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Benefit-cost analysis for sustainable water management in Beijing

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Since 2000, large numbers of water reuse systems have been constructed to solve the water scarcity in Beijing. However, the operations of these systems are not well as expected. The paper will conduct an analysis of economic and social impacts of water reuse systems in Beijing. The aim is to find out whether the systems have positive economic and social impacts or not. If the systems bring negative economic and social influence, it will demonstrate that the economic or social factors could be the reasons for the unsuccessful operations of water reuse system. The method of benefit cost analysis is carried out to estimate the economic cost, economic benefits, social cost, and social benefits of water reuse systems, and then a comparative analysis is implemented. Water reuse in Beijing mainly includes wastewater reuse and rainwater harvesting, which are studied separately in this study. Four wastewater reuse plants and three rainwater harvesting plants containing different sizes of plants are chosen for case study. The study determines that different sizes of water reuse systems have different results on benefits cost comparison. For small wastewater reuse plants, the economic and social benefits are more than cost; while for larger wastewater reuse plants, the economic and social benefits are less than the cost. Conversely, for small rainwater harvesting plants, the economic and social benefits are less than cost; while for large rainwater harvesting plants, the benefits are more than cost. Hence, from the respective of economic and social impacts, building small wastewater reuse plants are more feasible than large plants, while constructing large rainwater harvesting plants are more economically feasible.

Key words: Beijin, water, waste, systems.

INTRODUCTION

As the Chinese political and financial center, Beijing has a large and increasing population. Moreover, Beijing is located in the arid area of China. Rapid urbanization and climate change lead to serious water scarcity in Beijing. Arid regions around the globe are most often associated with physical scarcity. Northern China, including Beijing is an area of physical water scarcity (Seckler et al., 1998).

Beijing's climate is semi-humid monsoonal with a mean annual temperature of 10 to 12 centigrade. Mountains to the north, northwest and west shield the city from the encroaching desert steppes. The average

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altitude of the surrounding mountains is 1,000 to 1,500 metres. The Dongling mountain located at the border of the Hebei province is the highest point in Beijing, with an altitude of 2,303 metres. Because of its geographical location, Beijing has low average rainfall. Beijing's average precipitation is 550 mm per year, 80% of which falls between June and September (Beijing Water Authority 1986 to 2009).

In recent 10 years, precipitation decreased by 20%, which led to less groundwater recharge. Groundwater is the main water source in Beijing, the city sources 70% of total water supply from groundwater. However, overexploitation of groundwater due to increasing water demand and lower groundwater recharge both contribute to depletion of underground water stocks. Underground water levels in Beijing show significant decline since the mid-1950s. In rural areas of Beijing, the minimum depth of a well to access groundwater is around 80 metres deep while 20 years ago farmers could get groundwater from a well of only two metres depth. Figure 1 reflects the change in the depth of a well located in a village of the Huairou district of Beijing. It indicates that the depth of the well in 2007 was around 40 times deeper than in 1980. The depletion of underground water stocks further complicates the difficulty of supplying sufficient water in Beijing. Currently, the water consumption within Beijing is more than the water available to Beijing.

Water reuse could improve water supply and allow a water agency to respond to short-term needs in urban areas (Asano, 2001). In Beijing, water reuse projects include wastewater reuse and rainwater harvesting (Bao and Fang, 2007; Deng and Chen, 2003; Jia et al., 2005; Zuo et al., 2010). Wastewater reuse is the process of reclaiming grey water from industry and domestic sources and then reusing the water in industry as cooling water, domestically for toilet flushing and green irrigation, and in agriculture for irrigation. Until 2014, in the central region of Beijing, there were more than 2,000 small wastewater reuse systems. Although wastewater reuse systems have developed for many years, they are still at the early stage in developing areas.

Rainwater harvesting is to induce, collect and store runoff from various sources for various purposes. In China, people have rainwater harvesting projects for thousands of years, especially in the rural areas of the western north of China. Yet the most efficient use of rainwater for agricultural irrigation remains a subject of debate (Tian et al., 2002; Li et al., 2000; Mushtaq et al., 2007). A large number of rainwater harvesting projects have begun in Beijing since 2006, of which some are located in the urban areas of Beijing and others are in rural areas. In the urban areas, the collected rainwater is usually used for toilet flushing, car washing and green irrigation. In rural areas, the rainwater is mostly used for agricultural irrigation. Hence the paper focuses on the study of wastewater reuse and rainwater harvesting plants. In terms of the principals of sufficient data and continued operation, a total of seven plants are chosen, in which four plants are wastewater reuse and three are rainwater harvesting. The sizes of these plants are different.

The research aims to carry out benefit cost analysis on economic and social impacts of water reuse systems in Beijing. The discussions on water reuse are mostly from the technological perspective in the literature (Deng and Chen, 2003; Chu et al., 2004; Asano, 2005). Besides the technological issues, there are all kinds of economic and social problems in water reuse system (Pataki et al., 2011; Liu et al., 2014; Hu et al., 2014; Russell, 2014). Since it is complex to calculate the economic and social impact of the water reuse quantitatively, most studies in the literature merely describe the cost or benefits qualitatively or make a simple cost calculation for the water systems (Abeysuriya et al., 2005; Braden and Van Ierland, 1999). The study emphasizes on quantitative calculation of all cost and benefit of economic and social impacts, and then a comparative analysis is implemented.

MATERIALS AND METHODS

In this study, the analysis aims to determine the contribution of a water reuse project to the development of the total economy. All the economic and social effects caused by water reuse systems are taken into the calculation. The economic and social impact factors are adapted from literature (Hernandez et al., 2006). The method used in this research is benefits cost analysis (BCA), which is a largely accepted method to evaluate environmental projects. Although various economic methods have been employed to evaluate water management such as life cycle analysis, multi-criteria analysis, cost effectiveness study, contingent valuation methods and multiple goal programming, the BCA method is most suitable method for this study (Ashley et al., 1999; Hauger et al., 2002). Based on the theory of welfare economics, the BCA method can help to illuminate the trade-off involved in making different kinds of investments (Arrow et al., 1996). It can inform decision makers about how scarce resources can be put to the greatest social good.

In the CBA method, if benefits and cost stretch over time, present values of cost and benefits occurring in different periods are required. Net present value is the difference between the present value of benefits and the present value of cost. The discount rate used is another important issue in the CBA method. It is the rate at which future benefits and costs are discounted to present value (Prest and Turvey, 1968). The discount rate is based on how individuals trade off current consumption for future consumption (Arrow et al., 1996). People use different discount rates for different kinds of things (Gintis, 2000). For the evaluation of environmental resources, it is better to use the social discount rate (Brent, 1996). According to the publication Chinese Economic Evaluation Parameters on Construction (2006), the social discount rate used for benefit cost studies in China is 8% including the inflation rate.

The studied plants have different sizes. For wastewater reuse, plant 1 and plant 2 are small size and plant 3 and plant 4 belong to large size; while for rainwater harvesting, plant 1 is small size, plant 2 is medium size and plant 3 is large size. The detail of capacities of these plants is shown in Table 1. The economic and social impact factors for wastewater reuse are listed in Table 2. The economic cost caused by wastewater reuse systems includes initial investment (defined as VI) and O&M cost (defined as CO&M). The determination of economic cost (defined as CE) of wastewater

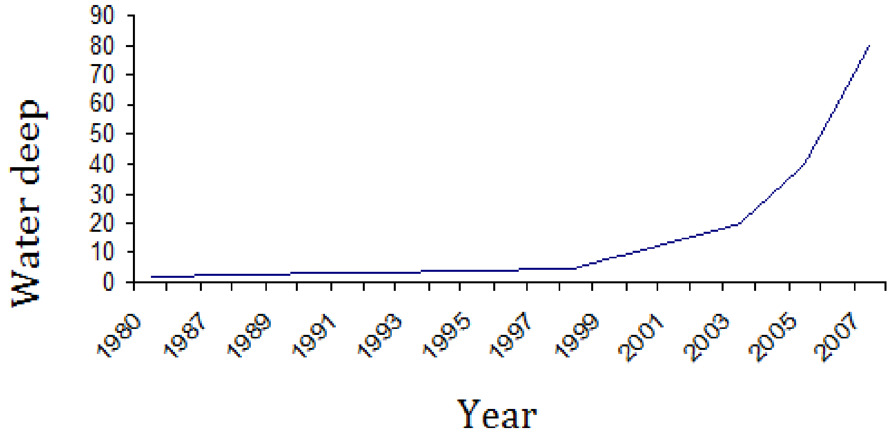

Figure 1. Change in well depth in a village within the Huairou district of Beijing (Source: Interviews with the farmers of the village).

Table 1. The capacity of the studied plants.

Wastewater reuse plants				
Capacity (m^3/day)	Plant 1 65	Plant 2 400	Plant 3 300,000	Plant 4 60,000
Rainwater harvesting plants				
Capacity (m^3)	Plant 1 50	Plant 2 600	Plant 3 1500	- -

Table 2. Economic and social effects of wastewater reuse plants.

Economic cost	**Initial investment operation and maintenance cost**
Social cost	Health risk
Economic benefits	Cost savings on water distribution Cost savings on water purification Cost saving on fertilizers
Social benefits	Raising social awareness Improving employment

reuse plants are shown in equation 1. Moreover, in equation 1, "n" means the time period which is 10 years in the study, and "r" means the discounting rate which is 8%.

$$C_E = V_I + \sum_{t=1}^{n} \frac{C_{O\&M}}{(1+r)^t} \quad (1)$$

Wastewater reuse may lead to human health risk because the reused water probably does not reach the official minimum health standards. The reuse water could be reused for toilet flushing, or green land irrigation. So wastewater reuse could have negative effects on human health. The origin of such calculation method for the social cost (defined as C_S) is shown in equation 2 and explained as follow. World Bank values the total health cost (defined as C_M) caused by water pollution in China, which is about 14.22 billion Yuan each year, and the total estimated DALYs (defined as M) caused by diarrhoea is 5,055,000 DALYs each year. The product of DALYs rate (defined as R) and population number (defined as K) gives the total DALYs of Beijing. It is supposed that the DALYs of Beijing resulting in diarrhoea is caused by total reused wastewater.

In equation 2, P means the probability of DALYs due to the wastewater reuse plant (P)

$$C_S = C_M / M \times R \times K \times P \quad (2)$$

Table 3. Economic and social effects of rainwater harvesting plants.

Economic cost	Initial investment and operation and maintenance cost
Social cost	Agricultural risk
Economic benefit	Increase in agricultural production
Social benefit	Raising social awareness

As shown in Table 1, economic benefits contain cost saving on water distribution and purification, and cost saving on fertilizers. The study assumes that the reclaimed water would be provided by the closest plant if there is no on-site project. Hence the economic benefits of water distribution and purification could be determined by multiplying the cost per metre pipe (C_L) and the distance of pipes (L). The economic benefit of cost saving on fertilizers could be determined through multiplying the unit cost of saving on fertilizers (defined as U_f) and the amount of reused water for agricultural irrigation (defined as f). The economic benefits of wastewater reuse (B_E) could be determined by equation 3.

$$B_E = C_L \times L + U_f \times f \quad (3)$$

About the social benefits of wastewater reuse (defined as B_S), the introduction of wastewater reuse could work as a campaigns to enhance social awareness on water saving. This can be determined by total expenditure on public awareness raising campaign (defined as S) and the ratio of number of users to total population in Beijing (defined as Q) as expressed in Equation 4. Moreover, the newly built wastewater reuse systems can create vacancy so that it benefits to improve the social employment. In equation 4, β is the employment elasticity, w is the number of increasing jobs in the plant, W is the total employment of Beijing and Y is the Beijing's Gross Domestic Product.

$$B_S = S \times Q + w/(W \times \beta) \times Y \quad (4)$$

The economic and social impact factors of rainwater harvesting are presented in Table 3. Similar to wastewater reuse, the economic cost of rainwater harvesting (defined as C_e) contains initial investment (defined as V_i) and O&M cost (defined as $C_{o\&m}$), which is shown in equation 5.

$$C_e = V_i + \sum_{t=1}^{n} \frac{C_{o\&m}}{(1+r)^t} \quad (5)$$

In the present study, the rainwater is mainly reused for agricultural irrigation. If the quality of water does not reach the requirement, it may bring the potential agricultural risk. Equation 6 shows the social cost of agricultural risk (defined as C_s) could be determined by the average income from the vegetable (defined as I) and the total decreasing amount of agricultural production (defined as D).

$$C_S = I \times D \quad (6)$$

Rainwater harvesting could increase the water supply amount in winter, resulting in the production increase. It is regarded as the economic benefit. The economic benefit (defined as B_e) of rainwater harvesting can be determined by the unit income of extra-farming in winter (defined as E) and the area of storage tanks (defined as A).

$$B_e = E \times A \quad (7)$$

Finally, rainwater harvesting also can help to increase the public awareness of water saving. Generally raising awareness of water saving is reached through all kinds of public education and advertisement campaigns. Rainwater harvesting could lead to that the cost is saved on awareness raising campaigns. So the cost saving on public education and advertisement campaigns can be regarded as the social benefit of rainwater harvesting (defined as B_s). Equation 8 presents the determination, in which "u" means the number of users, "F" means total expenditure on public awareness raising campaigns for water saving and "G" means total people number influenced by the campaign.

$$B_s = u \times F/G \quad (8)$$

RESULTS AND DISCUSSIONS

The present values of economic and social impacts of wastewater reuse plants are calculated and listed in Table 4. The economic costs are represented by initial investment and operational and maintenance cost, accounting for around 85% of total cost. Compared with social cost, the economic cost is a much larger value. But, about the benefits, different sizes have different situations. For the small plants, the economic benefits including all kinds of cost saving also account for around 85% of total benefits, while for the large plants, the social benefits account for larger proportion of total benefits.

The comparison between economic benefits and cost, and between social benefits and cost, shows that economic benefits are larger than economic cost for small size of plants. Conversely, the economic cost of large plants is much larger than the economic benefits. However, for the small plants, the social benefits are larger than the social cost; for the large plants, the social benefits are smaller than the social cost. So, from the respective of both social and economic impacts, building small wastewater reuse plants are more feasible than building large plants.

The estimation results of rainwater harvesting are shown in Table 5. Plant 1, plant 2 and plant 3 respectively represents small, middle and large plant. It is different to the result of wastewater reuse, that the

Table 4. Results of benefit cost analysis of wastewater reuse plants.

Variable	Plant 1	Plant 2	Plant 3	Plant 4
Cost				
Economic cost (Yuan)	3,437,000	5,042,000	425,530,000	112,890,000
Social cost (Yuan)	13,212	13,212	7,130,000	4,900,000
Total	3,450,212	5,055,212	432,660,000	117,790,000
Benefits				
Economic benefits (Yuan)	16,000,000	24,000,000	2,400,000	240,000
Social benefits (Yuan)	21,411	290,000	5,900,000	5,000,000
TOTAL	16,021,411	24,290,000	8,300,000	5,240,000

Table 5. Results of benefit cost result of rainwater harvesting plants.

Variable	Plant 1	Plant 2	Plant 3
Cost			
Economic cost	25,403	278,314	424,719
Social cost	24,705	329,406	494,109
Total	50,108	607,720	918,828
Benefits			
Economic benefits	26,840	241,563	697,848
Social benefits	66	285,773	571,465
Total	26,906	527,336	1279,313

economic cost value of rainwater harvesting plants is almost the same as the social cost value. Moreover, excepting the small plant, the total cost values of middle size and large plants are quite closed to the total benefits values. The comparison between economic cost and benefits, and between social cost and benefits, shows that for small and middle plants, the economic benefits are closed or less than cost, while for large plant, the economic benefit is larger than economic cost. Similarly, it is only the large plant whose social benefit is larger than social cost.

Conclusion

The study aims to study the economic and social influences of water reuse systems in Beijing through cost benefit analysis. Four wastewater reuse plants and three rainwater harvesting plants which have different sizes are taken into the estimation. The main economic cost, economic benefits, social cost and social benefits caused by the water reuse system are all presented and evaluated quantitatively. It is found that different sizes of water reuse systems have different results. Compared with other sizes of plants, the small wastewater reuse plants and large rainwater harvesting plants are more economically feasible and have positive net influence on the society. It means from the perspective of economic and social impacts, small wastewater reuse plants and large rainwater harvesting plants are deserved to be promoted largely.

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Conflicts of interest

The author has not declared any conflict of interest.

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