the opportunity cost of water resources. Ecological compensation mainly refers to the environmental value of water resources, which can also be called the external cost of alternative compensation. In terms of the WRTP of MWTP that is based on water quality, the water quality is also obviously an important reflection of the value of water resources. This factor also belongs to the opportunity cost of water resources.

In addition, considering the rationality of the WRTP of MWTP, it is necessary to analyze the water prices' affordability in water-receiving areas.

The specific method flow is shown in Fig. 2.

2.2.1 Hypothesis

It is one of the basic theorems of the market economy that supply and demand determine price. Importantly, however, water rights are different from general commodities. The primary principle of water rights trading is to maintain social and economic development. In order to eliminate the influence of supply and demand factors on the model, simplify the model, and reflect the essential problems of the model, Hypothesis 1 is proposed.

Hypothesis 1 Let the pricing of transactions be independent of market supply and demand factors and with the objective of maximizing overall social welfare.

The transaction of water rights in MWTP is usually dominated by the government, and that same government has almost no transaction problems. In order to define the research object of this paper and provide conditions for the calculation and the WRTP in MWTP, Hypothesis 2 is proposed.

Hypothesis 2 The buyers and sellers of water rights belong to different government administrations, and there are MWTP in the two regions to meet the water transfer needs of water conservancy transactions.

2.2.2 FCPM for the MWTP

2.2.2.1 The model for the WRTP under water quantity constraints

(1) Project cost
(2) Project construction investment

The construction cycle of MWTP is long and costly in terms of the drain on human, financial, and material resources. The time and capital costs should be taken into account when developing a WRTP to more accurately reflect the engineering construction investment in MWTP (Bjornlund & Mckay, 2002). Assuming that the moment the project is put into operation is the starting point of capital recovery time, according to the capital recovery formula, one can calculate the annual value of capital recovery for the equivalent amount of project construction investment A, as follows:

$$A = PV \cdot \frac{i(1+i)^t}{(1+i)^t - 1} \tag{1}$$

where the depreciation period of the project is t, the annual interest rate of the loan is i, and the present value of the project investment funds, discounted to the moment the project is put into operation is PV.

(② Project operation and maintenance costs

In the water transfer process, the main works and treatment works that support the smooth running of the MWTP need to be repaired and maintained in a timely manner. Therefore, a certain percentage of the total costs are spent each year to ensure the smooth operation of the projects (Liu, 2014). The annual value of the equivalent capital recovery from the construction investment and the operation and maintenance costs of the project is converted into a unit WRTP based on the investment in the project, as follows:

$$P_p = \frac{A + OP}{Q} \tag{2}$$

where the annual operation and maintenance cost of the MWTP is OP, and the annual quantity of water transferred by the project involved in the water rights transaction is Q.

(B) Resource cost

The resource cost reflects the value of the water resource itself, which is transferred and better reflected in the transfer of the water source to the water-receiving areas. Since the water resources of the water-source areas are transferred to the water-receiving areas, the water resources available in the water-source areas will be correspondingly reduced. The water resource fee collected by the water-source area's government from the local residents will also be correspondingly reduced. Therefore, the water-receiving areas should bear part of the water resource fee P_W that is lost by the water source government due to the water transfer.

(C) Ecological compensation

MWTP transfers water resources from the water-source areas to the water-receiving areas, while this alleviates the tension of water scarcity and water difficulties in the water-receiving areas; the transfer can also have certain impacts on the production, life, and ecology of the water-source areas (Sheng et al., 2022). Therefore, ecological compensation should be included in the pricing methodology when calculating the WRTP for MWTP to more truly reflect the value of the transfer.

The ecological compensation fee is calculated using the method widely recognized by the academic community, namely the ecosystem service value method (Gao et al., 2021). The specific evaluation indicators are shown in Table 1. The value of the ecosystem services of water resources is comprised of the utility of four functions (Leemans & Groot, 2003), and the formula is calculated as follows:

$$V = V_1 + V_2 + V_3 + V_4 \tag{3}$$

where V is the total value of the ecosystem services of water resources, and V_1, V_2, V_3, V_4 are the supply function, regulating function, cultural function, and ecological function, respectively.

Table 1 Classification of the value of ecosystem services in the water-source areas

Level 1 indicators	Secondary indicators	Assessment indicators	Assessment methods
Supply function	Food supply	Fishery products output	Market value method
Regulating function	Atmosphere regulation	Surface chlorophyll a concentration	Reforestation cost method
	Water containment	Storage capacity	Shadow engineering method
Cultural function	Research and education	The cultural value of water research	Outcome parameter approach
	Leisure and Tourism	Revenue from tourism	Expense-based approach
Ecological function	Biodiversity conservation	Value of water biodiversity conservation services	Outcome parameter approach

① Measurement of the value of the supply function

The value of the supplied water resources is mainly reflected in the food supply, while fisheries depend on water resources for survival and development. These factors which can better reflect the supply function of water resources. This study choose the market value method to measure the output value of fishery products, which is used as a proxy variable for the value of the supply function V_1.

② Measurement of the value of the regulating function

Water resources are an important part of ecosystems and play an role in carbon sequestration and oxygen release (Ahmed et al., 2021), as well as a regulating role in climate and gases. This study considers the regulating function of water resources in terms of both atmospheric regulation and water containment, which can be calculated as follows:

$$V_2 = V_{21} + V_{22} \tag{4}$$

$$\begin{cases} V_{21} = W_a \cdot PPem(Pc + 2.666Po) \\ V_{22} = V_i \cdot \frac{1}{n} \sum_{i=1}^{n} c_i\left(1 + x_i\right) \end{cases} \tag{5}$$

where V_{21} is the value of atmospheric regulation; V_{22} is the value of water containment; W_a is the watershed area; $PPem$ is phytoplankton primary productivity; Pc is the carbon sequestration costs; Po is the oxygen release costs; V_i is the quantity of water contained in year i; c_i is the average price of building 1m^3 of reservoir capacity in year i; and x_i is the price growth factor in year i.

③ Measurement of the value of the cultural function

On the one hand, ecosystems can provide materials and experimental sites for many scientific types of research and have a high education value. This is an important part of the service value of the cultural function of ecosystems. On the other hand, with the improvement in the society's living standards, leisure tourism has become something of a norm in daily life. Thus, the value of the leisure tourism function service to the ecosystem cannot be ignored (Chen et al., 2021). Accordingly, integrating the cultural functions of water resources in terms of research, education, leisure, and tourism can be calculated as follows:

$$V_3 = V_{31} + V_{32} \tag{6}$$

$$\begin{cases} V_{31} = W_a S_V \\ V_{32} = I_c \theta \rho \end{cases} \tag{7}$$

where V_3 is the value of the cultural function; V_{31} is the value of science and education; V_{32} is the value of leisure tourism; S_V is the average cultural and scientific research value per unit area of wetland; I_c is the total tourism revenue of the water source; θ is the proportion of people visiting the natural landscape; and ρ is the proportion of water bodies in the landscape.

④ Measurement of the value of the ecological function

Ecosystems provide habitats for a wide range of organisms and protect species diversity, and this paper uses outcome parameters to measure the value of the supporting function (Xie et al., 2003), as follows:

$$V_4 = CW_a \tag{8}$$

where V_4 is the value of the ecological function; C is the value of biodiversity per unit area of water; and W_a is the area of aquatic ecosystems.

⑤ Determination of ecological compensation standards

China's MWTP have reduced the country's water resources and caused certain losses to the ecological environments of the water-source areas. However, considering the actual situation of the water-source and water-receiving areas, the total value of ecosystem services of the water sources calculated according to the above steps needs to be adjusted to more reasonably determine the amount of compensation from the water-receiving areas (Johst et al., 2002). On this basis, the value of ecosystem services to be compensated by the water-receiving areas is calculated as shown below:

$$V' = V \cdot k \cdot \frac{S'}{S} \tag{9}$$

where V' is the value of ecosystem services for which the water-source areas should be compensated by the water-receiving areas; V is the total value of the ecosystem service function of the water source; k is the conversion coefficient of ecological value; S' is the amount of water transferred out of the water source; and S is the total multi-year average water resources of the water source.

⑥ Determination of ecological compensation payments

In order to make up for the shortcomings of the ecological trading market and to make the value of ecological services more acceptable to the public in the water-receiving areas, this paper combines Pearl's growth curve with the level of social development and the living standard of people in the water-receiving areas of the MWTP. This approach is taken to estimate the value of ecological services based on the actual price people pay for a certain ecological function. On this basis, the ecological compensation per unit of water transfer for MWTP under the water quantity constraint was further calculated using the ecological development factor, as follows:

$$AESV = V' \cdot \frac{1}{1 + e^{-t}} \tag{10}$$

$$P_z = \frac{1}{2} \cdot \frac{AESV}{Q} \tag{11}$$

where P_z is the ecological compensation per unit of water transferred from an MWTP under the water quantity constraint; $AESV$ is the amount of ecological compensation that should be paid to the water source by the water-receiving areas of the MWTP; V' is the value of ecosystem services to be compensated by the water-receiving areas; t is the stage of socio-economic development; and Q is the annual quantity of water traded by the MWTP.

Based on the above steps, the project cost, resource cost, and ecological compensation for MWTP can be derived. Taking into account the difference in the level of economic development and water scarcity between the water-source and water-receiving areas, as well as the strategic and welfare nature of the MWTP, an adjustment factor for the level of economic development and the scarcity of water resources is introduced. The aim is to adjust the resource cost and the ecological compensation by adjusting the WRTP under the water quantity constraint to a reasonable price range that the water-receiving areas are willing to pay. The calculation is as follows:

$$M_{k1} = P_p + \mu\gamma\left(P_w + P_z\right) \tag{12}$$

where M_{k1} is the price per unit of water transfer for the MWTP under the water quantity constraint in yuan/m^3; P_p is the project investment per unit of water transfer; P_w is the water resource fee per unit of water transfer; P_z is the ecological compensation per unit of water transfer; μ is the ratio of per capita disposable income between the transferee and the transferor's region; and γ is the adjustment coefficient of water scarcity.

2.2.2.2 The model for the WRTP under water quality constraints MWTP have a long duration and development history, and water quality plays a crucial role in the WRTP. By summarizing current water quality evaluation methods (Amiri et al., 2014; Ezugwu et al., 2019; Mukate et al., 2019; Pamei et al., 2022), an integrated water quality index was used to evaluate the water quality of the water-source area. In addition, the introduction of an expert scoring method to determine the weights of water quality parameters has improved the integrated water quality index, calculated as follows:

$$P_k = \sum_{j=1}^{n} \omega_j \frac{C_j}{C_{oj}} C_k \tag{13}$$

where P_k is the comprehensive pollution index of the water quality of section k of the water intake in the water-source area; ω_j is the weight of the jth pollutant; C_j is the measured concentration of the jth pollutant; C_{oj} is the evaluation standard value of the jth pollutant; C_k is the unified maximum allowable index of various pollutants in surface water; and n is the type of pollutants.

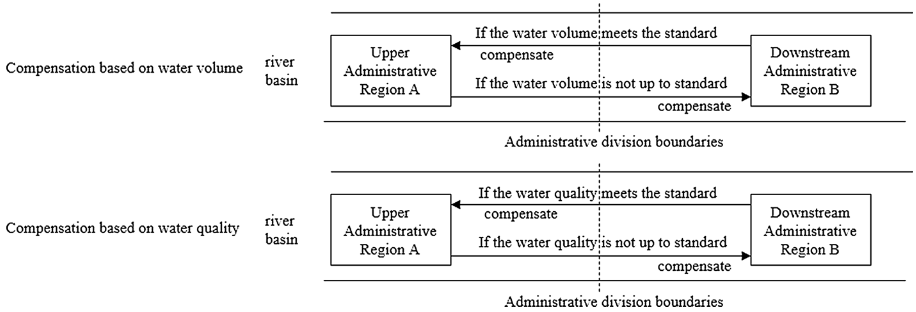

Fig. 3 Principles for WRTP based on water quantity and quality

The price per unit of water quality traded can be calculated from the combined water quality pollution index, as follows:

$$M_{k2} = \left(P_k^{st} - P_k^{sell}\right)C_{k2} = \left(\sum_{j=1}^{n} \frac{\omega_j C_j^{st}}{C_{oj}} C_k - \sum_{j=1}^{n} \frac{\omega_j C_j^{sell}}{C_{oj}} C_k\right)C_{k2} \tag{14}$$

where M_{k2} is the unit transfer price of an MWTP under the water quality constraint; P_k^{st} is the comprehensive pollution index required to be achieved by the water-source areas k cross section; P_k^{sell} is the comprehensive pollution index of the water quality of the water source diversion in the water-source areas; and C_{k2} is the unit cost invested in maintaining water quality.

In Eq. (14), when $P_k^{st} \le P_k^{sell}$, the transferor of the water rights in the water-source areas has not taken effective measures to control the water quality or the water quality control is not sufficient to achieve the water transfer quality negotiated by both parties of the water rights transaction. At this time, the water rights transferee in the water-receiving areas does not need to pay the water quality fee, so $M_{k2} = 0$.

2.2.2.3 The model for the WRTP under the constraints of water quantity and quality The process of trading water rights can ultimately fail if the quantity or quality of water transferred differ significantly from the standards negotiated between the parties (Grafton et al., 2012). Therefore, within a certain range acceptable to the transferee of the water rights, when the water quantity and water quality meet the standards, the water-receiving areas shall reward the water-source areas (Fig. 3). However, when the water quality or quantity does not meet the standard, the water-source areas shall compensate the water-receiving areas (Chen & Zhou, 2016).

On the basis of the unit transfer price under the water quantity and quality constraint, considering the price adjustment caused by the excess (difference) of water quantity and quality during the execution of the water diversion task, as well as the impact of related taxes and surcharges, the comprehensive price of water diversion per unit of the MWTP under the double constraints of water quantity and quality is finally obtained, as follows:

$$M_k = \frac{M_{k1} + M_{k2} + \Delta M}{(1 - T)} \tag{15}$$

where M_k is the comprehensive price per unit of water transfer for the MWTP under the double constraint of water quantity and quality in yuan/m^3; M_{k1} is the price per unit of water transfer under the constraint of water quantity; M_{k2} is the price per unit of water transfer under the constraint of water quality; ΔM is the adjustment for over (difference) units of the WRTP; and *T* is the taxes and surcharges.

2.3 Data sources

Due to differences in the years available for which various types of statistical data were available, data for 2020 were chosen for the calculation of the WRTP for the first phase of the SNWDP-ER. Project cost data were taken from the China South-to-North Water Diversion Project—Economic and Financial Volume (CCO of SNWDP, 2018). Resource cost is based on the maximization of social welfare and is selected as the lowest value in the Notice on Issues Relating to the Levy of Water Resource Fee, jointly issued by the National Development and Reform Commission and other departments of China. Ecological value conversion factors, research and education data, and biodiversity values were calculated using the results-based reference method. Regulation function and water quality data were obtained from the China National Environmental Monitoring Centre (www.cnemc.cn) and the Environmental Quality Standard for Surface Water (GB3838-2002). Murray Darling Basin water rights trading prices were obtained from the Australian Bureau of Agricultural and Resource Economics and Sciences (https: //www.agriculture.gov.au/abares/publications/weekly_update/weekly-update-250719#national- climate-outlook). The multi-year average statistics for water rights trading prices in the western USA were taken from Water Strategist Monthly (the data are available at http://www.bren.ucsb.edu/news/water_transfers.htm). Other data were obtained provincial and municipal statistical yearbooks, water resources bulletins, and the China Water Network (https://www.h2o-china.com). In the data collection section, EXCEL software was used to collate the data. In the data calculation part, MATLAB software was used to calculate and process Eqs. (1) to (15), which were involved in the FCPM.

3 Results

3.1 WRTP measurement under water quantity constraints

(1) Project cost

The static investment amount of the first phase of the SNWDP-ER was 38.3 billion yuan, which consisted of 45% loan and 55% capital. The stipulation was made that 20% of the project cost needs to be repaid by water charges, and the average depreciable life is 32.125a. The equivalent annuity of the project is calculated as 598.74 million yuan.

The annual operation and maintenance cost of the first phase of the SNWDP-ER is 500 million yuan, and the project investment for the transfer of Yangtze water from the water source in Jiangsu to the territory of Shandong is apportioned in proportion to the mileage of the transfer project. According to Eq. (2), the unit project investment cost for transferring water from the Yangtze River to Nansi Lake was 0.82 yuan/m^3, the unit investment cost for transferring water to Datun Reservoir in Dezhou was 1.36 yuan /m^3, and the unit investment cost for transferring water to Weihai in the Jiaodong region was 1.43 yuan /m^3. In summary, the average unit project investment cost for the transfer of water from the Yangtze River to the territory of Shandong Province was 1.20 yuan /m^3.

Table 2 Value of carbon sequestration and oxygen release services in the water-source areas

	Yangzhou	Huaian	Suqian	Xuzhou
Primary productivity of aquatic phytoplankton(*mg C/(m²d)*)	844.26	519.77	543.94	637.14
Quantity of carbon sequestered and oxygen released (*t*)	1503.94	1503.69	1195.58	625.03
Service value of carbon sequestration and oxygen release($ million)	199.62	199.58	158.69	82.96
Watershed area as a proportion of land area (%)	25.53	31.17	27.37	8.34
Service value of carbon sequestration and oxygen release ($ million)	50.96	62.21	43.43	6.92

(B) Resource cost

According to the requirements of the National Development and Reform Commission and other relevant departments, the minimum standard surface water resource fee in Jiangsu Province should be 0.20 yuan/m^3. As the SNWDP-ER is a public welfare and strategic project, this study takes the water resource cost P_W as 0.2 yuan/m^3 based on the nature of the SNWDP-ER.

(C) Ecological compensation
(D) Supply function

The market value method was used to measure the supply function value of ecological compensation in water-source areas. In 2020, the total water resources of Yangzhou, Huaian, Suqian, and Xuzhou in Jiangsu Province were 2.851 billion m^3, 4.876 billion m^3, 4.152 billion m^3, and 4.749 billion m^3, respectively. The total fishery output value of the four cities was 18.91 billion yuan, 10.160 billion yuan, 10.870 billion yuan, and 10.44 billion yuan, respectively. In that same year, Jiangsu Province transferred 674 million m^3 of water to Shandong Province, according to which the service value of Jiangsu Province's water source ecosystem in the supply function can be obtained as 2.042 billion yuan.

② Regulating function
a. Value of atmospheric regulation

The water-source areas of Yangzhou, Huaian, Suqian, and Xuzhou in 2020 were 1787.37 km^2, 2893.00 km^2, 2198.00 km^2, and 981.00 km^2, respectively, and the primary productivity of phytoplankton in the waters was 18.00 mg/m^3, 8.60 mg/m^3, 9.30 mg/m^3, and 12.00 mg/m^3, respectively. According to Formula (5), the quantity and service value of carbon sequestration and oxygen release in the water ecosystems of the four water source cities are calculated, as shown in Table 2.

The service value of the atmospheric regulation of the water-source areas ecosystems in Jiangsu Province is calculated to be 1.64 million yuan. Of that table, the service value of climate regulation of the water-source areas' ecosystems from carbon sequestration was 0.32 million yuan, and the service value of oxygen release from water-source areas was 1.13 million yuan.

b. Value of water containment

Table 3 Value of water conservation services in the water-source areas

	Yangzhou	Huaian	Suqian	Xuzhou
Average water storage (billion m^3)	9.87	23.52	29.78	6.94
Value of water containment (billion yuan)	8.86	21.13	26.76	6.24
Watershed area as a proportion of land area (%)	26.00	31.00	27.00	8.30
Value of water containment in the water-source areas (billion yuan)	2.30	6.55	7.23	0.52

In 2020, the average water storage in the Jiangsu Province cities of Yangzhou, Huaian, Suqian, and Xuzhou cities of Jiangsu Province was 987 million m^3, 2,352 million m^3, 2,978 million m^3, and 694 million m^3, respectively. According to Formula (5), the value of water containment in Yangzhou, Huaian, Suqian, and Xuzhou was 886 million yuan, 2,113 million yuan, 2,676 million yuan, and 624 million yuan, respectively. Taking the proportion of the watershed area of the four cities to the land area as the adjustment coefficient, the value of the water containment in 2020 was 1.66 billion yuan, as shown in Table 3.

③ Cultural function

a. Value of research education

The average scientific research value per unit area of wetlands in China was 382 yuan/hm^2, and the global wetland ecosystem scientific research value in 2020 was 881 US dollars/hm^2 (Costanza et al., 1997). Using the outcome parameter method, the average value of 3229.30 yuan/hm^2 was taken as the research value of the water ecosystem. Based on the watershed areas in Yangzhou, Huaian, Suqian, and Xuzhou, the research education value is calculated to be 543 million yuan, 1009 million yuan, 753 million yuan, and 317 million yuan, respectively. Therefore, the research and education value in Jiangsu Province was 2622 million yuan.

b. Value of leisure and tourism

Using the cost expenditure method, the value of leisure and tourism services in the water-source areas was calculated to be 11,201 million yuan according to Eq. (7) and as shown in Table 4.

In summary, the cultural function value of water-source areas in Jiangsu Province in 2020 was 13.82 billion yuan.

c. Ecological function

The value of biodiversity per unit area of water in China was 0.22 yuan/m^3 (Xie et al., 2003). According to the water-source areas of Yangzhou, Huaian, Suqian, and Xuzhou, combined with Formula (8), it is calculated that the biodiversity value of water-source areas in Jiangsu Province was 1.79 billion yuan.

⑤ Total value of ecosystem services

Table 4 Value of leisure and tourism in the water-source areas

	Yangzhou	Huaian	Suqian	Xuzhou
Tourism revenue (billion yuan)	608.41	266.04	146.60	322.18
The proportion of people visiting natural landscapes (%)	38.89	47.62	33.33	50.00
The proportion of water bodies to landscape (%)	95.24	80.00	85.71	80.00
Value of city-wide leisure tourism (billion yuan)	225.34	101.35	41.86	128.87
Watershed area as a proportion of land area (%)	26.00	31.00	27.00	8.30
Value of leisure and tourism in water-source areas ($ billion)	58.59	31.42	11.30	10.70

Table 5 Value of ecosystem services in the water source area

Value of ecosystem services (million yuan)		Yangzhou	Huaian	Suqian	Xuzhou	Total
Main indicators	Secondary indicators					
Supply function	Food supply	76,649.87	41,182.58	44,060.50	42,317.54	204,210.50
Regulating function	Atmosphere regulation	51.72	61.94	42.97	6.89	163.52
	Water containment	23,036.00	65,503.00	72,252.00	5179.20	165,970.20
Cultural function	Research and education	54,349.20	100,948.06	75,339.68	31,679.48	262,316.42
	Leisure and Tourism	585,962.00	314,185.00	113,022.00	106,962.10	1,120,131.10
Ecological functions	Biodiversity conservation	37,026.00	68,772.00	51,326.00	21,582.00	178,706.00
Total	777,074.79	590,652.58	356,043.15	207,727.21	1,931,497.74	

According to the above calculations, the total value of ecosystem services for water-source area in Jiangsu Province was 19.32 billion yuan, with specific data for each category shown in Table 5.

⑥ Determination of ecological compensation

According to Eq. (9), the value of ecosystem services to be compensated to the water-source areas in the Shandong Province is 154 million yuan. The Engel coefficient of Shandong Province in 2020 was 26.52%, and according to Formula (10), the ecological value development coefficient can be calculated as 0.6837, and the amount of ecological compensation payable to water-source areas is 105 million yuan, according to Formula (11). Then, the ecological compensation amount per unit of water transfer in 2020 can be obtained as 0.08 yuan/m^3.

(D) WRTP under water quantity constraints.

Table 6 Standard and measured data at Sanjiang Camp

	Unit	reference ranges	Mean	Measured data	Weight
PH	–	6~9	8.21	7.78	0.185
Dissolved oxygen	mg/L	≥5(III class)	8	10.65	0.236
Permanganate index	mg/L	≤6(III class)	3	3.43	0.206
Ammonia nitrogen	mg/L	≤1(III class)	0.325	0.304	0.191
Total phosphorus	mg/L	≤0.2(III class)	0.07	0.09	0.074
Total nitrogen	mg/L	≤1(III class)	1.42	2.04	0.108

According to the above analysis, the average price per unit of water transfer when calculated based on the project cost is 1.20 yuan/m^3. The price per unit of water transfer, when calculated based on the resource cost, is 0.2 yuan/m^3. The price per unit of water transfer, when calculated based on the ecological compensation, is 0.08 yuan/m^3. Considering different levels of economic development between Jiangsu and Shandong Province, and the scarcity of water resources, the ratio of per capita disposable income between Shandong Province and Jiangsu Province is 76%, so μ is taken as 0.76. Most of Shandong Province is comprised of semi-humid areas, so γ is taken as 1.0. According to Formula (12), the unit WRTP under the constraint of water quantity is 1.41 yuan/m^3.

3.2 WRTP measurement under water quality constraints

The first phase of the SNWDP-ER in 2020 will mainly divert water from Sanjiangying in the Yangtze River section of Yangzhou City to the territory of Shandong Province. In this study, PH, dissolved oxygen, permanganate index, ammonia nitrogen, total phosphorus, and total nitrogen are used as indicators for water quality evaluation in this study (Sharma et al., 2022). The standard and measured data for the relevant indicators in the Sanjiangying section are shown in Table 6.

As can be seen from Table 6, the weighting of the six water quality parameters from highest to lowest is: dissolved oxygen > permanganate index > ammonia nitrogen > PH > total phosphorus > total nitrogen. This finding indicates that dissolved oxygen has the greatest impact on water quality, while total nitrogen has the least impact on water quality.

Water of Class III and above can be used for domestic consumption after artificial treatment and can basically meet the of human production and life needs. Therefore, Class III water is chosen as the standard for water quality evaluation. The safe PH range of water for the growth of water fish is from 6 to 9. As can be seen from Table 6, the average PH value of the study section in 2020 was 8.21, which means the water was conducive to the reproduction and growth of fish. A higher dissolved oxygen content in the water body indicates better water quality, and the mean value of the dissolved oxygen content standard is 8.0 mg/L. This level exceeds the content standard of Class III water. The mean value of permanganate index is 3 mg/L, which is already in line with the standard for Class II water. The mean values for ammonia nitrogen and total phosphorus are both within the standard for Class III water, but the total nitrogen content was significantly higher than the standard for Class III water. Excess nitrogen may lead to eutrophication of the water body and reduce water quality.

According to Formula (13), the calculation value of 0.327 can be obtained from the integrated water quality index. The average value of the integrated water quality index of the11 provinces and cities along the Yangtze River was 0.359, the same as the integrated water quality index to be achieved in Jiangsu Province. The integrated water quality index of water source areas in Jiangsu Province was lower than the integrated water quality index of water quality in the Yangtze River, indicating that Jiangsu Province attaches great importance to the quality of transferred water.

The watershed area of Jiangsu Province is 101600km^2, and the water source area is 8123km^2. In this paper, the proportion of water source land to the watershed area in Jiangsu Province is used to determine the environmental protection cost-shared for three years. The capital invested in the improvement in the water environment in Jiangsu Province was 175.4 billion yuan, and this study calculates that the cost of environmental protection shared is 14.023 billion yuan. The three-year water transfer quantity in Jiangsu Province, from 2018 to 2020, was 844 million m^3, 703 million m^3, and 674 million m^3, respectively. From this, it was concluded that the unit cost of maintaining water quality in the water source is 6.31 yuan/m^3. Finally, according to Formula (14), one can be calculated that the transaction price of water rights under water quality constraints is 0.13 yuan/m^3.

3.3 WRTP measurement under the dual constraints of water quantity and quality

Based on the above combination, the unit transfer price under the water quantity constraint is 1.41 yuan/m^3, and the unit transfer price under the water quality constraint is 0.13 yuan/m^3. Since Shandong and Jiangsu Province have not adjusted the WRTP so that the price is based on the compliance with regard to water quantity and water quality, this paper sets the excess (difference) price adjustment as 0 yuan. Thence, the comprehensive price of unit water transfer without considering taxes and surcharges can be obtained as 1.54 yuan/m^3. Taxes and surcharges should be included in the water price during the operation period of the SNWDP-ER; their combined tax rate is 5.5% (CCO of SNWDP, 2018). Therefore, based on the considerations of taxes and surcharges, the comprehensive price per unit of water transfer for the Shandong section of the SNWDP-ER was finally determined to be 1.63 yuan/m^3 according to Eq. (15).

4 Discussion

(1) The actual WRTP of the first phase of the SNWDP-ER is too low to cover the corresponding cost.

According to the calculations of this study, the WRTP for the MWTP after considering tax is 1.63 yuan /m^3. However, the current average water transfer price in the Shandong section of the first phase of the SNWDP-ER is 1.25 yuan /m^3, which is far lower than the WRTP of major projects under the FCPM. These finding indicate that the water price cost is inverted. The low water supply price of water conservancy projects objectively leads to the unreasonable phenomenon of “the more water you use, the higher the return.” The low price not only lacks the power mechanism needed to save water, but also easily leads to the excessive consumption of resources, resulting in the phenomenon of “the tragedy of the Commons.”

(B) The WRTP based on full cost is within the affordable range of residents.

The ability of water users to pay is an important factor that must be considered in the formulation of urban water prices. In urban areas, the water consumption of urban residents is relatively stable. Studying the affordability of water prices for urban residents is an important basis upon which to demonstrate whether the water price policy is feasible. Due to the unbalanced level of economic development among cities in water-receiving areas, in order to maximize the water affordability of all urban residents in water-receiving areas to match their income, the minimum per capita water charge expenditure (Zaozhuang, 97.33 yuan) and the largest per capita disposable income (Qingdao, 64,889 yuan) can be used as the affordability coefficient of urban domestic water price. In addition, the minimum per capita disposable income (Dezhou, 29,594 yuan) and the largest annual per capita water consumption (Dongying, 65.53 m^3) in the water-receiving areas of Shandong Province can be calculated as 6.77 yuan/m^3. This is much higher than the appropriate price of 1.63 yuan per m^3. Therefore, the price of water in the WRTP, based on the FCPM, is completely within the range of affordability for water users.

(C) Learn from the advanced experience of water market in developed countries, and provide a reference for the WRTP in developing countries.

The USA and Australia have rich experience in using market mechanisms to allocate water resources. Their water rights transactions are not only much higher than other countries in terms of quantity, but also highly efficient in function (Ghosh, 2019; Grafton et al., 2012). By comparing the transaction prices of water rights for major projects with those in the Murray Darling Basin of Australia, the western region of the USA, and China, one can see that the major engineering water rights trading price (1.63 yuan/m^3) > the western region of the US water rights trading price (1.59 yuan/m^3) > the Murray Darling Basin water rights trading price of Australia water rights trading price (1.30 yuan/m^3) > the China water rights trading price (1.23 yuan/m^3).[1] Two interesting phenomena can be found. First, the transaction price of major water rights transaction price is the highest, which may be caused by the high proportion of engineering cost (77.92%). Second, the trading price of regional water rights in China is the lowest. In fact, the water price of 1.23 yuan /m^3 is much lower than that of residential and industrial water in various regions. Although different from China's national conditions and stages of development, the water rights market in the USA and Australia is worth learning from in terms of how to establish appropriate water rights trading systems (Easton & Pinder, 2022). Therefore, considering the quantity and quality of the WRTP, the trading price accounting method is generally feasible.

(D) The idea of taking the FCPM benchmark proposed in this paper is based on the background of the whole coordinated and sustainable development of the basin, and it also takes into account both fairness and efficiency.

Through the case study of the first phase of the East Route of the South-to-North Water Diversion project, the FCPM based on water quantity and quality is preliminarily established. In addition, the specific cost items included in each link of the WRTP of the

[1] Translated at the average exchange rate of USD to RMB in 2020.

major project and the corresponding basic accounting method are given. Making up for the extra development opportunity cost paid by the water source in the water rights trading and pricing process of major projects is not only meant to compensate and appease the water source. Doing so also eliminates the opportunity cost between generations. In the initial stage of a water market, the full cost pricing method of "external cost + internal cost + opportunity cost" is easier for both parties to reach an agree upon the method also has good practical feasibility.

(E) The WRTP for major projects is helpful to promote water market reform and one such reform to help users pay.

Under the full-cost water rights trading model for major projects, water users will pay all the explicit and implicit costs of water use, forming a user payment mechanism. While promoting water conservation and water fairness, a “water money is used for water” situation is realized, and the boundary of fund management becomes clearer. Second, this helps to improve the competition mechanism of the water market. FCPM accounting makes it possible for the user to pay. Adopting this method will form a stable and reliable investment return mechanism foundation for the marketization of water rights trading for major projects. Then, professional water utilities will be attracted to participate in water services through the market competition mechanism, and the efficiency of operation and management will thus be improved. Third, FCPM will help reduce the pressure of financial payment. In the past, major water conservancy projects and other investment and construction projects have only had financial input as a source of capital, and they lacked performance evaluations. However, under the FCPM, the investment return can be obtained year by year through the recovery of water fees, effectively reducing the pressure and risk associated with government financial expenditure.

An MWTP is a long-term and complex project, and the WRTP method is not set in stone. This paper has made certain achievements based on previous research, but has only studied the method for WRTP in the Shandong section of the first phase of the SNWDP-ER. The pricing method in the Hebei and Tianjin sections, as well as the pricing model and pricing process for water rights trading, has not been analyzed. In future research, the application of pricing methods for water rights trading in the Hebei and Tianjin sections of MWTP should be explored in depth, and the influence of market supply and demand on the bargaining of water rights trading should also be considered (Di et al., 2020). On this basis, combined with modern technical methods such as machine learning, the dynamic analysis of the method of the WRTP is carried out. Furthermore, the pricing model and pricing process in the water rights transaction system of MWTP are further studied.

5 Conclusions

Focusing on the issue of WRTP for MWTP, this paper innovatively introduces water quality factors into the water rights transaction pricing model, based on the FCPM. Also, research is conducted on WRTP from the perspective of combining water quantity and water quality. The rationality of the pricing method of water rights transactions for MWTP is illustrated through the case study of the SNWDP-ER. The specific results are as follows:

(1) The average comprehensive water transfer price of the first phase of the South-to-North Water Diversion project to Shandong Province in 2020 was 1.63 yuan/m^3, and that price is within the affordable range of residents. This result indicates that the water rights trading pricing method adopted in this paper for major water diversion projects is reasonable.
(2) The average unit water transfer price under the water quantity constraint was 1.41 yuan/m^3. The average cost of unit project investment was 1.20 yuan/m^3, the water resource fee was 0.2 yuan/m^3, and the ecological compensation of water source was 0.08 yuan/m^3.
(3) The unit water transfer price under the water quality constraint calculated in this study is 0.13 yuan/m^3, accounting for 8.44% of the water rights transaction price. This finding reflects that some water rights transactions do not fully consider the quality of water resources when setting prices, resulting in a low transaction price and damaging the interests of the water rights transferor.
(4) An adjusted unit transfer price, based on taxes and surcharges, of 0.09 yuan/m^3, further validates the time cost.

Funding Funding was provided by Postgraduate Research & Practice Innovation Program of Jiangsu Province Grant no (KYCX22_0703).

Data availability The data involved in the study can be obtained from the corresponding author at reasonable request.

Declarations

Conflict of interest The authors promise no competing interest.

Ethical approval Not applicable.

Consent to participate and for publication All authors agree.

References

Ahmed, S. S., Bali, R., Khan, H., Mohamed, H. I., & Sharma, S. K. (2021). Improved water resource management framework for water sustainability and security. *Environmental Research, 201*(8), 111527. https://doi.org/10.1016/j.envres.2021.111527

Amiri, V., Rezaei, M., & Sohrabi, N. (2014). Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. *Environmental Earth Sciences, 72*(9), 3479–3490. https://doi.org/10.1007/s12665-014-3255-0

Bakker, K. (2014). The business of water: Market environmentalism in the water sector. *Annual Review of Environment and Resources, 39*(1), 469–494. https://doi.org/10.1146/annurev-environ-070312-132730

Berrittella, M., Rehdanz, K., & Tol, R. (2006). The economic impact of the South-North Water Transfer Project in China: A computable general equilibrium analysis. *Social Science Electronic Publishing, 41*(2), 222–228. https://doi.org/10.2139/ssrn.952938

Bhave, A. G., Conway, D., Dessai, S., & Stainforth, D. A. (2018). Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River Basin in Karnataka, India. *Water Resources Research, 54*(2), 708–728. https://doi.org/10.1002/2017WR020970

Bhojwani, S., Topolski, K., Mukherjee, R., et al. (2019). Technology review and data analysis for cost assessment of water treatment systems. *Science of the Total Environment, 651*, 2749–2761. https://doi.org/10.1016/j.scitotenv.2018.09.363

Bjornlund, H., & Mckay, J. (2002). Aspects of water markets for developing countries: Experiences from Australia, Chile, and the US. Environ. *The Developing Economies, 7*, 769–795. https://doi.org/10.1017/S1355770×02000463

Brewer, J., Glennon, R., Ker, A., & Libecap, G. (2008). presidential address water markets in the west: Prices, trading and contractual forms. *Economic Inquiry, 46*(2), 91–112. https://doi.org/10.1111/j.1465-7295.2007.00072.x

CCO of SNWDP (2018). China's South-to-North Water Diversion Project -Economic and Financial Volume. State Council Construction Committee of SNWDP. Beijing

Chen, Y., Luo, D., & Cheng, Y. (2021). A study on the base price of regional water rights trading by full cost method considering ecological compensation. *Water Economics., 39*(05), 72–78+82.

Chen, Y., & Zhou, Y. (2016). Measurement of ecological compensation standards in watersheds based on water quality and quantity: An example from Ningxia Hui Autonomous Region in the Yellow River Basin. *China Agricultural Resources and Zoning., 37*(4), 119–126.

Chen, Z., Wang, H., & Qi, X. (2013). Pricing and water resource allocation scheme for the South-to-North water diversion project in China. *Water Resources Management, 27*(5), 1457–1472. https://doi.org/10.1007/s11269-012-0248-1

Costanza, R., Arge, R. D., Groot, R. D., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Vanden, B. M. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*(6630), 253–260. https://doi.org/10.1016/S0921-8009(98)00020-2

Di, D., Wu, Z., Wang, H., & Huang, S. (2020). Optimal water distribution system based on water rights transaction with administrative management, marketization, and quantification of sediment transport value: A case study of the Yellow River Basin, China. *Science of the Total Environment, 722*, 137801. https://doi.org/10.1016/j.scitotenv.2020.137801

Easton, S., & Pinder, S. (2022). Measuring the price of Australian water. *Australian Journal of Management., 47*(1), 24–33. https://doi.org/10.1177/0312896221992454

Ezugwu, C. K., Onwuka, O. S., Egbueri, J. C., et al. (2019). Multi-criteria approach to water quality and health risk assessments in a rural agricultural province, southeast Nigeria. *HydroResearch, 2*, 40–48. https://doi.org/10.1016/j.hydres.2019.11.005

Gao, X., Shen, J., He, W., Zhao, X., Li, Z., Hu, W., Wang, J., Ren, Y., & Zhang, X. (2021). Spatial-temporal analysis of ecosystem services value and research on ecological compensation in Taihu Lake Basin of Jiangsu Province in China from 2005 to 2018. *Journal of Cleaner Production, 317*, 128241. https://doi.org/10.1016/j.jclepro.2021.128241

Ghosh, S. (2019). Droughts and water trading in the western United States: Recent economic evidence. *Journal of the American Water Resources Association, 45*(6), 1508–1518. https://doi.org/10.1080/07900627.2017.1411252

Gleick, P. H. (2003). Water use. *Annual Review of Environment and Resources, 28*(1), 275–314. https://doi.org/10.1146/annurev.energy.28.040202.122849

Grafton, R. Q., Libecap, G. D., Edwards, E. C., et al. (2012). Comparative assessment of water markets: Insights from the Murray-Darling Basin of Australia and the Western USA. *Water Policy, 14*(2), 175–193. https://doi.org/10.2166/wp.2011.016

Jamshidi, S., Niksokhan, M. H., & Ardestani, M. (2014). Surface water quality management using an integrated discharge permit and the reclaimed water market. *Water Science and Technology, 70*(5), 917–924. https://doi.org/10.2166/wst.2014.314

Johst, K., Drechsler, M., & Wätzold, F. (2002). An ecological-economic modelling procedure to design compensation payments for the efficient spatio-temporal allocation of species protection measures. *Ecological Economics, 41*(1), 37–49. https://doi.org/10.1016/S0921-8009(02)00019-8

Khan, S., Dassanayake, D., Mushtaq, S., & Hanjra, M. A. (2010). Predicting water allocations and trading prices to assist water markets. *Irrigation and Drainage, 59*(4), 388–403.

Kuwayama, Y., & Brozović, N. (2013). The regulation of a spatially heterogeneous externality: Tradable groundwater permits to protect streams. *Journal of Environmental Economics and Management, 66*(2), 364–382. https://doi.org/10.1016/j.jeem.2013.02.004

Leemans, H., & Groot, R. (2003). Millennium ecosystem assessment: Ecosystems and human well-being: A framework for assessment. *Physics Teacher, 34*(9), 534–534. https://doi.org/10.1119/1.2344558

Li, Z., Wang, Y., & Li, C. (2018). Paying close attention to the effect of ecological environment in water right trade. *Water Resources Development Research, 18*, 19–21. https://doi.org/10.13928/j.cnki.wrdr.2018.12.004

Liu, W., (2014). Discussion on the influencing factors of inter-basin water transfer prices. Price Theory and Practice. 11:107–108. JournalArticle/5b435b79c095d716a4c7d75b

Michelsen, A. M., Booker, J. F., & Person, P. (2000). Expectations in water-right prices. *International Journal of Water Resources Development, 16*(2), 209–219. https://doi.org/10.1080/07900620050003125

Mosha, D. B., Vedeld, P., Kajembe, G. C., & Tarimo, A. K. (2016). Reflections on evolving water management institutions and institutional bricolage: A case of irrigation schemes in Iringa Rural and Kilombero districts Tanzania. *Water Policy, 18*(1), 143–160. https://doi.org/10.2166/wp.2015.020

Mukate, S., Wagh, V., Panaskar, D., et al. (2019). Development of new integrated water quality index (IWQI) model to evaluate the drinking suitability of water. *Ecological Indicators, 101*, 348–354. https://doi.org/10.1016/j.ecolind.2019.01.034

Murdock, S., Albrecht, D. E., Hamm, R. R., & Backman, K. (1991). Role of socio demographic characteristics in projections of water use. *Journal of Water Resources Planning and Management, 117*, 235–251. https://doi.org/10.1061/(ASCE)0733-9496(1991)117:2(235)

Null, S. E., & Prudencio, L. (2016). Climate change effects on water allocations with season dependent water rights. *Science of the Total Environment, 571*, 943–954. https://doi.org/10.1016/j.scitotenv.2016.07.081

Ortega, J. F., Juan, J., & Tarjuelo, J. M. (2005). Improving water management: The irrigation advisory service of Castilla-La Mancha (Spain). *Agricultural Water Management, 77*(1–3), 37–58. https://doi.org/10.1016/j.agwat.2004.09.028

Pamei, M., Hemso, E., & Puzari, A. (2022). Evaluation of the Physico-Chemical and the sustainability of ground and surface water quality using statistical correlation method and Water Quality Index in Dimapur District, Nagaland. *Environmental Nanotechnology, Monitoring & Management, 18*, 100699. https://doi.org/10.1016/j.enmm.2022.100699

Payne, M. T., & Smith, M. G. (2013). Price determination and efficiency in the market for water rights in New Mexico's Middle Rio Grande Basin. *International Journal of Water Resources Development, 29*(4), 588–604. https://doi.org/10.1080/07900627.2012.730670

Pérez-Blanco, C. D., Essenfelder, A. H., & Gutiérrez-Martín, C. (2020). A tale of two rivers: Integrated hydro-economic modeling for the evaluation of trading opportunities and return flow externalities in inter-basin agricultural water markets. *Journal of Hydrology, 584*, 124676. https://doi.org/10.1016/j.jhydrol.2020.124676

Philpot, S., Hipel, K., & Johnson, P. (2016). Strategic analysis of a water rights conflict in the south western United States. *Journal of Environmental Management, 180*, 247–256. https://doi.org/10.1016/j.jenvman.2016.05.027

Pohlner, H. (2016). Institutional change and the political economy of water megaprojects: China's south-north water transfer. *Global Environmental Change, 38*, 205–216. https://doi.org/10.1016/j.gloenvcha.2016.03.015

Pullen, J. L., & Colby, B. G. (2008). Influence of climate variability on the market price of water in the Gila-San Francisco Basin. *Journal of Agricultural and Resource Economics, 33*(3), 473–487.

Reznik, A., Feinerman, E., Finkelshtain, I., et al. (2016). The cost of covering costs: A nationwide model for water pricing. *Water Economics and Policy, 2*(4), 21–29. https://doi.org/10.1142/S2382624X16500247

Sechi, G. M., Zucca, R., & Zuddas, P. (2011). *The water pricing problem in a complex water resources system: A cooperative game theory approach*. Springer. https://doi.org/10.1007/978-3-642-20009-0_81

Sharma, R., Kumar, R., Sharma, D. K., et al. (2022). Water pollution examination through quality analysis of different rivers: A case study in India. *Environment, Development and Sustainability, 24*, 7471–7492. https://doi.org/10.1007/s10668-021-01777-3

Sheng, J., Wang, H., & Qiu, W. (2022). Water quality and incentive coordination in water markets: The eastern route of China's South-North Water Transfer Project. *Journal of Hydrology, 607*, 127526. https://doi.org/10.1016/j.jhydrol.2022.127526

Svensson, J., Wang, Y., Garrick, D., & Dai, X. (2021). How does hybrid environmental governance work? Examining water rights trading in China (2000–2019). *Journal of Environmental Management, 288*, 112333. https://doi.org/10.1016/j.jenvman.2021.112333

Wang, Y., Liu, D., Cao, X., Yang, Z., Song, J., Chen, D., & Sun, S. (2017). Agricultural water rights trading and virtual water export compensation coupling model: A case study of an irrigation district in China. *Agricultural Water Management, 180*, 99–106. https://doi.org/10.1016/j.agwat.2016.11.006

Wu, X., Wu, F., Li, F., & Xu, X. (2021). Dynamic adjustment model of the water rights trading price based on water resource scarcity value analysis. *International Journal of Environmental Research and Public Health, 18*(5), 2281–2281. https://doi.org/10.3390/ijerph18052281

Xie, G., Lu, C., Leng, Y., Zheng, D., & Li, S. (2003). Valuation of ecological assets on the Qinghai-Tibet Platea. *Natural Resources Journal, 18*(2), 189–196. https://doi.org/10.11849/zrzyxb.2003.02.010