Study on benefits evaluation of water diversion project: Case study in water transfer from the Yangtze River to Lake Taihu

To cite this article: D Wang et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 344 012120

View the article online for updates and enhancements.
Study on benefits evaluation of water diversion project: Case study in water transfer from the Yangtze River to Lake Taihu

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Abstract. To resolve the uneven distribution of water resources and the imbalance between water demand and water supply in Taihu Basin, the Yangtze River to Lake Taihu water transfer (YTWTP) project has been built since 2002. It is considered as a necessary measure to insure the water supply of Taihu basin. For the prospective development of the YTWTP, the comprehensive benefits of the YTWTP were evaluated in this paper. Presently, many studies focus on the intergraded water resources management and the improvement of water environment after water diversion. There are fewer studies on comprehensive benefits evaluation of water diversion. Thus, in this paper, an evaluation framework for comprehensive benefits evaluation of water diversion project was constructed. It was contained of several quantitative methods. The water diversion in 2011 of the YTWTP was selected as the evaluation object. Both the direct and indirect benefits were calculated. It was shown that the comprehensive benefit came to 9.9379 billion yuan. Among them, the direct benefits reached 9.4189 billion yuan, the rest were the indirect benefits. Based on the integrated evaluation framework, the evaluation results indicated that the YTWTP has brought significant benefits on the intake area of Taihu basin. It can be considered as a reference on benefits evaluation of other water transfer projects.

1. Introduction

As we all know, water resources play a critical role in the sustainable development of human society. It is considered to be an essential investment in agriculture, industry, tourism, life consumption and so on [1]. As a result of the temporal and spatial variations of water resources, the shortage of water resources becomes a common phenomenon all over the world [2,3] Worse still, with the aggravation of climate change and human activity, the imbalance between water supply and demand becomes increasingly prominent in recent years [4,5]. The severe water-shortage situations prevent the development of economic in a certain extent. In order to overcome water-shortage and water pollution, the creation of inter-basin water diversion from surplus to deficit regions is one of the rational options. It can not only reallocate water resources reasonably, enhance the resilience of the water system and reduce the risk of shortages, but also improve the imbalance between water supply and demand and promote the sustainable utilization of water resources available [6-8]. However, some inter-basin water transfer projects may cause some negative effects [9,10]. Hence, a water transfer project can be executed if it can be economically and environmentally justified [11]. During the construction of a water diversion project, the social, economic and environmental impacts on the intake area should be
discussed [12].

To date, many water diversion projects have been built worldwide, such as the water transfer from the Yangtze River to Lake Taihu project (YTWTP) in China, the California state water transfer project in United States [13] and the national river-linking project in India [14]. When an inter-basin water diversion project operates, the transferred freshwater improve the water quality, increase the water supply, promote the comprehensive utilization of water resources and ensure the water supply security of intake area. Meanwhile, it will bring remarkable economic, social and environmental benefits to intake area inevitably. In addition, the benefits of water diversion are directly determined by the quantity of transferred freshwater. Hence, it is vital to evaluate the comprehensive benefits of water diversion project for the optimum operation and the prospective water diversion. Owing to the complexity of impact factors of the benefits evaluation, and the uncertainty of evaluation methods, it is difficult to propose a systemic evaluation framework for the quantitative assessment of water diversion benefits. Consequently, the research on comprehensive benefits evaluation of water diversion is a hot issue of studies on regional response to water diversion [15,16].

Currently, there is a growing body of literature focus on inter basin water diversion, which mainly refer to integrated water resources management [17], optimal allocation of transferable water resources [18], hydrological and ecological impacts [19], the improvement of water environment after water diversion [20] and so on. For instance, Gupta [17] et al. analyzed whether water transfers were compatible with the concept of integrated water resources management from a multi-disciplinary perspective. A new methodology based on crisp and fuzzy Shapley games was developed for optimal allocation of inter-basin water resources [18]. Chen et al. [21] addressed the complexity in decision making of water resources redistribution in two neighboring river basins by use of fuzzy sets incorporating objective and subjective uncertainties. Xi et al. [22] developed an inter-basin water transfer-supply and risk assessment model with consideration of rainfall forecast information and indicated it can reduce the comprehensive risk and improve the utilization efficiency of water resource. Bonacci et al. [19] examined the effects of hydrological changes caused by inter-basin water transfer and the reservoir development on the hydrological regimes of two rivers. In benefits assessment of water transfer, Matete et al. [23] developed an ecological economics framework to evaluate the impact and economic benefits of Lesotho Highlands Water Project. Wu et al. [24] quantitative analyzed the economic benefits of HuZhou city in Taihu basin under the YTWTP. Obviously, there are quite fewer researches on the comprehensive benefits assessment. Hence, we tentatively construct a comprehensive benefits assessment framework by adopting quantitative methods for the development of water diversion projects.

In this paper, the purpose is to evaluate the economic, social and environmental benefits of the water diversion of the YTWTP in 2011 from a multi-faceted perspective. So, a quantitative assessment framework that integrated social, environmental and economic benefits assessment models was designed and implemented. The paper mainly contained six sections. The next section gave a brief introduction to study area. The evaluation approaches of water transfer benefits were discussed in section 3. Evaluation methods were applied for assessing the water transfer benefits. In section 4, the evaluation results of water transfer benefits and the analysis of evaluation results were presented. The conclusions were drawn in the last section.

2. Study area

The TaiHu basin located in the south of the lower Yangtze River Delta between 119°08′~121°55′E and 30°05′~32°08′N with an area of 36900 km² in China. The terrain of the basin is higher in periphery and lower in middle. It is a humid region with a mean annual precipitation of 1180 mm. The temporal and spatial distributions of precipitation are uneven extremely. During May to September, Rainstorms usually occur and rainfall in these five months takes up over 60 percent of the annual total amount. The average annual runoff amount is 177×10^8 m³. The precipitation and runoff amount varies greatly within a year. The basin has a complicated river network system with river density of 3.25 km/km². The Lake TaiHu is considered to be the center of the river network system. It is the third
largest freshwater lake in China with 172 tributaries connecting to it. Its water surface area, average water depth and volume are about 2338 km², 1.89 m, 44.3×10⁸ m³ respectively [25]. The Lake TaiHu possesses many functions, such as flood control, water supply, irrigation and water recreation. So it plays an important role in the regional development of economic and society [26]. In addition, the urbanization level of TaiHu basin is very high. The development of TaiHu basin drives the development of the whole country.

In order to alleviate the water shortage and improve the water quality, the YTWTP has been implemented since 2002. The route of water transfer is from the Yangtze River to the Wangyu River, then to Lake Taihu and flowing out of the lake via the Taipu River in the southeast eventually. There are two major rivers in the YTWTP, i.e. the Wangyu River and the Taipu River, which acted as the influent and effluent rivers respectively. The Wangyu River is the major channel for water transfer from the Yangtze River to Lake Taihu and it is connected with many tributaries around Lake Taihu. With the purpose of keeping water balance of Lake Taihu and avoid flood risk in rainy seasons, water flow out of the lake through the Taipu River and other rivers on the southeast side. The YTWTP has reduced the water shortage of the surrounding cities, such as SuZhou, WuXi, ShangHai and HangZhou. In 2011, the total days of water transfer was 251 d. The total amount of water diversion from the Yangtze River to the Wangyu River reached 31.85×10⁸ m³, among which 16.08×10⁸ m³ of water flowed into Lake Taihu and the rest of them were provided to both shores of the Wangyu River. The water provided for the downstream area through the Taipu River came to 8.03×10⁸ m³.

Compared with other years, the precipitation of taihu basin was less in 2011. It can be considered as a dry year. Because of the lower water level of Lake Taihu, the water quality of Lake Taihu was bad the water pollution was more serious. Plenty of freshwater was transferred to Lake Taihu from the Yangtze River to improve the water quality by the YTWTP. Consequently, the water diversion of the YTWTP in 2011 was selected as a reference for the benefits evaluation of water diversion projects.

In this study, the main intake area (WuXi, SuZhou, ShangHai, JiaXing, HuZhou and HangZhou) of the Taihu Basin was selected as the study area. The data used for evaluating the benefits of the water transfer from the Yangtze River to Lake Taihu in 2011 were supported by the Taihu Basin Administration. The study area and the route of water transfer from the Yangtze River to Lake Taihu were shown in figure 1.

Figure 1. Study area and route of the water transfer.

3. Methods
For calculating the water diversion benefits, the partition coefficient method, productivity variation method and estimation model of economic loss from water pollution were adopted. The comprehensive benefits of the YTWTP are expressed in the form of currency.

3.1. Partition coefficient method
Partition coefficient method was considered as an appointed method in ‘Economic evaluation of water conservancy construction project specifications’ promulgated by MWR in 1996. It deems water supply can increase the production value. Hence, the water supply should be allocated partial benefits. The corresponding benefits are calculated through assessing contribution proportion of added value occupied by water supply (Reflecting the principle of partition) [24].

For the primary, secondary and tertiary industry, the water supply benefits can be calculated as follows:

$$B = \frac{I}{W} \cdot f q k$$  \hspace{1cm} (1)

where B is the increased water supply benefits, yuan; q is the increased water supply, m$^3$; it is allocated according to the proportion of water consumption of each industry and is provided by the Taihu Basin Administration in this paper; k is the utilization coefficient of water diversion, it is mainly determined by the shortage of local water resources and the ability of water resources development and utilization; f is the partition coefficient of water supply benefits, it is connected with industrial development level, industrial internal structure, operation and management level, water saving level, actual water supply situation and market price system; I is the industrial added value, yuan; W is the industrial water consumption, m$^3$.

3.2. Productivity variation method

Productivity variation method is a measurement for evaluating the impact of environmental condition variation by using the variation of productivity. It deems the variation of environmental quality can bring about the variation of production value. The corresponding income or loss can reflect the variation of environmental quality. For example, when a water diversion project operates, it will lead to the improvement of local water quality and the increment of local water supply ability. Correspondingly, the cost for the improvement of water quality will inevitably decrease as well. The benefits brought by improvement of water environment are defined as follows

$$B = (d q - \psi q)_{2} - (d q - \psi q)_{1}$$  \hspace{1cm} (2)

where B denotes the benefits, d is the water price, yuan/m$^3$; q is the increased water supply, m$^3$; $\psi$ is the cost of water supply, yuan/m$^3$; subscript 1,2 denote the before and after improvement of water environment situation respectively.

3.3. Estimation model of economic loss from water pollution

Estimation model of economic loss from water pollution is based on “pollutant concentration-loss” curve [27]. In this study, we adopted the logistic estimation model of economic loss from water pollution (logistic model). Water pollution can bring great influences on different objects (such as population health and tourism) of intake area. Suppose $A_i$ denotes the maximum economic loss rate of each object caused by water pollution; $\gamma_i$ denotes the economic loss rate of water pollution of each object; it reflects the variations of water pollutants and varies with the water quality type c. the relationship between $\gamma_i$ and c is

$$\gamma_i = \frac{A_i}{1 + \exp (g - \mu c)}$$  \hspace{1cm} (3)

where $\gamma_i = \frac{\Delta F_i}{F_i}$; $\Delta F_i$ is the economic loss of each object; $F_i$ is the gross economic value of each object; g is the integral constant; $\mu$ is a shape parameter of the logistic curve. In order to
determine the parameter $g$ and $\mu$, we made two assumptions in this paper. Firstly, according to present water quality evaluation standard in China, when water quality exceeds V grade (i.e. $c=6$), water pollution will cause great impact on the social economy and the corresponding economic loss rate approximates to maximum critical value. Suppose $\gamma_i = 0.995$. Secondly, when water quality is II grade (i.e. $c=2$), water can meet most of the demand of social activities and realize its value. Suppose $\gamma_i = 0.005$.

Through these two assumptions, the parameter $g$ and $\mu$ can be obtained. $g = 10.5891$, $\mu = 2.6479$. Hence, the logistic estimation model of economic loss from water pollution is described in the following way

$$
\gamma_i = \frac{A_i}{1 + \exp(10.5891 - 2.6479c)}
$$

(4)

The parameter $A_i$ is determined according to the actual statistic data of each object. The decreased economic loss of water pollution before and after water diversion is considered as the benefits of water diversion projects.

4. Results
Both the direct and indirect benefits of water diversion were calculated. The direct benefits were water supply benefits brought by the increased water supply. While, the indirect benefits were environmental, ecological and social benefits which came from the improvements of water quality after water diversion. Currency was selected for describing the benefits of water diversion.

4.1. Direct benefits
Because the YTWTP increases the assurance rate of water supply, the benefits of each industry will also increase inevitably. The direct benefits mainly included increased water supply benefits of primary, secondary and tertiary industry, which were calculated by the partition coefficient method.

In partition coefficient method, the utilization coefficient of water diversion $k$ and partition coefficient of water supply benefits $f$ should be determined. According to practical investigation of water resources utilization of the intake area, the coefficient $k$ was rapidly estimated with a value of 0.60. In addition, because of lacking standard methods, the coefficient $f$ was estimated rapidly by the statistics analysis of historical data. Based on the analysis results and pre-existing research results, in this paper, the partition coefficient of primary industry $f$ was deemed to be 0.53; in secondary industry, the partition coefficient $f$ equaled to 0.033; afterwards the partition coefficient $f$ was 0.04 in tertiary industry.

The increased water supply benefits of each industry in intake area of Taihu basin in 2011 were calculated and shown in table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>WuXi (×10⁸ yuan)</th>
<th>SuZhou (×10⁸ yuan)</th>
<th>ShangHai (×10⁸ yuan)</th>
<th>JiaXing (×10⁸ yuan)</th>
<th>HuZhou (×10⁸ yuan)</th>
<th>HangZhou (×10⁸ yuan)</th>
<th>Total (×10⁸ yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct benefits</td>
<td>1.665</td>
<td>9.386</td>
<td>1.491</td>
<td>3.704</td>
<td>5.129</td>
<td>1.240</td>
<td>22.615</td>
</tr>
<tr>
<td></td>
<td>3.142</td>
<td>19.622</td>
<td>6.114</td>
<td>2.425</td>
<td>2.269</td>
<td>1.087</td>
<td>34.659</td>
</tr>
<tr>
<td></td>
<td>3.094</td>
<td>18.289</td>
<td>10.345</td>
<td>1.886</td>
<td>1.929</td>
<td>1.369</td>
<td>36.912</td>
</tr>
<tr>
<td>Indirect benefits</td>
<td>1.76</td>
<td>0.81</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>0.028</td>
<td>0.073</td>
<td>0.230</td>
<td>0.014</td>
<td>0.005</td>
<td>/</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>1.43</td>
<td>0.84</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>2.27</td>
</tr>
<tr>
<td>Total (×10⁸ yuan)</td>
<td>11.119</td>
<td>49.02</td>
<td>18.18</td>
<td>8.029</td>
<td>9.332</td>
<td>3.696</td>
<td>99.376</td>
</tr>
</tbody>
</table>

Note: A is the increased water supply benefits of primary industry, B is the increased water supply benefits of secondary industry, C is the increased water supply benefits of tertiary industry, D is benefits of population health improvement, E is benefits of water quality improvement of waterworks, and F is tourism benefits. “/” represents the benefits of corresponding
city are not calculated due to limited data.

4.2. Indirect benefits
Besides the direct benefits, the YTWTP can also bring a lot of obvious indirect benefits for the development of society and economy, such as benefits of population health improvement, benefits of water quality improvement of waterworks and tourism benefits.

After the YTWTP operates, the water quality of intake area has improved greatly. The improvement of water quality is beneficial to improve population health and reduce the medical expenses of inhabitants. The logistic model was applied for calculating the benefits of population health improvement. The parameter $A_i$ was quickly calibrated by actual data with the value of 1.349. For population health, the gross economic value $F_i$ means the total medical expenses. Because of limited data, only the benefits of WuXi and SuZhou city in 2011 were calculated (see table 1).

The improvement of water quality also reduces the treatment cost of waterworks and brings significant benefits to water suppliers. Productivity variation method was selected for evaluating the benefits which mainly refer to the decreased cost of reagent. As a result of limited data, we only calculated the benefits of waterworks of WuXi, SuZhou, ShangHai, JiaXing and HuZhou city in 2011 (see table 1).

The improvement of water quality can improve the development of urban landscape. With the increase of urban tourist attractions, it will bring plenty of tourism benefits and play an active role in prompting the development of tourism in intake area. The logistic model was used for assessing the tourism benefits. Parameter $A_i$ was calibrated with the value of 0.0521 based on the existing data. For tourism, the gross economic value $F_i$, means the total income of tourism. Due to limited data, only the tourism benefits of WuXi and SuZhou city in 2011 were given (see table 1).

4.3. Comprehensive benefits
Considering the direct and indirect evaluation results of water transfer benefits from the Yangtze River to Lake Taihu in 2011, the comprehensive benefits of water transfer in intake area were determined (see table 1 and figure 2).

![Figure 2](image_url)  
**Figure 2.** Comprehensive benefits in intake area of Taihu basin in 2011.

From table 1, the total increased water supply benefits are 9.4189 billion yuan. The increased water supply benefits of primary industry, secondary industry, and tertiary industry are 2.2615, 3.466, 3.6914 billion yuan respectively. It can be concluded that the YTWTP has an important influence on the secondary and tertiary industry compared with the primary industry. The increased water supply
benefits of each city in the intake area are calculated too. Among them, no matter the primary, secondary, tertiary industry or the total, SuZhou city possess the maximum increased water supply benefits.

Besides the direct benefits, the indirect benefits of the YTWTP are also calculated and shown in table 1. Because of limited data, many other indirect benefits are difficult to calculate. Based on table 1, the benefits of water quality improvement of waterworks of ShangHai city is greatest than any other cities. That’s because the waterworks of ShangHai city possess higher water supply capacity than the other cities.

Moreover, the comprehensive benefits come to 9.9376 billion yuan. Between them, the direct benefits reach 9.4186 billion yuan, the rest are the indirect benefits. Furthermore, compared with other cities of the intake area, SuZhou city possesses the higher comprehensive benefits. That’s because SuZhou city locates at the east bank of Wangyu River and can benefit from the fresh water of Yangtze River directly. Above all, based on our investigation, the cost of water diversion is no more than 0.01 yuan per cubic meter water. So it is less cost and greater benefits for the YTWTP.

In brief, according to the above evaluation results, the YTWTP brings enormous benefits and significant impacts to the intake area. In addition, it can be considered as a reference on the benefits evaluation for other water transfer projects.

5. Conclusions
With the rapid development of economy in recent years, water pollution and eutrophication problems in Lake TaiHu become more and more serious, which have serious negative influence on people’s normal life and sustainable development of the Taihu Basin. For the sake of improving water environment, increasing water supply, ensuring the safety of water supply and promoting utilization of water resources, the YTWTP was implemented in 2002. The project has brought great economic, environmental and social benefits for the basin.

In order to keep the optimum operation of YTWTP and the sustainable use of water resources, the water diversion benefits of the YTWTP were evaluated in this paper. Considering there are still no fixed approaches for evaluating the water diversion benefits precisely. We tentatively constructed a comprehensive benefits assessment framework for evaluating the water diversion benefits of the YTWTP by existing engineering assessment theory and methods. The water diversion of the YTWTP in 2011 was taken as an example.

Both direct benefits and indirect benefits were calculated. The increased water supply benefits were determined by the partition coefficient method. The productivity variation method was adopted for the benefits of waterworks. The estimation model of economic loss from water pollution was for the tourism benefits and the benefits of population health improvement. The results show that the comprehensive benefits come to 9.9376 billion yuan. Between them, the direct benefits reach 9.4186 billion yuan, the rest are the indirect benefits. The increased water supply benefits of primary industry, secondary industry, and tertiary industry are 2.2615, 3.466, 3.6914 billion yuan respectively. Compared with other cities of the intake area, SuZhou city possesses the higher comprehensive benefits. In a word, for the YTWTP, the cost of the water diversion is less while the benefits are greater. The YTWTP brings enormous benefits and significant impacts to the intake area.

Considering the limited data and operability, some other indirect benefits are difficult to calculate. In future, we will go on studying on benefits evaluation of water transfer project and proposing a perfect evaluation system. The present evaluation framework of the water diversion benefits can serve as a reference on the benefits evaluation of other water diversion projects.

Acknowledgments
This study was supported by the National key R & D projects of China (Grant No. 2016YFC0400901). We are also grateful to three referees for their extremely helpful comments and suggestions on an earlier version of this paper.
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