Study on the price of water rights trading between agriculture and industry based on emergy theory

Wenge Zhang, Li Tan, Huijuan Yin and Xinwei Guo

ABSTRACT

A water rights trading scheme in China is currently in its initial stage of development, but is without a complete pricing mechanism. This paper proposes a pricing model for transfers of water rights from agriculture to industry in water-deficient areas of China. Both the cost price and the earnings price are considered and incorporated into the model. The cost price includes construction costs, operation and maintenance costs, renewal and reconstruction costs, and economic compensation for ecological damage. The earnings price is calculated according to a reasonable return coefficient and the difference in economic value of the water resources to the buyer and seller. The value of water resources was estimated based on emergy theory in accordance with the principle of mutual benefits equilibrium. This pricing model is then applied to the transfer of surplus water rights arising from agricultural water conservation schemes to industrial uses in the Southbank Ordos Irrigation Zone of the Inner Mongolia Autonomous Region. The results indicate that this pricing model could provide technical support to the scientific and reasonable pricing of water rights transactions in water-deficient areas and that it could play an active role in promoting the healthy development of future water markets.

Key words | agricultural water conservation, price, value of water resources, water rights transaction

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INTRODUCTION

Accelerating industrialization has led to increasingly acute conflict between water supply and demand, and water shortages are becoming an ever-greater constraint on social and economic development. Water rights trading could optimize the allocation of water resources in different regions or sectors, and has become an important method to solve water shortages (Wang *et al.* 2017). In the face of fierce competition for water, especially in areas of extreme scarcity, implementing trading schemes in irrigated areas might be an important tool to improve market allocation and promote water conservation (Rey *et al.* 2014). Water rights trading is economically feasible when the benefits for both parties exceed the transaction costs (Wang *et al.* 2012). Water rights transactions have benefits in the development of water markets, as they eliminate the priority of water use that is caused by low water-use efficiency and low economic efficiency in the allocation and management of water resources (Debaere *et al.* 2014). Trading thus allows water resources to be reallocated from low-value to high-value activities (Fu *et al.* 2016).

Water rights trading pricing is the core issue of any scheme (McCann *et al.* 2005). However, most studies, both in China and elsewhere, have focused on the efficiency and benefit of water rights trading (Wheeler *et al.* 2014; Bekchanov *et al.* 2015a, 2015b; Xu *et al.* 2016). A study carried out by Wheeler *et al.* (2014) on the southern Murray–Darling Basin, Australia, found that as many as 86% of irrigators

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traded water rights, and that the transactions increased farmers' incomes. Bekchanov *et al.* (2015b) showed that rights trading improved the efficiency of water use by reducing consumption by irrigation and thus maintained stable incomes. Xu *et al.* (2016) studied the water rights transactions in the Xiying Irrigation Zone in the Shiyang River Basin, showing that the water market can effectively improve the efficiency of water use.

However, few works have studied the price of water rights transactions and they have used methods of traditional economics. Muchara *et al.* (2016) applied the residual value method to estimate water values among smallholder farmers in the Mooi River Irrigation Scheme of KwaZulu-Natal, South Africa. Phuong & Gopalakrishnan (2003) determined the theoretical framework of the contingent valuation method and identified its empirical application to the valuation of rural water resources. Cui & Schreider (2009) established a water option pricing model based on stochastic process theory, and verified the correctness of the model by analyzing the price dynamics of the water market in northern Australia. Reddy *et al.* (2015) analyzed the price of industrial water rights transactions based on the principle of minimum economic loss.

At present, considering economic value and social value, the value of the water resources economy has been calculated from the perspective of the market by mostly traditional economic methods. But ecological value has often been neglected, and dimensional unity could not be achieved. Using emergy value analysis, the connection between economic, social and ecological systems and water systems is constructed, which can reflect the economic value of water resources more clearly and unify measurement. To conclude, emergy value theory is an effective method to evaluate water price.

Most water rights trading in the water-deficient areas of China is carried out under the promotion of the government. There is no reasonable pricing mechanism for transactions, which makes both buyers and sellers less active. With the aim of understanding the characteristics of water conservation and water rights transactions in agriculture, this study establishes a pricing model for trading from the perspectives of the costs of agricultural water conservation and the benefits of water rights transactions for stakeholders.

COMPREHENSIVE PRICING MODEL OF WATER RIGHTS

Characteristics of water rights transactions in agricultural water conservation

For farmers to gain a surplus of water rights to transfer to industry, the industrial water users must first invest in water conservation projects in the irrigated area. The cost of such investment should be considered in the price of the water rights (cost price). Due to the increase in value of the water resources transferred from agriculture to industry, the benefits of the water rights transfer should also be considered (earnings price).

Total cost and cost price of water rights transfer from agriculture

The construction and operation costs of water conservation projects must be fully reflected in the total cost of the transfer of agricultural water rights to industry, to ensure the sustainability of the water rights market. The total cost of water rights involving water conservation projects should account for the following:

(1) Construction costs
(2) Operation and maintenance costs
(3) Renewal and reconstruction costs
(4) Economic compensation for ecological damage.

The following formula gives the total cost, C, during the water rights transaction period:

$$C = C_j + C_y + C_g + C_s \qquad (1)$$

where C_j is the construction costs during the water rights transaction period, RMB; C_y is the operation and maintenance costs during that period, RMB; C_g is the renewal and reconstruction cost, RMB; and C_s is the economic compensation for ecological damage during the water rights transaction period, RMB.

(1) Construction costs

The construction costs of a water conservation project include, for example, expenses incurred in the renewal and reconstruction of anti-seepage canal lining, ancillary buildings, end-of-canal water conservation systems, water-monitoring facilities and devices, canal slope renovation, road repair, canal greening, temporary construction costs, basic reserve costs, and experimental and research expenses.

(2) Operation and maintenance costs

The operation and maintenance costs for a water conservation project include the recurrent costs incurred during the normal operation of engineering facilities (e.g., fuel and electricity); maintenance costs such as regular overhauls, renewal, and routine annual repairs; project management costs such as staff salaries, administrative expenses, daily monitoring, and scientific research and experimental expenses; and other recurrent expenditures. A preliminary estimate of annual operation and maintenance costs can be generally calculated as a percentage of the total investment (typically 2–3%).

(3) Renewal and reconstruction costs

Renewal and reconstruction costs are incurred when a water conservation project's service life is shorter than the water rights transaction period. Such costs can be calculated according to the service life (N_s) of the main water conservation component, the water rights transaction period (N_z), the project construction cost, and other indicators. If $N_s \geq N_z$ (i.e., the service life is longer than or equal to the transaction period), renewal and reconstruction expenses are deemed not to occur. Otherwise, all or part of any renewal and reconstruction expenses should be accounted for when calculating the cost of the water rights.

(4) Economic compensation for ecological damage

Economic compensation for ecological damage refers to the repair costs or compensation associated with damage to the environment or other interests.

There are no unified standards or calculation methods for assessing the economic loss associated with ecological damage in the Chinese water rights market. To estimate such costs, the construction cost of a water conservation project can be multiplied by an ecological compensation coefficient for the water rights transaction period, as follows:

$$C_s = bC_j \tag{2}$$

where C_s is the cost of economic compensation for ecological damage during the water rights transaction period, RMB; b is the ecological compensation coefficient with reference to the engineering operation fee, set in the range of $b = 2$–3%; and C_j is the construction cost, RMB.

(5) Water transaction volume

Considering the agricultural water guarantee rate is 50–75% and the industrial water guarantee rate is 95–97%, to ensure the availability of water for both, the water transaction volume can be calculated assuming a value equivalent to 80% of the water saved from agricultural water conservation projects by the following formula:

$$W_n = \eta W \tag{3}$$

where W_n is the annual water transaction volume, m^3; η is the conversion coefficient (0.8 herein); and W is the total volume of water saved from agricultural water conservation projects, m^3.

(6) Cost price of water rights transaction

The cost price of a water rights transaction, P_c ($RMB/m^3 \cdot$ year), can be calculated as follows:

$$P_c = C(Q)/(T \times W_n) \tag{4}$$

where $C(Q)$ is the total cost of the water rights transaction, RMB; and T is the water rights transaction period, years.

Mutual benefit and earnings price of water rights transaction

Emergy analysis

The theory and method of emergy analysis were developed by H. T. Odum, an American ecologist, in the late 1980s (Lan *et al.* 2002). Converting different and non-comparable emergy values to a unified emergy allows the real values of various energies of different grades to be weighted and compared (Tang 2005).

Calculation of the economic value of water resources in agriculture and industry based on emergy theory

The economic value of water resources in industry and agriculture reflects their contribution to industrial and agricultural economic production, which can be calculated by multiplying the contribution rate of water resources by the output emergy value of industrial and agricultural production systems. The specific steps are as follows.

(1) Build the system energy and energy network according to the relationship between the main energy flow, material flow, and currency flow inside and outside the industrial and agricultural production system, as well as its relationship with industrial and agricultural production. The main energies input to the system include renewable natural resources such as solar energy, wind energy, and water resources, as well as labor and other organic energy, raw materials, funds, and other non-renewable resources. The system output mainly comprises the industrial and agricultural products.

(2) Collect, sort, and classify the raw data of the energy flow, material flow, and currency flow of the research object, then calculate their emergy. Next, convert the energy, material, or currency (each expressed in different units) into a unified dimension of emergy by the emergy conversion rate. The formula is as follows:

$$EM = \tau \times B \tag{5}$$

where EM is emergy, seJ; τ is the emergy conversion rate, seJ/J or seJ/g, and B is the amount of emergy or material, J or g.

(3) Calculate, using the following formulas, the economic value of water resources used in agricultural and industrial production according to the calculated results of the emergy flow of agricultural and industrial production systems:

$$WCR_{\mathrm{I}} = EM_{\mathrm{IW}}/EM_{\mathrm{IU}} \tag{6}$$

$$WCR_{\mathrm{A}} = EM_{\mathrm{AW}}/EM_{\mathrm{AU}} \tag{7}$$

where WCR_{I} is the water contribution rate in industry, %; WCR_{A} is the water contribution rate in agriculture, %; EM_{IW} is the emergy of industrial water, seJ; EM_{IU} is the emergy of the total input to the industrial production system, seJ; EM_{AW} is the emergy of agricultural water, seJ; and EM_{AU} is the emergy of the total input to the agricultural production system, seJ.

$$EM_{\mathrm{I}} = WCR_{\mathrm{I}} \times EM_{\mathrm{IY}} \tag{8}$$

$$EM_{\mathrm{A}} = WCR_{\mathrm{A}} \times EM_{\mathrm{AY}} \tag{9}$$

where EM_{I} is the emergy value of water in the industrial production system, seJ; EM_{A} is the emergy value of water in the agricultural production system, seJ; EM_{IY} is the emergy of the total industrial yield, seJ; and EM_{AY} is the emergy of the total agricultural yield, seJ.

$$EM¥_{\mathrm{I}} = EM_{\mathrm{I}}/EDR \tag{10}$$

$$EM¥_{\mathrm{A}} = EM_{\mathrm{A}}/EDR \tag{11}$$

where $EM¥_{\mathrm{I}}$ is the currency value of water in the industrial production system, RMB; $EM¥_{\mathrm{A}}$ is the currency value of water in the agricultural production system, RMB; EM_{I} is the emergy value of water in the industrial production system, seJ; EM_{A} is the emergy value of water in the agricultural production system, seJ; and EDR is the emergy/currency ratio of the system.

$$EM¥_{\mathrm{PI}} = EM¥_{\mathrm{I}}/W_{\mathrm{I}} \tag{12}$$

$$EM¥_{\mathrm{PA}} = EM¥_{\mathrm{A}}/W_{\mathrm{A}} \tag{13}$$

$$V_{\mathrm{IA}} = EM¥_{\mathrm{PI}} - EM¥_{\mathrm{PA}} \tag{14}$$

where $EM¥_{\mathrm{PI}}$ is the economic value of water in industry, seJ/m^3; $EM¥_{\mathrm{PA}}$ is the economic value of water in agriculture, seJ/m^3; W_{I} is industrial water consumption, m^3; W_{A} is agricultural water consumption, m^3; and V_{IA} is the difference between the economic value of water in industry and in agriculture, RMB/m$^3 \cdot$ year.

Earnings price of water rights transactions

The earnings price is calculated as follows based on the difference between the economic value of water in industry and in agriculture, and the reasonable return coefficient:

$$P_E = k \cdot V_{IA} \qquad (15)$$

where k is the coefficient set when determining the reasonable return of a water rights transaction and P_E is the earnings price of the water rights transaction (RMB/$m^3 \cdot$ year).

Integrated pricing

According to the above analysis, the price of water rights transactions should include both the cost price and the earnings price. In summary, the following gives a comprehensive pricing model for the transfer of water rights from agriculture to industry:

$$P_Z = P_C + P_E \qquad (16)$$

where P_Z is the price of the water rights transaction (RMB/$m^3 \cdot$ year); and P_C is the cost price of the water rights transaction (RMB/$m^3 \cdot$ year).

Given the complexity of pricing water-rights transactions, the negotiating capability of both parties and the role of the government will also influence the price in addition to direct and indirect costs. Therefore, it is difficult to specify accurately the actual price, only a range. The integrated pricing model proposed here gives the price of water rights transactions by comprehensively considering the opportunity costs and the benefits, and the given price can be used as a ceiling for the transaction. The price calculated by the cost method only reflects the project costs of the water rights transfer, which is the minimum value for compensation, and thus can be used as the price floor of the water rights transaction. That is, the final price of the water rights transaction (P) should meet the following restriction: $P \in [P_C, P_Z]$.

CASE STUDY

Total costs and the cost price of water rights transfer

(1) Construction costs

The estimated total construction cost of water conservation projects in the Ordos Irrigation Zone is RMB 1,120.94 million.

(2) Operation and maintenance costs

Based on the Code for Economic Evaluation of Water Conservancy Construction Projects (SL72-94), the cost of management, repair, and maintenance of the water conservation projects (payable to the irrigation area water management authority and provided to the water rights owner) is equivalent to 2% of the construction cost. The total operation and maintenance cost of the water conservation projects in the Ordos Irrigation Zone is therefore RMB 560.47 million.

(3) Renewal and reconstruction costs

The lift irrigation project includes a floating pontoon lift pump, which has a shorter service life than the water rights transaction period (25 years). The project investment is RMB 29.81 million, and this value is taken as the renewal cost.

(4) Economic compensation for ecological damage

The annual economic compensation for ecological damage can be calculated assuming a value equivalent to 2% of the construction cost of the water conservation projects during the water rights transaction period: RMB 560.47 million.

(5) Water transaction volume

The total water saving of the Ordos project is 167.98 million m^3. The water transaction volume is 134.3866 million m^3 according to Equation (3).

(6) Cost price of water rights transaction

The water rights transfer period in Ordos City is 25 years, starting from 2015.

Total costs of water rights transaction $= 1{,}120.94 + 560.47 + 29.81 + 560.47 =$ RMB 2,271.69 million.

Cost price of water rights transaction $= 2{,}271.69/(134.39 \times 25) = 0.68$ RMB/($m^3 \cdot$ year).

Table 1 | Emergy analysis of the industrial eco-economic system in Ordos City (2015)

Item	Original data	Emergy conversion rate	Emergy/seJ
1. Emergy input			8.07×10^{23}
1.1 Renewable resources			1.29×10^{22}
1.1.1 Solar	5.42×10^{20} J	1	5.42×10^{20}
1.1.2 Wind	5.26×10^{18} J	1.5×10^{3}	7.89×10^{21}
1.1.3 Industrial water			1.29×10^{22}
1.1.3.1 Surface water	1.61×10^{8} m^3	7.84×10^{13}	1.26×10^{22}
1.1.3.2 Groundwater	0.87×10^{8} m^3	3.86×10^{12}	3.37×10^{20}
1.2 Non-renewable resources			7.95×10^{23}
1.2.1 Raw coal and coal products	3.51×10^{18} J	3.98×10^{4}	1.4×10^{23}
1.2.2 Natural gas	7.80×10^{16} J	4.80×10^{4}	3.73×10^{21}
1.2.3 Gas and other fuel	9.37×10^{15} J	6.60×10^{5}	6.18×10^{21}
1.2.4 Electricity	1.27×10^{17} J	1.59×10^{5}	2.02×10^{22}
1.2.5 Raw material	$2.21\times10^{10}$$	1.54×10^{13}	3.41×10^{23}
1.2.6 Depreciation of fixed assets	$1.64\times10^{10}$$	1.54×10^{13}	2.54×10^{23}
1.2.7 Labor	$1.91\times10^{9}$$	1.54×10^{13}	2.94×10^{22}
2. Emergy output			1.43×10^{24}
2.1 Raw coal	1.96×10^{19} J	3.98×10^{4}	7.8×10^{23}
2.2 Power generation	2.55×10^{18} J	1.59×10^{5}	4.05×10^{23}
2.3 Natural gas	1.23×10^{18} J	4.80×10^{4}	5.90×10^{22}
2.4 Cement	4.29×10^{6}t	3.3×10^{16}	1.42×10^{23}
2.5 Raw salt	1.04×10^{4}t	1.00×10^{15}	1.04×10^{19}
2.6 Pig iron	1.76×10^{5}t	8.60×10^{14}	1.51×10^{20}
2.7 Chemical and detergent	6.29×10^{6}t	1.00×10^{15}	6.29×10^{21}
2.8 Nitrogen fertilizer	1.84×10^{6}t	3.8×10^{15}	6.98×10^{21}
2.9 Textile	$1.97\times10^{9}$$	1.54×10^{13}	3.03×10^{22}
2.10 Wine and beverage	$1.62\times10^{8}$$	1.54×10^{13}	2.49×10^{21}
2.11 Pharmaceutical manufacturing	$1.99\times10^{8}$$	1.54×10^{13}	3.06×10^{21}

Data sources: Ordos Statistical Yearbook, Ordos Water Resources Bulletin. References: solar value conversion rate data and energy calculation formula (Lu 2009; Jiang 2010).

Calculation of the economic value of water in industry and agriculture

Economic value of water in industry

Values calculated by emergy analysis for the emergy of the industrial eco-economic system in Ordos City in 2015 are listed in Table 1.

The calculated emergy values of the industrial eco-economic system in Ordos City and the combined Equations (6), (8), (10), and (12) lead to the economic value of water resources in industry (see Table 2).

Economic value of water in agriculture

Values calculated by emergy analysis for the agricultural eco-economic system in Ordos City in 2015 are listed in Table 3.

Using the calculated emergy values for the agricultural eco-economic system in Ordos City and the combined

Table 2 | Value of water resources in the industries of Ordos City (2015)

Item	Symbol or formula	Value
Industrial water consumption (m^3)	W_I	2.48×10^8
Emergy of industrial water (seJ)	EM_{IW}	1.29×10^{22}
Total emergy of input to industry (seJ)	EM_{IU}	8.07×10^{23}
Total emergy of industrial yield (seJ)	EM_{IY}	1.43×10^{24}
Water contribution rate in industry (%)	$WCR_I = EM_{IW}/EM_{IU}$	1.6
Emergy value of water in industrial production system (seJ)	$EM_I = WCR_I \times EM_{IY}$	2.29×10^{22}
Emergy/currency ratio (seJ/￥)	EDR	1.54×10^{13}
Currency value of water in industrial production system (￥))	$EM¥_I = EM_I/EDR$	1.48×10^9
Economic value of water in industry (￥/m^3)	$EM¥_{PI} = EM¥_I/W_I$	5.98

Equations (7), (9), (11), and (13), the economic value of water resources in agriculture is calculated (see Table 4).

RESULTS AND DISCUSSION

(1) Based on the above analysis, the cost price of transferring water rights from agriculture to industry in Ordos City, Inner Mongolia, is $P_C = 0.68$ RMB/($m^3 \cdot$ year) (here $k = 0.1$) and the earnings price is $P_E = 0.54$ RMB/($m^3 \cdot$ year). Equation (16) gives the price of the water rights transaction as $P_Z = 1.22$ RMB/($m^3 \cdot$ year). Finally, the integrated price of this specific transaction is determined as $P \in [0.68, 1.22]$ RMB/($m^3 \cdot$ year).

(2) The actual price of the water rights transaction in Ordos City is 0.51 RMB/($m^3 \cdot$ year), which is calculated as follows: the total cost of the transaction is RMB 1711.22 million, which comprises only the construction costs, operation and maintenance costs, and renewal and reconstruction costs. The water rights transaction period is 25 years with an annual water transaction volume of 134.39 million m^3. Given that the water rights trading price = total cost of water rights transaction/(transaction period × annual water transaction volume), the price of the water rights transaction is 0.51 RMB/($m^3 \cdot$ year). This is a lower cost price than calculated by the method proposed here, because it does not consider economic compensation for ecological damage of the water rights transfer. This occurs because water rights trading is in its initial stages in China.

(3) Practical water rights transactions in Ordos City do not consider the earnings price, which is taken into account in this study. From the perspective of agricultural water resources value, the actual price of the water rights transaction does not bring a significant return to agriculture; however, from the perspective of their value to industry, the potential benefits to industry brought by this price are relatively prominent. The price range for water rights given here comprehensively considers both the buyer's reasonable interests and the seller's income, and is thus higher than the cost price so as to promote successful trading.

(4) This article comprehensively considers the actual situation of water-deficient areas and establishes a reasonable return coefficient of 0.1, which is determined by the relative scarcity of water resources and the economic development level of the buyers and sellers. When water rights are traded in water-sufficient areas, there are more factors affecting the reasonable return coefficient, such as the influence of human factors or other economic interests. The determination of the reasonable return coefficient needs further study.

CONCLUSION

(1) By considering not only cost price but also the earnings price, this study proposes a reasonable method for pricing water rights transactions in water-deficient areas in China. The cost price accounts for the necessary costs of water conservation projects as well as the interests of stakeholders. The earnings price aims to consider the relationships and interests of the stakeholders in the water rights transaction, and thus promote the optimal allocation of water resources; it is calculated here using the difference in the economic value of water

Table 3 | Emergy analysis of the agricultural eco-economic system in Ordos City (2015)

Item	Original data	Emergy conversion rate (seJ/unit)	Emergy (seJ)
1 Emergy input			4.37×10^{22}
1.1 Renewable environmental resources			4.01×10^{22}
1.1.1 Solar	5.42×10^{20}J	1	5.42×10^{20}
1.1.2 Wind	5.26×10^{18}J	1.5×10^{3}	7.89×10^{21}
1.1.3 Agricultural water			4.01×10^{22}
1.1.3.1 Surface water	4.54×10^{8} m^3	7.84×10^{13}	3.56×10^{22}
1.1.3.2 Groundwater	7.28×10^{8} m^3	3.86×10^{12}	2.77×10^{21}
1.1.3.3 Precipitation	1.15×10^{17} J	1.54×10^{4}	1.77×10^{21}
1.2 Non-renewable environmental resources			1.1×10^{21}
1.2.1 Topsoil loss	1.76×10^{16}J	6.25×10^{4}	1.1×10^{21}
1.3 Non-renewable industrial auxiliary emergy			2.19×10^{21}
1.3.1 Electricity	2.99×10^{15} J	1.59×10^{5}	4.75×10^{20}
1.3.2 Nitrogen fertilizer	6.8967×10^{4}t	4.62×10^{15}	3.19×10^{20}
1.3.3 Phosphate fertilizer	2.6801×10^{4}t	1.78×10^{16}	4.77×10^{20}
1.3.4 Compound fertilizer	2.5491×10^{4}t	2.80×10^{15}	7.14×10^{19}
1.3.5 Machinery	1.13×10^{13} J	7.50×10^{7}	8.48×10^{20}
1.4 Renewable organic emergy			3.22×10^{20}
1.4.1 Manpower	6.04×10^{14} J	3.80×10^{5}	2.30×10^{20}
1.4.2 Animal power	2.85×10^{14} J	1.46×10^{5}	4.16×10^{19}
1.4.3 Seeds	2.53×10^{14} J	2.00×10^{5}	5.06×10^{19}
2 Emergy output			1.17×10^{22}
2.1 Planting products			
2.1.1 Wheat	2.14×10^{14} J	6.8×10^{4}	1.46×10^{19}
2.1.2 Potato	1.72×10^{15} J	2.70×10^{4}	4.64×10^{19}
2.1.3 Maize	2.12×10^{16} J	8.51×10^{4}	1.80×10^{21}
2.1.4 Sorghum	8.41×10^{12} J	8.30×10^{4}	6.98×10^{17}
2.1.5 Soybean	6.68×10^{13} J	6.90×10^{5}	4.61×10^{19}
2.1.6 Oil plants	4.58×10^{15} J	6.90×10^{5}	3.16×10^{21}
2.1.7 Beet	2.16×10^{14} J	2.70×10^{4}	5.83×10^{18}
2.1.8 Vegetable	1.15×10^{15} J	2.70×10^{4}	3.11×10^{19}
2.1.9 Fruit	2.72×10^{13} J	5.30×10^{4}	1.44×10^{18}
2.2 Livestock products			
2.2.1 Beef	1.33×10^{14} J	4.00×10^{6}	5.32×10^{20}
2.2.2 Mutton	1.18×10^{15} J	2.00×10^{6}	2.36×10^{21}
2.2.3 Other meats	1.10×10^{15} J	1.70×10^{6}	1.87×10^{21}
2.2.4 Dairy	4.71×10^{14} J	2.00×10^{6}	9.42×10^{20}
2.2.5 Wool products	1.40×10^{14} J	4.40×10^{6}	6.16×10^{20}
2.2.6 Poultry and eggs	4.00×10^{13} J	2.00×10^{6}	8.00×10^{19}
2.3 Fishery products			
2.3.1 Fishery yield	8.57×10^{13} J	2.00×10^{6}	1.71×10^{20}

Data sources: Ordos Statistical Yearbook, Ordos Water Resources Bulletin. References: solar value conversion rate data and energy calculation formula (Lu 2009; Jiang 2010).

Table 4 | Value of water resources in agriculture of Ordos City (2015)

Item	Symbol or formula	Value
Agricultural water consumption (m^3)	W_A	11.82×10^8
Emergy of agricultural water (seJ)	EM_{AW}	4.01×10^{22}
Total emergy of input to agriculture (seJ)	EM_{AU}	4.37×10^{22}
Total emergy of agricultural yield (seJ)	EM_{AY}	1.17×10^{22}
Water contribution rate in agriculture (%)	$WCR_A = EM_{AW}/EM_{AU}$	0.92
Emergy value of water in agricultural production system (seJ)	$EM_A = WCR_A \times EM_{AY}$	1.08×10^{22}
Emergy/currency ratio (seJ/￥)	EDR	1.54×10^{13}
Currency value of water in agricultural production system (￥)	$EM¥_A = EM_A/EDR$	0.70×10^9
Economic value of water in agriculture (￥/m^3)	$EM¥_{PA} = EM¥_A/W_A$	0.59

resources between the buyers and sellers. It seeks fairness, and essentially balances the interests of both buyers and sellers to encourage trading.

(2) This study determines a reasonable return coefficient based on the degree of water scarcity and the level of economic development in different regions, and so considers both parties to the transaction. The establishment of a reasonable return coefficient needs to be adapted to the local conditions, and thus needs to be formulated according to the actual situation of the region; therefore, a uniform standard is not set.

(3) A reasonable price is conducive to trading, thereby improving the water rights market. Considering the earnings price makes the trading price of water rights closer to the real value of water resources, and thus is an important theoretical consideration for perfecting the pricing theory of water rights.

(4) At present, the water rights transaction market in China is still in its initial stage, and its market mechanism is not yet perfect. The price of the transaction is dominated by the government, and only a price range is available. However, it is essential to ensure that water rights trading develops, as it is of great significance to water usage in water-deficient areas.

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