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Discussion on water resources value accounting and its application

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Abstract. The exploration of the compilation of natural resources balance sheet has been proposed since 2013. Several elements of water resources balance sheet have been discussed positively in China, including basic concept, framework and accounting methods, which focused on calculating the amount of water resources with statistical methods but lacked the analysis of the interrelationship between physical volume and magnitude of value. Based on the study of physical accounting of water resources balance sheet, the connotation of water resources value is analyzed in combination with research on the value of water resources in the world. What's more, the theoretical framework, form of measurement and research methods of water resources value accounting are further explored. Taking Chengdu, China as an example, the index system of water resources balance sheet in Chengdu which includes both physical and valuable volume is established to account the depletion of water resources, environmental damage and ecological water occupation caused by economic and social water use. Moreover, the water resources balance sheet in this region which reflects the negative impact of the economy on the environment is established. It provides a reference for advancing water resources management, improving government and social investment, realizing scientific and rational allocation of water resources.

1 Introduction

Influenced by congenital conditions of water resources and scale of economic and social development, there are prominent water resource problems in China. Water shortage, severe water pollution and degradation of water ecology have become significant constraints on regional economic development. In 2013, The Third Plenary Session of the eighteen first proposed to explore the compilation of natural resources balance sheet in order to get a clear picture of natural resource assets and an accurate grasp of occupation, use, consumption, recovery and value addition, among other activities, of natural resource assets by the economy (Jia et al., 2017), which was of great significance for China to comprehensively deepen the reform. Water resources balance sheet, an integral part of natural resources, is an accounting statement that calculates depletion of water resources, water environmental damage and ecological water occupation due to social and economic water consumption with indicators including water quantity, water quality and water ecology, and reflects negative impacts of economy and society on environment. Gan et al. (2014) have put forward the basic positioning about compilation of water resources balance sheet. That is, it should serve the most rigorous water resources management and the compilation of natural resources balance sheet, focus on accounting physical volume of regional economy and the environment, and target the water value accounting and integrated environmental and economic accounting. At present, insufficient research on water resources value accounting not only influences the compilation of water resources balance sheet but also restricts the reflection of the economic value of natural resources in national economic accounting. Therefore, it is necessary to discuss water resources value accounting in an in-depth way.

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2 Research status

Since the introduction of the concept "natural resources balance sheet", there has been a lot of research on this theory in China. Wang (2017) considered that natural resources balance sheet serves as a bridge and a bond between System of National Accounts (SNA) and System of Environmental-Economic Accounting (SEEA), therefore, it should be deemed as an independent system based on SEEA and supplementing SNA. Geng et al. (2017) introduced the design, balance relationship and compilation purpose of balance sheet, put forward two possible statement compilation schemes, and tried to compile land resources balance sheet and water resources balance sheet of Yongning County, Ningxia by collecting data with questionnaire. Feng et al. (2014) proposed the compilation principle of physical volume, namely first in physical and then in monetary terms, first in stock and then in flow terms and first in category and then in integration terms, and a conceptual framework of natural resources balance sheet which comprises categorized physical sheet and integrated monetary sheet of natural resources was developed. Now there remain some challenges faced by natural resources accounting, including insufficient theoretical research, lack of relatively unified, standard and mature statistic accounting system across the world. In addition, at present stage, studies mostly focus on the compilation of natural resources assets balance based on physical volume. If accounting is merely based on physical volume, natural resources assets account can only be used as a satellite account and statistically serves as a ledger. It can't reflect the utilization, consumption and protection benefits of natural resources in combination with factors including economic growth and can't realize the shift from balance sheet of natural resources to balance sheet of asset (Jiao et al., 2015; Huang et al., 2017). Thus, the shift from physical volume of natural resources to their magnitude of value is the key technical issue for advancing resources accounting.

2.1 Research status of water resources value

Water resources, as a kind of basic resource, provide means of production and means of livelihood for our human society, keep ecological balance, and are valuable assets without a doubt. In 1988, the research group of resources accounting and its inclusion in SNA proposed theoretical accounting framework regarding such three aspects as physical volume accounting, value magnitude accounting and water quality accounting for water resources, though the group hasn't put forward mature theory and approach of integrating it into SNA (Xu et al., 2006; Jiang et al., 1999). Shen et al. (1998) defined value of water resources from varying aspects including land rent theory, labor theory of value, theory of marginal utility and non-use value theory by specific characteristics of water resources, and proposed that the value connotation of water resources was mainly reflected by such three aspects as scarcity, resource property right and labor value. Xu et al. (2006) further developed the theory "payment for water quality resources use" which means that the payment for water use depends on water quality, and advanced the principle of "quality water at premium price". Huang et al. (2017) suggested a technology route for research on water resources valuation, i.e., the application of shadow prices approach to evaluate water resources depletion, cost method to evaluate water environmental damage, and emergy analysis method to evaluate ecological water occupation, respectively. Water resource value accounting, the key to promoting compilation of water resources balance sheet, lays a theoretical foundation for formation of water market mechanism, facilitates efficient and reasonable allocation of water resources and is of great significance for building a water-conservation society. Nevertheless, water resources not only offer means of livelihood for economic society as a commodity, but also are characterized by its mobility, renewability and duality of advantage and disadvantage as a type of natural resources. So it is difficult to quantify the value of water resources and there is little research on water resources value accounting. In light of the above problems, this study discusses the value of water resources, studies existing water resources value accounting models, and tries to use various methods to calculate the value and price of water resources in such three aspects as water resources, water environment and water eco-system, so as to provide a reference for establishing a reasonable accounting approach to water resources value.

2.2 The connotation of water resources value

Value is the foundation of price while price is a monetary expression of value. Natural resources property right system in China has defined national ownership of natural resources including water resources. Water price is fundamentally determined by the government rather than the market. Thus, the value of water resources is not fully reflected in market price and can't fully reflect the scarcity of resources. Wang et al. (1999) divided water resources into three categories, i.e., resource-oriented ones, engineering ones and renewable ones, to discuss the value content and price structure of water resources and proposed that water resources value accounting was based on shadow price. Gan et al. (2012) held the view that, water resources value, a special relationship with the appraisal subject established in the socio-economic and environmental system cyclic process, was represented by use value, property value, labor value, and compensated value, and was reflected by equilibrium price in the market-oriented economy. At national level, water resources value shows the attributes of property value and compensated value; national activities reflect actions of managers and exploitation and maintenance of water resources embody labor value attribute of water resources; as for users, their activities represent use value attribute of water resources (Chinese Environmental Economic Accounting Report, 2009).

Water resources value accounting should start with definition of accounting subject and should cover both unpolluted and directly available water resources and polluted and worthless water resources, appraise value of water resources regarding water resources depletion, water environmental damage and ecological water occupation in an integrated manner, and reflect water flow processes in socio-economic and environmental system in the form of economic information. The value of water resources is different from commodity value. Whether water resources are in their natural state or have agglutinated indiscriminate human labor, the production of water resources value is closely linked to their scarcity and economically manifests the ownership (Jiang and Wang, 1996). With the help of water resources value accounting, we can derive water resources price reflecting resource scarcity, use economic leverage to protect and improve water quality, increase water price reasonably to lessen wasted water resources, in order to avoid water resources crisis and realize sustainable development.

3 Research on water resources value accounting approach

3.1 Theories of water resources value

In a traditional sense, water resources are "inexhaustible" and views like "priceless resources" give rise to the free utilization without pay of water resource (Jiang, 1998a) and restrict sustainable economic and social development. With the development of western economics, land rent theory, Marxism labor theory of value, marginal utility theory of value, environmental value theory, ecological value theory, existential value view or non-use value view and other views have gradually emerged. According to land rent theory of Marx, land rent is a form in which land ownership is realized economically and represents revenues obtained by land owners merely depending on their ownership of land. In China, water resources are owned by the State and land rent paid for water resources is an important part of water resources price. According to Marx's labor theory of value, labor consumption of water resources invested by our human beings determines the price of water resources. This prompts discussion on whether natural resources without necessary social labor are valuable or not. The labor theory of value overemphasizes human's social labor time but ignores consumption compensation of water resources itself. Therefore, this theory is unable to address value issues related to natural resources including water resources. Marginal utility theory of value holds that (Wang et al., 2003), utility is the source of price and a necessary condition for the formation of value; the combination of utility and scarcity generates commodity value; marginal utility is a measure to gauge the magnitude of value. However, marginal utility theory of value has its flaw. It confuses commodity value with use value or goods utility, and is subjective in the evaluation of utility, thus eliminates the economic component of water resources value (Jiang, 1998a). Environmental value theory and ecological value theory examine the interaction between environment and water resources, dependence of economic development on nature, respectively. However, both of them merely focus on framework building and haven't developed any complete theoretical system. According to the above analysis of water resources value theories we can find that, there are no unified views on the sources of water resources value among the varied value theories discussed above. Therefore, the value accounting approaches differ significantly from each other, leading to different conclusions and difficult to get applied and promoted.

3.2 Value accounting model of water resources

Now, models and approaches of water resources value accounting mainly include shadow prices method, marginal opportunity cost model, supply-demand pricing model, fuzzy mathematics model, emergy analysis method, etc. Shadow price can reflect the scarcity of resources and is derived through solving linear programming, adjustments based on market prices at home and abroad or opportunity cost approach. But, shadow price is difficult to calculate and can't represent the value of water resources. Hence, there is a great restriction on model application. Marginal opportunity cost model provides definite calculation formula:

$$\mathrm{MOC} = \mathrm{MPC} + \mathrm{MUC} + \mathrm{MEC} \tag{1}$$

where MOC is marginal opportunity cost, MPC is marginal production cost, MUC is marginal user cost, MEC is marginal external cost.

The downside is that, it is difficult to determine MUC and MEC in the formula, and MOC only takes into consideration volume of water resources and ignores quality. With simple calculation formula and easily available data, supply-demand pricing model is suitable for the market-oriented economy environment. However, the disadvantage of this model is that, value of water resources is only determined by volume, ignoring function and ecological influence of water resources. Though fuzzy mathematics model considers multiple uncertain complex factors involved in water resources problems to establish function and matrix calculation formula and has relatively comprehensive analysis coverage, in the course of synthesize evaluation of water resources value, certain experience is required to determine the weight (Jiang et al., 1998b), which increases operational difficulty. Started from the emergy cycle and conversion of water resources eco-economic system, water resources emergy theory, which integrates the connotation of water resources value with emergy theory based on concepts including emergy conversion rate, converts different emergy flows, materials flows and currency flows in eco-system or socio-economic system into emergy in unified standards for

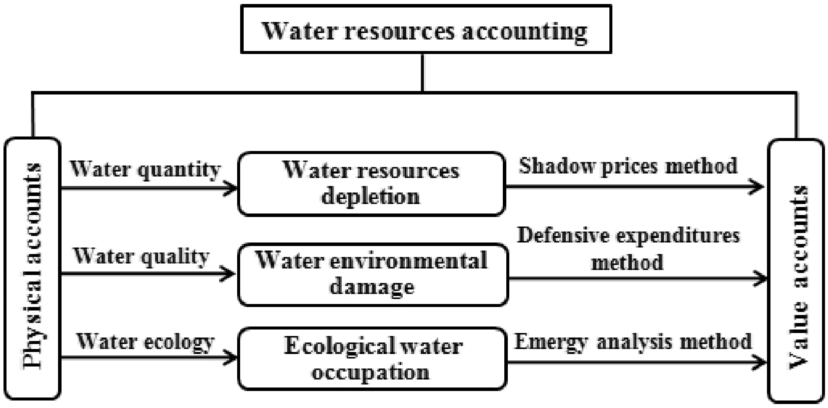

Figure 1. Technical routes of water resources accounting.

measurement and analysis. As a result, it can provide reasonable explanations for value sources, formation mechanism and other problems regarding water resources value research, and it is the new development direction for water resources value theory (Lv et al., 2009; Wang and He, 2015).

According to this paper, because of multiple purposes and renewability of water resources, we should use different methods to account water resources value from varied perspectives including water resources depletion, environmental damage and ecological occupation resulting from social and economic water consumption as shown in Fig. 1. Depletion of water resources represents a process of change in volume of water resources. The severer the depletion, the more prominent the scarcity is. Scarcity can be measured by shadow price and greater scarcity indicates higher shadow price. Water environmental damage refers to unfavorable changes in water resources environment and functional degradation of water eco-system. The deterioration of water quality is an important cause for water environmental damage and it also leads to reduced ability of water resources functional utility to satisfy subject needs, i.e., weakened utility value of water resources. Restoration cost method is applicable to non-market price appraisal of resource environment without direct market performance pattern and it uses cost required for restoration of damaged environment into its original state as the value of the original resource environment (Wang and Qu, 2001). The method can be used to measure damage of water environment. Overuse of water resources takes up existing water resources necessary for normal development and keeping a relatively stable status of eco-system. In turn, eco-environmental degradation imposes huge pressures on normal social and economic operation and exerts multiple impacts on socio-economic-eco-system. Emergy analysis approach unifies varied energies of quality and quantity in eco-system into emergy, reflects the actual price and contribution of emergy at different levels, and can assess value indicators of eco-system in a more objective manner by taking factors difficult to account into consideration.

4 Research on water resources accounting in Chengdu

4.1 Study area

Chengdu, located in central Sichuan Province and the western part of Sichuan Basin, belongs to Minjiang and Tuojiang basins in Yangtze River system and boasts a land of 12 121 km^2 and a permanent population of 14 657 500. Blessed with abundant rainfalls and sufficient water resources, it has built up the water supply infrastructure system project mainly backed by Dujiangyan and combining storage, diversion and pumping together. In 2015, Chengdu's average precipitation, total precipitation, total water resources reached 882.0 mm, 10 690 and 6632 million m^3 (including 6581 million m^3 of surface water and 2484 million m^3 of groundwater), respectively. Chengdu has high-quality water as it lies at the upstream of Yangtze River Basin, most of its river resources are composed of meteoric waters, underground undercurrents and melt snow and rivers are far away from man-made pollution before they flow into Chengdu Plain.

4.2 Physical accounts of waters resources assets in Chengdu

Physical account of water resources is the first step towards compilation of water resources balance sheet and also provides data basis for value accounting of water resources assets. Physical assets accounting reflects information about total water resources of a region and their changes based on statistics of water resources and measured in physical unit (Jian et al., 2016). Statistics of physical accounts of waters resources assets in Chengdu cover three sub-indicators, i.e., water resources, water environment and water eco-system.

Table 1. The physical accounts of water resources assets in Chengdu.

Type	Item	Unit	Surface water	Groundwater	Total water resources
Water	Opening stocks	100 million m^3	1.93	93.59	95.52
	Increases in stocks		296.57	27.78	324.35
Resources	Precipitation		41.48	24.84	66.32
	Inflows		232.42	2.94	235.36
	Returns		22.67	0	22.67
	Decreases in stocks		296.59	29.46	326.05
	Abstraction		49.7	2.74	52.44
	Outflows		244.66	24.33	268.99
	Ecological water consumption of river and lake		2.23	2.39	4.62
	Closing stocks		1.91	91.91	93.82
	Available amount		56.14	3.76	59.90
	Depletion		19.38	0	19.38
Water environment		10 000 tons	Wastewater	COD	Ammonia nitrogen
	Discharge		135 848.04	17.7	2.0
	Treatment		110 539.75	–	–
	Reduction		25 308.29	5.69	0.60
Water ecology		100 million m^3	Volume based ecological water occupation	Quality based ecological water occupation	Total
	Opening value		40.46	25.99	66.45
	Closing value		39.85	21.39	61.24
	Changes		−0.61	−4.60	−5.21

Note: Depletion of surface water = Abstraction of surface water − Available surface water resources (2)
Depletion of groundwater = Abstraction of shallow groundwater − Available shallow groundwater + Abstraction of deepgroundwater (3)
Volume based ecological water occupation = local water withdrawal − returned water − environmental wateruse (4)
Quality based ecological water occupation = amount of unqualified rivers + amount of unqualified lakes + amount of unqualified reservoirs (Bai et al., 2001) (5)

Table 2. Emergy assessment of water resources value in research area.

Item	Chemical emergy of rainwater	Solar emergy of rainwater	Unit water resources solar emergy	Unit water resources value	
	$\times 10^{16}$ J^{-1}	$\times 10^{20}$ sej^{-1}	$\times 10^{11}$ (sej m^{-3})	/(USD m^{-3})	/(CNY m^{-3})
	5.28	8.13	1.23	0.12	0.80

Water resources depletion, waste water discharge and ecological water occupation in Chengdu are estimated based on *Chengdu Water Resources Bulletin*, *Chengdu Environment Quality Bulletin, Chengdu Statistical Yearbook (2014–2015)* and other materials as well as "The Three Red Lines" control indicators. Considering the availability of data, Chengdu physical accounts of water resources assets in 2015 are established as shown in Table 1.

It can be seen that, in terms of water resources, in 2015, beginning stock and ending stock of water resources in Chengdu were 9552 and 9382 million m^3, respectively, a decrease of 170 million m^3, and total water resources depletion reached 1938 million m^3; in terms of water environment, untreated wastewater was 253 million tons, and as total COD and ammonia nitrogen emissions in 2015 should be limited to 120 100 and 14 000 tons according to implementation opinions on cutting down total amount of major pollutants under the Twelfth Five-year Plan of Chengdu; emissions of COD and ammonia nitrogen should be reduced by 56 900 and 6000 tons; in terms of water eco-system, ecological water occupation caused by human activities in 2015 reached 6124 million m^3, a decrease of 521 million m^3 compared to that at the end of 2014.

Table 3. The value accounts of water resources assets in Chengdu.

Item				
1. Water resources	Opening stock value	Net value change (100 million CNY)	Closing stock value	Depletion cost
1.1. Surface water	6.45	−0.07	6.38	64.73
1.2. Groundwater	312.59	−5.61	306.98	0
1.3. Total water resources	319.04	−5.68	313.36	64.73
2. Water environment	Amount of pollutants to be reduced (10 000 tons)		Environmental degradation cost (100 million CNY)	
2.1. Wastewater	25 308.29		3.97	
2.2. COD	5.69		5.46	
2.3. Ammonia nitrogen	0.60		10.02	
3. Water eco-system		Opening water occupation value	Closing water occupation value (100 million CNY)	Value changes in current year
3.1. Ecological water occupation		52.89	48.75	−4.14

4.3 Water price in Chengdu

Price is a bridge between physical volume and magnitude of water resources value. Three different methods are adopted to calculate the value for water resources, water environment and water eco-system in physical account.

1. Firstly, shadow prices method is used to calculate water resources value. By reference to shadow price calculation made by He and Chen (2005) for nine major basins in China in important years by applying non-linear dynamic input-occupancy-output model, in 2015, shadow price in Chengdu was about 3.34 $\mathrm{CNY\,m^{-3}}$, slightly higher than local domestic water price (2.96 $\mathrm{CNY\,m^{-3}}$).

2. Defensive expenditures method is adopted to calculate water environment degradation cost. The calculation formula is:

$$\begin{aligned}\text{defensive expenditures} &= \text{reduced cost of unit pollutants}\\ &\times \text{amount of pollutants to be reduced}\\ &= \text{treatment cost of wastewater}\\ &\times \text{wastewater to be treated} \qquad (2)\end{aligned}$$

   According to investigation, Chengdu's unit wastewater treatment cost is about 1.57 $\mathrm{CNY\,m^{-3}}$, including 0.17 $\mathrm{CNY\,m^{-3}}$ of fixed wastewater treatment cost, 1.07 $\mathrm{CNY\,m^{-3}}$ of unit wastewater treatment operation expense and 0.33 CNY of unit wastewater treatment statutory tax. Based on results of national environmental and economic accounting for water, reduced expenses of COD and ammonia nitrogen were 9.6 and 167.0 $\mathrm{CNY\,kg^{-1}}$, respectively.

3. Emergy analysis method is used to account ecological water occupation which mainly considers the water resources necessary for various types of ecosystems occupied by economic and social overuse. This part of water originally belongs to natural water resources, and therefore the value of natural water resources is taken as the value of ecological water occupation. According to the concept analysis of the energy conversion process of water resources, the rainwater in the study area is used as the energy source of the water resources, assuming that solar emergy of rainwater is equal to that of water resources. Relevant calculation formulas are (Chen et al., 2006):

$$\begin{aligned}&\text{chemical emergy of rainwater} = \text{water volume}\\ &\quad\times \text{Gibbs free emergy} \times \text{density} \qquad (3)\end{aligned}$$

$$\begin{aligned}&\text{solar emergy of rainwater}\\ &\quad= \text{chemical emergy of rainwater}\\ &\quad\times \text{solar emergy conversion rate of rainwater} \qquad (4)\end{aligned}$$

$$\begin{aligned}&\text{unit water resources solar emergy}\\ &\quad= \text{solar emergy of water resources}\\ &\quad\div \text{amount of water resources} \qquad (5)\end{aligned}$$

$$\begin{aligned}&\text{unit water resources value}\\ &\quad= \text{unit water resources solar emergy}\\ &\quad\div \text{emergy/currency rate} \qquad (6)\end{aligned}$$

Relevant parameters are: Gibbs free emergy is 4.94 $\mathrm{J\,g^{-1}}$ (Odum, 1996); solar emergy conversion rate of rainwater is 1.54×10^{4} $\mathrm{sej\,J^{-1}}$ (Zeng et al., 2011); emergy currency^{-1} rate in research area in 2015 is 1.00×10^{12} $\mathrm{sej\,USD^{-1}}$ (Zeng et al., 2011); RMB exchange rate is 6.49 $\mathrm{CNY\,USD^{-1}}$. Results of water resources emergy in Chengdu are shown in Table 2.

4.4 Value accounts of waters resources assets in Chengdu

Value accounts of water resources assets derive corresponding aggregate indicators through overall accounting of water resources assets based on physical account. Figure of each item in value accounts of water resources is equal to the price of water resource and their quantity in physical account. We can learn from Table 3 that, at the end of 2015, the value of water resources stock in Chengdu totaled 31 336 million CNY including 638 million CNY of surface water stock, 30 698 million CNY of groundwater stock and water resources depletion cost reached 6473 million CNY; environmental degradation costs based on wastewater discharges was 397 million CNY, and amounts of COD and ammonia nitrogen to be reduced were 546 million CNY and 1002 million CNY, respectively; Based on emergy analysis method, unit water resources value in Chengdu in 2015 is 0.80 CNY m^{-3}, then we multiply it with ecological water occupation in the current year and then derive ecological occupation cost at 4875 million CNY.

4.5 Discussion

In this paper, the water resources accounting of Chengdu was carried out based on the idea of first physical, then value. The research results are discussed as follows:

1. In the physical account, the calculation method of ecological water occupation is not perfect which has a duplicate part with the water resource depletion. In the future research, in consideration of the minimum ecological base flow occupied by the process of water abstraction, the process impact of the decline in ecological service function can be analyzed dynamically.

2. The practice of water resources accounting indicated that, accurate shadow price in the calculation of water resources depletion cost requires support from complete data and calculation should be made at municipal level or above; as pollutant control expense calculated by protection expense method is less than environmental damage caused by pollutant emission, such expense can only be used as the lower limit for environmental degradation cost; now, water eco-system in water resources balance sheet haven't been well studied in China and both physical volume of ecological water occupation and calculation method for ecological value of water resources still await further research and practice.

5 Conclusions

Beginning with the connotation of water resources value, this paper analyzed basic principles and existing flaws of water resources value theories and accounting methods, proposed to primarily account water resources depletion cost, water environment degradation cost and ecological water occupation cost from three aspects, i.e. water resources, water environment and water eco-system. Physical and value accounts of water resources in Chengdu, China were established based on shadow prices method, defensive expenditures method and emergy analysis method. Although these methods have certain deficiencies which need to be improved in future research, this paper makes a preliminary attempt to shift from physical accounts of water resources to value accounts and advances the compilation of water resources balance sheet.

Data availability. The data used in this article are from the Chengdu Water Authority (2015; http://www.cdwater.gov.cn/wsbs/bmcx/sl/system/2017/03/1/000002497.html); the Chengdu Bureau of Statistics (2016; http://www.cdstats.chengdu.gov.cn/htm/detail_63038.html); and the Chengdu Environmental Protection Bureau (2015; http://www.cdepb.gov.cn/cdepbws/Web/Template/GovDefaultInfo.aspx?cid=65205&aid=B1C16A95EB0242198B5D67870E8BE084).

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