Valuation of Urban Water Eco-System Service Functions

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Abstract. Water eco-system service functions refer to the natural environment conditions and utilities formed by the water eco-system and ecological process to maintain human survival. They are the eco-environmental conditions for human survival and development and the basic resources of human social and economic development. During the rapid development of the urbanization process, the urban water eco-system has been increasingly influenced by human activities. Humans have severely destroyed the original urban water system while exploiting and utilizing water resources on a large scale, and consequently resulted in a series of water environment problems. In order to build a harmonious urban eco-system and reasonably utilize and protect water resources, it is of great importance to analyze and improve the urban water eco-system service functions and conduct the valuation, so as to arouse the public's awareness of recognizing and protecting the urban water resources.

1. Introduction
China has seen a constant progress in its urbanization level since the last century. However, during the rapid development of the urbanization process, the urban water eco-system has been increasingly influenced by human activities. Humans have severely destroyed the original urban water system while exploiting and utilizing water resources on a large scale, and consequently resulted in a series of water environment problems [1]. For example, lakes become increasingly smaller, and rivers begin to run dry. These problems have not only affected the normal production and life of humans, but also undermined the stability and balance of the eco-system. Therefore, in order to build a harmonious urban eco-system and reasonably utilize and protect water resources, it is of great importance to analyze and improve the urban water eco-system service functions and conduct the valuation, so as to arouse the public's awareness of recognizing and protecting the urban water resources [2].

2. Comprehensive assessment system of urban water eco-system service functions
The classification of eco-system service functions is not only the prerequisite for the assessment of eco-system service functions, but also the basis of building an assessment indicator system for the service functions [3, 4].

Water eco-system service functions refer to the natural environment conditions and utilities formed by the water eco-system and ecological process to maintain human survival [5]. They are the eco-environmental conditions for human survival and development and the basic resources of human social and economic development. Usually, the water eco-system service functions include the provision of products and regulation function, cultural function and life support function [5, 7]. Cities
are the natural-manual complex eco-systems. Urban water eco-system, closely related to human activities, is different from the traditional water eco-system in natural environment. As the existing assessment system of urban water eco-system is underdeveloped and non-authoritative, it is necessary to re-study the urban water eco-system service functions and provide a scientific basis for eco-environmental protection.

2.1. Provision of products
Eco-system products refer to the factors produced by the eco-system to maintain human production and life activities and bring direct benefits to human activities through direct provision of products or services, including the provision of aquatic products, water supply, shipping, power generation, etc. The product provided can be exchanged in the market as a commodity, entering the production process in a physical form and directly reflecting the economic value.

2.1.1. Provision of aquatic products. The urban water eco-system provides a large number of eco-resources for humans, including the non-staple food that people need such as fish, shrimp, crab, shellfish and lotus root; raw materials for industrial and agricultural production such as bulrush, reed and mat grass; medicines such as bulrush roots, cattail pollen and lotus nut; and livestock feeds such as aquatic plants, escargots and clams. These resources can not only enhance urban self-services and guarantee sufficient supply, but also reduce the pressure of transportation and promote the advocacy of environmental conservation.

2.1.2. Water supply. As the most important service function of the urban water eco-system, the value of water supply service depends on the water quality. In a city with one million population, the daily domestic water consumption reaches hundreds of thousands of cubic meters. Therefore, urban waterworks are often built beside the lake, on the one hand, to supply sufficient potable water, on the other hand, to ensure the surrounding agricultural irrigation. Taking Hongze Lake in Jiangsu as an example, the irrigation water of 7-14 billion cubic meters flows from the general irrigation canal to the lower river region every year, covering an irrigation area of 18 million mu. Meanwhile, water is also indispensable for urban industrial development. According to the statistics, 30-40 cubic meters of water is required for the production of every ton of steel, 200-300 cubic meters for paper and 3000-5000 cubic meters for chemical fiber.

2.1.3. Shipping. Among the water, land and air transportation, water transportation costs the least. The development of water transportation plays an important role in the exchange of goods between different cities and between urban and rural areas, and in the promotion of production and development. Closely linked with the Yangtze River, Yellow River, Huaihe River, Haihe River and the Grand Canal, the eastern plain of China is crisscrossed by lakes and rivers, which has formed a transport network stretching all directions and significantly promoted the exchanges between regions and cities.

2.1.4. Hydro power generation. Water is a clean energy. Hydro power generation is to turn the potential energy of water into mechanical energy and finally to electric energy. Hydro power development can alleviate the environmental problems resulting from traditional thermal power generation. In some mountainous cities, hydro power generation is developed in a manner appropriate to local conditions, which can not only ensure effective power supply, but also save the coal resources and protect the environment.

2.2. Regulation services
Regulation function refers to the services and benefits that humans obtain from the regulation of eco-system. Regulation function of urban water eco-system mainly includes water storage and disaster prevention, groundwater recharge, purification, atmospheric regulation and so on.
2.2.1. Water storage and disaster prevention. Compared to non-urbanized areas, urbanized areas are more vulnerable to flood and waterlogging, mainly due to the following reasons: (1) Small water systems have been filled and the impervious surface areas have been expanded increasingly during the urbanization, greatly undermining the surface's interception and infiltration of water and resulting in the sudden occurrence and high flow of surface runoff; (2) The improved urban drainage system has increased the drainage capacity in urban areas, which accelerated the joining of rainfall and runoff with main rivers, and shortened the retardation of peak period for main rivers, thus leading to the rapid rise of water volume and significant increase of flood peak level in main rivers and bringing about violent flood more easily; (3) More pollutants in urbanized areas provide a large number of condensation nuclei for the rainfall. The thermal turbulence formed by the thermal island effect and the mechanical turbulence produced by the buildings and pavements both provide the motivation for convection. Impervious surface areas reduce the water that can evaporate. All these factors have led to the increase of rainfall, reduction of evaporation and high occurrence of floods in urban areas. Therefore, the protection of urban water eco-system plays an important role in flood storage, diversion and infiltration, flood discharge regulation, regulation of time lag for the peak flow between main rivers, increase of evaporation and alleviation of thermal island effect.

2.2.2. Groundwater recharge. The interaction between urban water eco-system and groundwater serves as a key link of terrestrial hydrological cycle. The shallow groundwater can be a long-term water source for supplying water for the surrounding areas, maintaining the water level or finally flowing to the groundwater system. About two-thirds of cities in China take groundwater as the only source of water. If groundwater cannot be recharged, it will lead to the decline of water table, earth subsidence, soil salinization and other serious consequences. Therefore, to maintain the hydrological cycle of natural systems, reduce the pressure of municipal works, save investment and prevent disasters, it is crucial to retain the urban water system and use permeable ecological embankments, so as to maintain the mutual infiltration and interaction with groundwater.

2.2.3. Purification. After the pollutants brought about by the point and non-point source pollution and atmospheric sedimentation get into the urban water eco-system, they will be transferred, converted, diffused and concentrated. A series of changes will take place in their forms, chemical composition and properties. Finally, they will be purified.

2.2.3.1. Water purification. Water can provide or maintain a good physical and chemical metabolism environment for pollutants, thus increasing the purification capability of regional environment. Pollutants can be degraded finally through the dilution and diffusion of water flow, absorption of aquatic plants and oxidative decomposition of microorganisms in the water. In this way, water can be purified.

2.2.3.2. Air purification. Waters can increase air humidity through the water surface evaporation and transpiration in plants, which is favorable to the removal of pollutants in the air and contributes to air purification. For example, the humidity increase can greatly shorten the retention time of sulfur dioxide (SO₂) in the air, accelerate the sedimentation of airborne particulate matters, and promote the decomposition and transformation of various pollutants in the air. Besides, the water eco-system can also increase negative ions in the air.

2.2.4. Atmospheric regulation

2.2.4.1. Regulation of local climate. Due to the vast area of waters, plants grow rampantly in offshore areas, featuring high water surface evaporation and transpiration. It is the heat and moisture exchange that regulates local climate and makes the climate of surrounding region milder and more humid than that of other regions. The water surface evaporation can maintain the local rainfall. Rainwater returns
to the atmosphere through the transpiration in plants and gets back to waters in the form of rainfall. In terms of air temperature, because of the regulation of waters, both the average maximum temperature and extreme temperature are relatively lower in the surrounding region compared with the land in summer. The opposite is true in winter. In terms of humidity, waters can increase the air humidity through the water surface evaporation and transpiration in plants, thus increasing the humidity in the surrounding region.

2.2.4.2 Regulation of atmospheric composition. The regulation of atmospheric composition is mainly achieved by the water eco-system through carbon dioxide (CO\textsubscript{2}) fixation and oxygen (O\textsubscript{2}) release. The floating vegetation and aquatic plants in the water can exchange the carbon dioxide and oxygen with atmosphere through the photosynthesis and respiration, which is important for maintaining the dynamic balance of carbon dioxide and oxygen in the atmosphere. Carbon dioxide fixation through the photosynthesis is an important source of carbon in the carbon cycle of the eco-system. Firstly, it can be transmitted to the next trophic level via ingestion. Secondly, dry branches and fallen leaves of plants accumulate in the water and form the sludge that is rich in organic matrix. Therefore, the water eco-system plays a significant role in preventing the increase of global carbon dioxide concentration. The oxygen released by advanced aquatic plants can be provided to humans and other organisms for their respiration. It is indispensable for the earth to maintain life activities.

2.2.5. Nutrient cycling. Nutrients in the eco-system are recycled through complicated food web. It is an indispensable link of global biogeochemical cycle. Water is not only a kind of food, a kind of raw material, but also a carrier of material and energy transfer. Water cycle consists of the cycle in the manual control system including ditches and culverts and the natural cycle such as rainwater and surface runoff. The two cycles are combined in an intricate manner. As the water flows, a variety of materials can be transferred. Aquatic organisms, as important structural and functional components of the water eco-system, can turn light energy and minerals into organic substances and release oxygen as they grow up, absorb mineral nutrients such as nitrogen and phosphorus in the water and sediment and accelerate the cycle of nutrient elements through direct fishing or via the food chain.

2.3. Cultural function
Cultural function refers to the non-material interests that humans obtain from the natural eco-system through cognitive development, subjective image, recreation and aesthetic experience. Cultural function of the water eco-system mainly includes cultural diversity, education value, inspiration and enlightenment, aesthetic value, cultural heritage value, recreation and ecological tourism value. As the "soul" of "natural landscape", water can be used for a wide variety of recreation services. Meanwhile, water eco-environment as a unique geographical unit and living environment plays a crucial role in forming a unique type of traditional culture.

2.3.1. Cultural diversity. Natural eco-environment can influence human aesthetic tendency, artistic creation and religious belief profoundly. Nature is an important source of high-level spiritual pursuit and development. People’s curiosity about nature is the eternal driving force for the development of science, technology and religion. It is the various eco-systems that foster the diversity of cultural and spiritual life.

2.3.2. Aesthetic value and scientific research. Nature is an important object of aesthetic studies and an endless source of artistic expression. The sense of beauty comes from artistic forms and cultural symbols, and is related to human biological needs and nerve sensory requirements. The sense of beauty is an adaptive emotional function, especially the non-conscious inborn virtue tendency, and has adaptive value from the perspective of evolution. It is often accompanied by rich resources and conditions. People often judge the potential value of a habitat for future survival and reproduction according to shapes, colors, sounds, smell and other signals. With the aggravated shortage of global
water resources, more and more scientific researchers have been devoted to the research of water resource utilization. Urban water eco-system has also become an important subject of study. Various urban waters as an important part of the water eco-system can not only be a subject for scientific studies and set reasonable water resource planning goals, but also be used for promotion and education, especially serving as the environmental protection and education base.

2.3.2.1. Recreation and ecological tourism value. Urban waters, including lakes and rivers, have supported the most common outdoor activities for people for a long period of time. Some activities are held in water, such as boating, fishing, swimming, water skiing and drifting, while other activities use the unique natural landscape to create a beautiful environment for gathering, play and rest, such as camping and photographing along the lake or river. Being good for body building, relaxation and recreation, such recreational activities have become a significant part of people's recreational life. The urban water eco-system can bring people with spiritual enjoyment with its beautiful forms, sounds or habits, and improve the quality of life. Scenic areas in various forms are good places for recreation and entertainment. Human nature can be fully embodied in the natural environment.

2.3.2.2. The role of living environment in combination with real estate development. People have an inexplicable affection for water. With its excellent environmental quality and strong attraction, the urban water eco-system has enhanced the material and environmental quality and cultural taste of the surrounding region, thus affecting the urban land price of the surrounding regions and drive regional development. The high-quality environment, broad space and outstanding landscape quality created by the urban water eco-system are unparalleled compared with any other urban area. Therefore, its potential value will have an immeasurable impact on urban economy.

2.4. Life support function
Life support function maintains the natural ecological process and regional eco-environmental conditions. It is the foundation of the above service functions. Unlike other service functions, it influences humans indirectly, and the influence cannot be embodied in the short run, such as soil formation and conservation, photosynthetic oxygen production, nitrogen cycle, water cycle, primary productivity and providing of living environment. Take living environment as an example, wet land provides a living environment for all kinds of aquatic organisms with its high landscape heterogeneity and serves as the base of inhabiting, reproduction, migration and overwintering for wildlife. Some waters are the stopover point of endangered waterfowl, and others raise many endemic species including amphibians and fishes.

2.4.1. Soil formation and conservation. Lakes are the home of surface runoff and sediments, with the function of soil formation and conservation.

2.4.2. Providing living environment and maintaining biodiversity. Biodiversity is a prerequisite for human survival and development. Urban waters can provide habitats and protect urban biodiversity. Also, they can serve as the Noah's Ark which the wildlife in urban areas lives on. Meanwhile, as a heterogeneous patch in the city, there should be a connection between urban water systems and between water systems and urban green space as far as possible, thus to constitute a multi-layer, multi-functional, compound and network-type eco-system.

3. Valuation of urban water eco-system services

3.1. Provision of products

3.1.1. Provision of material products. Based on the market valuation method, the formula is as below:

\[ V = \sum S_i \times Q_i \times P_i \]  

(1)
Where $V$ refers to the value of material production; $S_i$ refers to the production area of the material production $i$; $P_i$ refers to the market price of the material production $i$; $Q_i$ refers to the yield per unit area of the material production $i$.

3.1.2. Water supply

3.1.2.1 Domestic water. Based on the market valuation method, the formula is as below:

$$V_p = P_p \times Q_p$$  (2)

Where $V_p$ refers to the value of domestic water; $P_p$ refers to the price of domestic water; $Q_p$ refers to the consumption of domestic water.

3.1.2.2 Industrial water. Based on the market valuation method, the formula is as below:

$$\sum V_{pi} = P_{pi} \times Q_{pi}$$  (3)

Where $V_{pi}$ refers to the value of industrial water in the industry $i$; $P_{pi}$ refers to the price of industrial water in the industry $i$; $Q_{pi}$ refers to the consumption of industrial water in the industry $i$.

3.2. Regulation function

3.2.1. Water storage and disaster prevention. Based on the alternative engineering method, the formula is as below:

$$V_r = a P_r \times Q_r$$  (4)

Where $V_r$ refers to the value of moisture regulation; $a$ refers to the relevant empirical coefficient of urban groundwater interaction; $P_r$ refers to the annual cost and operation of every ton of water regulated by urban water supply and drainage facilities; $Q_r$ refers to the volume of water that can be regulated in a certain water system every year.

3.2.2. Groundwater recharge. Based on the shadow price method, the formula is as below:

$$V_r = P_r \times Q_r$$  (5)

Where $V_r$ refers to the value of groundwater regulation and storage; $P_r$ refers to the unit price of regulation and storage; $Q_r$ refers to the total volume of groundwater.

3.2.3. Purification capability

3.2.3.1 Water purification. Based on the alternative engineering method, the formula is as below:

$$V_r = P_r \times Q_r$$  (6)

Where $V_r$ refers to the total costs of water purification; $P_r$ refers to the unit processing cost of pollutants; $Q_r$ refers to the assimilative capacity of the water.

3.2.3.2 Air purification. For negative ions and dust, based on the alternative engineering method, the formula is as below:

$$V_r = P_{r1} \times Q_{r1} + P_{r2} \times Q_{r2}$$  (7)

Where $V_r$ refers to the value of air purification; $P_{r1}$ refers to the unit price of negative ion production; $Q_{r1}$ refers to the increase of negative ions for the water eco-system; $P_{r2}$ refers to the decrease of unit dust price; $Q_{r2}$ refers to the decrease of dust volume.

3.2.4. Atmospheric regulation. Based on the alternative engineering method, the formula is as below:

$$V_r = \frac{\alpha}{\infty} P_r + \beta \times Q_{r2} \times P_r$$  (8)

Where $V_r$ refers to the value of climate regulation; $\infty$ refers to the performance ratio of atmospheric regulation; $\beta$ refers to the power consumption for the evaporation of 1 cubic meter of water; $P_r$ refers to the power price; $Q_{r1}$ refers to the heat absorbed for water surface evaporation; $Q_{r2}$ refers to the volume of surface water evaporated.
3.3. Cultural function

3.3.1. Tourism. Based on the travel cost method, the formula is as below:

\[ V_r = r \times V_R \]  \hspace{1cm} (9)

Where \( V_r \) refers to the tourism income of the water eco-system; \( r \) refers to the ratio of water landscape in the tourism income; \( V_R \) refers to the tourism income of the whole city.

3.3.2. Recreation and entertainment. Based on the willingness to pay method, the formula is as below:

\[ V_r = r_f \times C_r \]  \hspace{1cm} (10)

Where \( V_r \) refers to the recreation and entertainment value of public water landscape; \( C_r \) refers to the total cost of the willingness to pay for travelling in the city; \( r_f \) refers to the ratio of free parks in the recreation and entertainment value.

3.4. Support function

3.4.1. Carbon dioxide fixation. Based on the alternative engineering method, the formula is as below:

\[ V_r = P_r \times Q_r \]  \hspace{1cm} (11)

Where \( V_r \) refers to the total value of carbon dioxide fixation; \( P_r \) refers to the afforestation cost or carbon tax of carbon dioxide; \( Q_r \) refers to the volume of fixed carbon dioxide.

3.4.2. Oxygen release. Based on the shadow price method, the formula is as below:

\[ V_r = P_r \times Q_r \]  \hspace{1cm} (12)

Where \( V_r \) refers to the overall value of oxygen release; \( P_r \) refers to the shadow price of industrial oxygen production; \( Q_r \) refers to the volume of oxygen released by plants in a year.

3.4.3. Material cycle. For the total amount of nutrients, based on the method of shadow price, the formula is as below:

\[ V_r = P_N \times Q_N / \alpha + P_P \times Q_P / \beta \]  \hspace{1cm} (13)

Where \( V_r \) refers to the total value of nutrient cycle; \( P_N \) refers to the urea price; \( P_P \) refers to the perphosphoric acid price; \( \alpha \) refers to the percentage content of \( N \); \( \beta \) refers to the percentage content of \( P \).

3.4.4. Diversity protection. Based on the willingness to pay method, the formula is as below:

\[ V_r = \sum_{i=1}^{2} (A_{ri} \times P_{ri}) \]  \hspace{1cm} (14)

Where \( V_r \) refers to the overall value of biodiversity; \( P_{ri} \) refers to the price of willingness to pay for the protected animals of Class \( i \); \( A_{ri} \) refers to the number of species for the protected animals of Class \( i \).

3.4.5. Providing habitats. There are many mutually exclusive options in any eco-system. If you choose a certain opportunity, you will lose others for utilization and the chance to obtain benefits from the latter. Therefore, the maximum benefits that can be obtained from the option where you lose the opportunities for utilization are called the opportunity cost that the eco-system has to pay for choosing the option. For habitats, the formula is as below:

\[ W = S \times P \]  \hspace{1cm} (15)

Where \( W \) refers to the value of providing habitats; \( S \) refers to the area of water system; \( P \) refers to the price of land in the city.

In addition, the method of shadow project can be applied. For example, when small aquatic systems in the urban area have been destroyed, the wildlife in the surrounding region will lose their habitats. In this case, protection areas are required to be built manually in other proper places. The costs for building and maintaining the protection area can be seen as the value of providing habitats for small aquatic systems in the urban area. The formula is as below:

\[ W = S (P_1 + P_2 + P_3 + P_4) \]  \hspace{1cm} (16)
Where $W$ refers to the value of providing habitats; $S$ refers to the area of water system; $P_1$ refers to the construction investment of unit area for the protection project; $P_2$ refers to the scientific research investment of unit area for the protection project; $P_3$ refers to the publicity investment of unit area for the protection project; $P_4$ refers to the maintenance funds of unit area for the protection project.

4. Conclusion
The practical significance of the value of aquatic ecosystem service function lies in the actual change of the value of service function, and the actual change of the value of service function is closely related to the aquatic ecosystem pattern and environment habitat. It can be said that the results of the impacts of urban people on water ecological pattern and water environment Habitat can be expressed by the actual changes of water ecological service function.

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