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Economic evaluation of the Sponge City program in China: Case study of Changde city

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Abstract
For tackling the problems of city flood and water pollution, the Sponge City program was established in 2014. Although the Sponge City program is newly established, it exacerbates hot disputes in the Chinese academic research field. Currently, whether the constructed and in-progress projects of the Sponge City program are economically feasible is still an open question. The paper carries out an intensive economic analysis on the Chuan project, which is a demo project in the Sponge City program in China. Through examining all economic, environmental and social cost and benefits of the Chuan project, it is found that the total benefits caused by the project is much more than the total cost. It means the water projects in the Sponge City program are deserved to be promoted in China. However, no sustainable income to cover the O & M cost of the project, which can hamper the project's sustainable operation.

Keywords: water management, economic analysis, cost benefit analysis, sponge city.

Paper type: Research paper

1. Introduction

According to the China environment report that examined the years 1951–2016, precipitation in China has increased, and the occurrence of heavy rainfall and extreme rainstorm events are more frequent. The amount of precipitation that fell in 2016 was found to be the highest amount experienced by the country in 50 years (Figure 1), with the eastern, middle, and southern areas of China all facing several heavy rainfall incidents (Figure 2). Overall, heavy rainfall is occurring more frequently and for longer periods of time. Indeed, the longest period of heavy rainfall in 2016 was notably longer than other such periods that have occurred since 1951. The rise in precipitation amount and the increased frequency of heavy rainfall events resulted in serious city flooding, regularly occurring in approximately 200 cities in China. A city flooding results in substantial economic loss, threatens human life, and impedes agricultural and industrial production (Shi 2013; Yu et al. 2015; Yin et al. 2015).

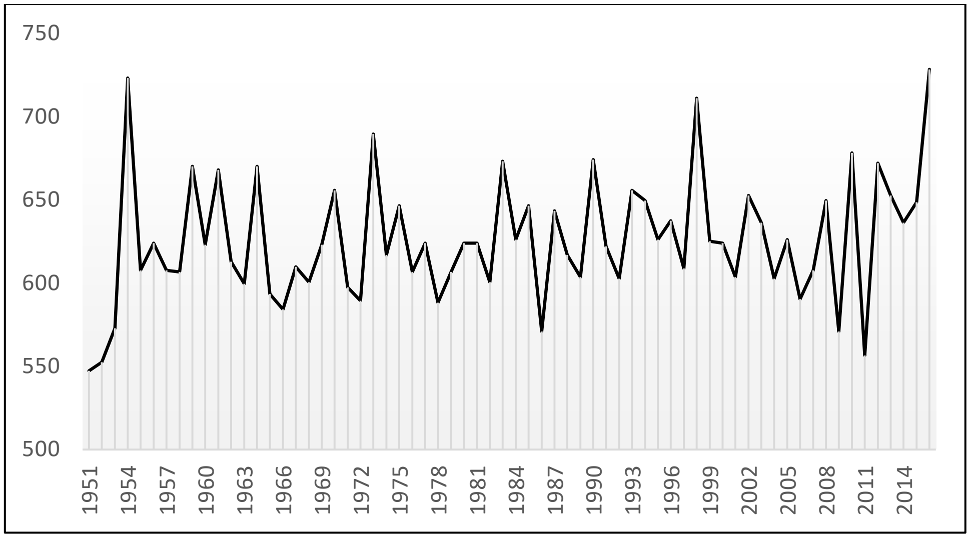

Figure 1. Precipitation in China (1951–2016), measurement unit: mm (China Environment Report 2016).

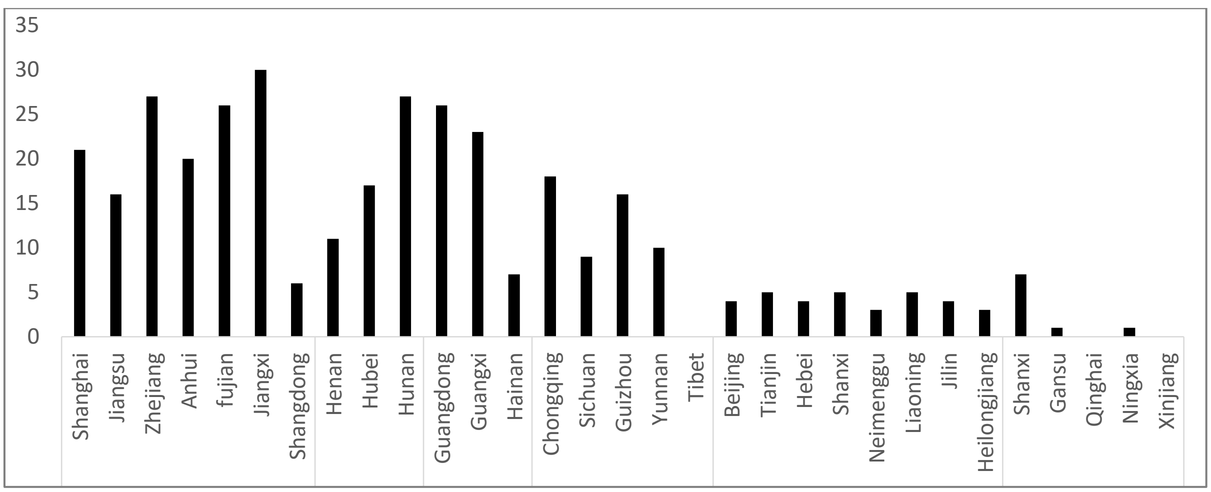

Figure 2. Frequency of Heavy Rainfall in China by Province in 2016, measurement unit: times.

For tackling the problems of city flood and water pollution, the Sponge City program was established in 2014. The program consists of policies and experiments in demo cites. The technical specification for sponge city construction was issued in November 2014. Sixteen cities were chosen for the demonstration of the program in 2015, of which most are middle-sized towns. At the beginning of 2016, another 14 cities, including Beijing, Tianjin, Shanghai, and Shenzhen, were included in the demonstrations. It is expected that the number of demo cities will increase continuously (Yu et al. 2015). The location of and annual rainfall in demo cities are shown in Figure 3.

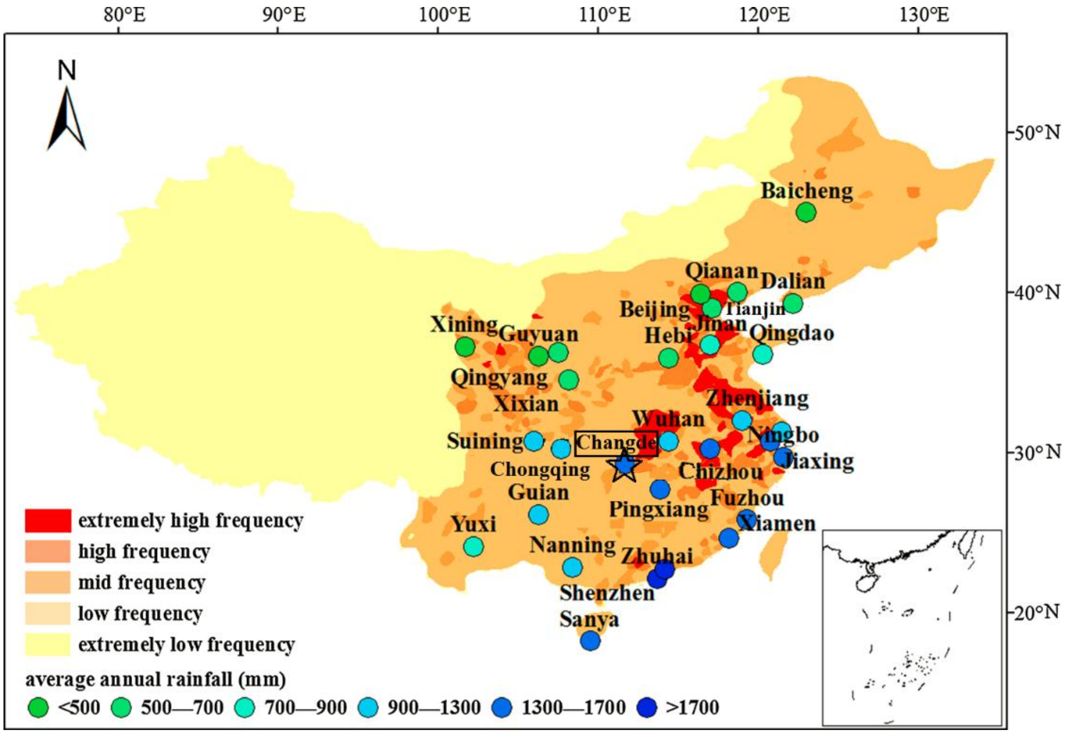

Figure 3. Location of and Annual Rainfall in Demo Cities and the Spatial Distribution of Water Disaster Frequency in China (Sang and Yang 2016).

Although the Sponge City program is newly established, it exacerbates hot disputes in the Chinese academic research field. From the perspective of urban planning, the program can help to improve the urban water environment and decrease the use of concrete in the cities (Yu et al. 2015; Shi et al. 2016). However, from the perspective of urban management, the feasibility of the program is doubtful. There are no coordination and cooperation within different departments in a Chinese city, which are the precondition of successful implementation of the Sponge City program. (Xu et al. 2016; Song and Zhang 2016). The engineers also have two standpoints: supporters of the program begin to design all types of water treatment projects based on the concept of the sponge city (Wang and Wu 2015); while, the opponents think the program focuses on rainwater harvesting or flooding treatment projects, which are not sufficient to satisfy the demands of city flood prevention (Song and Zhang 2016; Sang and Yang 2016). Discussions of the Sponge City program from an economic perspective are rare in the literature; some articles only point out the possible financial problems, such as sufficient investment or sources of finance (Xu et al. 2016; Zhang et al. 2016). There is no extensive economic feasibility analysis, although economic feasibility is greatly relative to sufficient financial sources and sound management of the Sponge City program. Currently, whether the constructed and in-progress projects of the Sponge City program are economically feasible is still an open question.

In terms of the sponge program, the majority of required capital should be financed from private sources and a local government, and only 10% of total investment should be subsidized by the central government. Each demo city can obtain around 1.2–2 billion Yuan in subsidies from the central government, which should be spent with the capital from other sources. For project investment, the central government subsidy should account for only 10%, the local government should contribute 40%, and the remaining 50% should be sourced from private investment. Whether private investors are interested in such investment or not, depends on the economic feasibility of the project. So, an economic analysis of the Chinese Sponge City program is an essential issue.

There are various methods using in economic analysis of water project, which includes Life Cycle Assessment, Material Flow Analysis, Environmental Risk Assessment, Cost Benefit Analysis and so on (Recha et al. 2015). Since the studied case has operated for short time, there is not big data for analysis. Compared with other methods, the method of cost benefit analysis is more suitable to the study. In literature, the cost benefit analysis method is largely used for water projects analysis. Liang and Van Dijk (2010) applied cost benefit analysis method to determine the feasibility of decentralized wastewater reuse systems; Liang and Van Dijk (2011) made an integrated economic cost and benefits analysis on rainwater harvesting systems; Molinos-Senante et al. (2011) carried cost benefit analysis method on water reuse projects (Liang and van Dijk 2011; Liang and Van Dijk 2010; Molinos-Senante et al. 2011).

This study carries out an economic analysis of a project of the Sponge City program, from the angle of economic, environmental, and social influences using the method of cost benefit analysis. The aim of the research is to find out if the studied case is economically feasible.

The studied project is “Chuan Ma Tou project” which is named the Chuan project in the paper. The Chuan project is located in Changde city which is marked in Figure 3. Changde city is a demo city in the Sponge City program due to its hydrological and geological situation. Changde city often suffers from flooding as it is located by a tributary of the Yangzi River, and the city is surrounded by canals containing polluted water; accordingly, some water projects have been constructed and operated in the city since 2008. The study only focuses on the economic analysis of the Chuan project. Section 2 introduces the Chuan project; and section 3 presents the economic analysis; results and discussion are shown in section 4; the conclusion is drawn in section 5.

2. The Chuan project in Changde city

Changde city is located in the north part of Hunan province, which was an important political, economic, and cultural center in the Ming dynasty because the city has rich water systems and convenient transportation. However, currently the city has polluted and smelly rivers, canals, and lakes (Zeng 2004). Figure 4 shows that part of the canals are blocked by solid waste. Yang et al. (2011) checked the water quality of the rivers in Changde city, and found that the river is heavily polluted by phosphorus, as shown in Table I. Other studies found that the rate of fecal coliform in the rivers is higher than the required standard. The standard of fecal coliform rate in the "Environmental Quality Standards for Surface Water" (GB3838-2002) issued by the Ministry of the Environment in 2002 is less than 40,000 bacteria in one liter of water. Moreover, Changde city suffers from flooding every four years.

Figure 4. Solid waste in the river (image: author's own).

Table I. River water quality of Changde city.

Items	Average rate yearly (mg/L)	Standard rate (mg/L)
COD_{Mn}	1.5–1.65	≤6
BOD_5	1.01–1.3	≤4
NH_3-N	0.15–0.17	≤1
P	0.21–0.33	≤0.2

Source: Yang et al. 2011

To solve the problem of flood and water pollution, eight water projects will be constructed along the Chuan Zi River, which is a branch of the Yangzi River. These projects are part of the Sponge City program. Figure 5 shows the locations of the projects, and Table II presents the status: only two are built and others are in progress or will be built. The eight water projects are expected to achieve the objectives of improving the water quality and recovering the original and natural appearance of the Chuan Zi River, and decrease flood frequency in Changde city. As mentioned previously, only the Chuan project is studied in the paper.

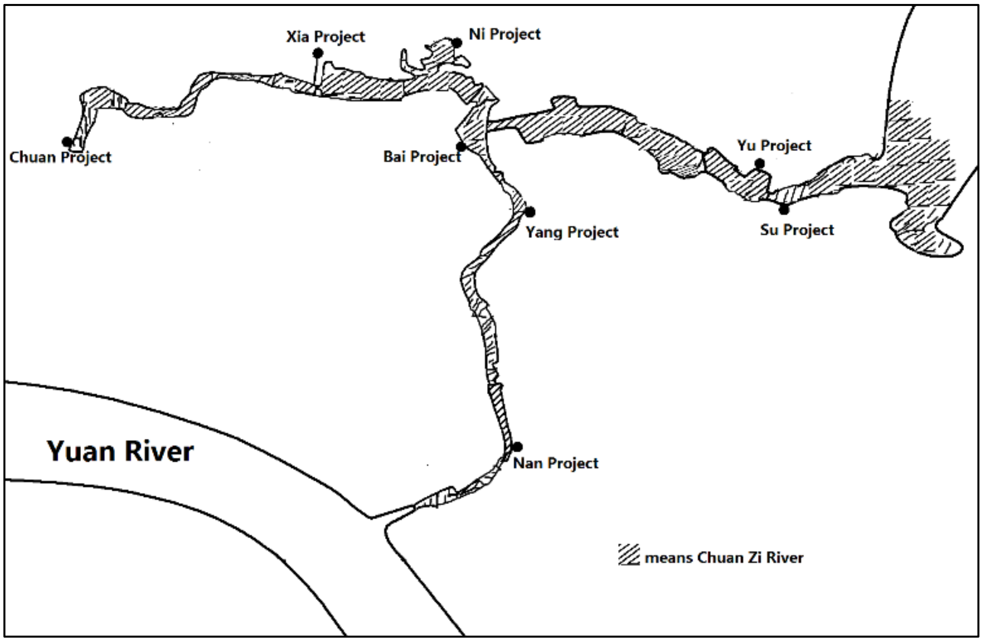

Figure 5. Distribution of eight water projects.

As is shown in Figure 6, the Chuan project consists of rainwater harvesting plants and an ecological purification area, which began operation in 2011. The ecological purification area consists of different kinds of plants, including phytoplankton and reeds. In the rainy season, rainwater harvesting plants can spare rainwater and help to release the stress of flood. The rainwater is purified by the rainwater harvesting plants and the ecological purification area before flowing into the river. This ensures that the pollution substance cannot flow into the river. In a non-rainy season, the river water could be purified naturally because the ecological purification area is linked with the river. Meanwhile, the ecological purification area has the function of water reservation. The ecological purification area is a wetland park for all residents nearby.

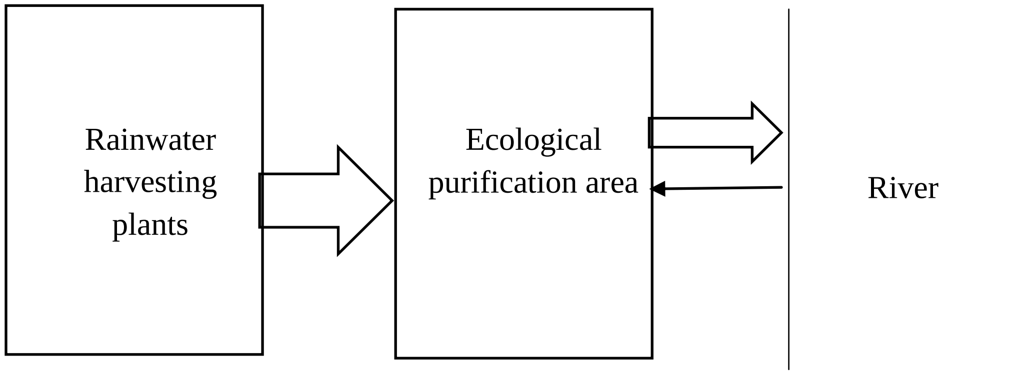

Figure 6. Structure of the Chuan project.

Before constructing the Chuan project, the location was a smelly water drain. Now it has become a popular and clean wetland park. The location of the Chuan project is the head stream of the Chuan Zi River. The water of the headstream becomes clear and flood stress is released in heavy rainfall. The Chuan project effectively improves the water environment of the head stream of the Chuan Zi River.

3. The economic analysis

The economic, environmental and social cost and benefits of the Chuan project were evaluated in the study. Table II lists all possible economic, social, and environmental effects. The operation of the Chuan project does not lead to any environmental cost, because it operates naturally and automatically without consuming energy. It should be noted that because there is not market values for certain cost and benefits values, an indirect method is used for certain cost and benefits values' determination.

Table II. Economic, social, and environmental effects of the Chuan project.

Items	All possible effects
Economic cost	Initial investment O & M* cost
Environmental cost	N*
Social cost	Residential resettlement
Economic benefits	Decrease in economic loss due to flood
Environmental benefits	Improvement on river water quality
Social benefits	Increase in residents' leisure area Increase in jobs

*O & M - operation and maintenance;

*N - no environmental cost

3.1. Economic cost

From the perspective of society, construction, operation, and maintenance are regarded as consumption of resources, so initial investment, operation and maintenance (O & M) cost are included in the economic cost evaluation. Because there are not many trade items in the initial investment and O & M cost, market prices should have not large distortions and could be directly used as economic values. The total initial investment in the Chuan project is around 0.13 billion Yuan; 60% of which is used for water stretch re-construction and compensation for residential resettlement and 40% is used for the construction of rainwater harvesting plants, an ecological purification area and a leisure park. The O & M cost focuses on the salaries of management personnel since no machines or chemicals required for the operation of the Chuan project. In total, 30 workers are involved in the management, of which 20 workers are in charge of cleaning and maintaining the ecological purification area and leisure park and ten workers are in charge of rainwater harvesting maintenance. The average salary of a worker is around 4000 Yuan per month.

$$C_E = I + \sum_{t=1}^{n} \frac{w \times N}{(1+r)^t} \quad (1)$$

The economic cost (defined as C_E) of the Chuan project can be determined by Equation 1, in which I is an initial investment, w is an average salary, N is a number workers, r is a discounting rate, and n is an evaluation period. According to the publication of the National Development Reform and Commission “Chinese Economic Evaluation Parameters on Construction”, the nominal discount rate (r) used for benefit cost studies in China is 8%, which is determined by social economic growth, an expected inflation rate and opportunity cost of capital. Moreover, the evaluation period (n) is assumed to be 5 and 10 years, respectively.

3.2. Social cost

According to the interview with the Chuan project manager, residents of 15 households (around 90 residents) were moved to other places when the Chuan project was constructed. Although the compensation provided to the residents for residential settlement can induce some negative effects, such as increasing living, education, and transportation costs (Camagni et al. 2002; Luo 2007), the Chuan project caused a social cost of residential resettlement. Quantifying the social cost of residential resettlement is rare in the literature, and the existing research mostly focuses on evaluating the main influences in terms of the situation of studied cases (Hattori and Fujikura 2009; Bayrau and Bekele 2007). In this study, public transportation is the main travel method for Changde city’s residents. All effected households may suffer from increased transportation costs, while other effects such increased education and medical costs may not occur for all relocated people. So, the increased transportation cost due to residential resettlement is determined as the social cost of the Chuan project. It is assumed that all relocated residents take one additional transfer each day via public transportation. The average public transportation cost in Changde is around 2 Yuan for a round trip. This means all relocated residents have to pay for one additional round trip per day, which is regarded as the increased public transportation cost per person per day (defined as *u*). As mentioned previously, the total affected population (defined as *U*) is around 90 people. Accordingly, the social cost of residential resettlement (defined as C_S) can be derived using Equation 2.

$$C_s = \sum_{t=1}^{n} \frac{u \times U}{(1+r)^t} \tag{2}$$

3.3. Economic benefit

In recent years, flooding has occurred frequently in Chinese cities and causes an enormous economic loss. The Chuan project can effectively reduce the occurrence of flooding and thus prevent economic loss in Changde city. So, reduced economic loss could be regarded as the economic benefit of the Chuan project. It is too complicated to evaluate the economic loss due to flood in Changde city directly, and it is not easy to find an existing study in Changde city. Studies of the economic loss due to city flooding in China illustrate that it is determined by the economic development level and social situation of a suffered area (Shi 2013; Zhang et al. 2011; Dai and Cao 2012; Feng 2001; Liu et al. 2009). Recently Shi et al. (2013) analyzed the economic loss caused by flooding in Wuhan city, and the results shows that the direct economic loss is around 0.6 billion Yuan and indirect loss is around 0.1 billion Yuan. Wuhan city is close to Changde city, is located beside the Yangzi River and frequently suffers from flooding. The social development and culture of both cities are similar. Hence, an indirect method was carried out in this study through the average GDP conversion between Changde city and Wuhan city. According to the statistic yearbooks (2013) of Wuhan and Changde cities, the average GDP per area of Wuhan city is 0.106 Yuan/km^2, and the average GDP per area of Changde city is 0.0124 Yuan/km^2. This means Wuhan's economic development is 8.5 times higher than in Changde. It assumes that the average flood influence degrees of the two cities are similar. The economic loss due to city flood in Changde city is estimated to be around 80 million Yuan in 2012. According to the research, the flood frequency in Changde city is around one flooding incident every four years (Chen 1998). So the average economic loss for Changde city is 20 million Yuan per year (defined as *A*), and it is supposed that the flooding influence on Wuhan city is the same. The total population affected by flood in 2014 is around 0.61 million (Li and Wan 2015). The Chuan project covers 4.15 km^2 area, and around 0.012 million people live in that area. The residents in the Chuan project area suffered from flood because it is located beside the river. The saved amount of economic loss of the Chuan project (defined as B_E) could be determined by the average economic loss of Changde city (*A*) and the probability of the loss of Chuan project's area (defined as *g*), which can be obtained through the ratio of the suffered population in Chuan project's area to the total suffered population in Changde city.

$$B_E = \sum_{t=1}^{n} \frac{A \times g}{(1+r)^t} \quad (3)$$

3.4. Environmental benefit

The Chuan project largely diminishes water pollution on the Chuan Zi River, and improves the quality of the water environment. The reduction of water pollution can be regarded as the environmental benefit of the Chuan project. Li et al. (2003) made an extensive evaluation of the economic loss caused by water pollution in China, which includes industry, agriculture, municipal facility, and human health loss. This estimated that the economic loss is 1.6% of GDP in the upstream area of the Yangzi River, 1.2% of GDP in the middle area of the Yangzi River and 5% of GDP in the downstream area (Li et al. 2003). Changde city is located at the middle area along the Yangtze River, of which the center is Wuling district. Because the Chuan Zi River is the only water net in the Wuling district, it is supposed that the pollution loss comes from the Chuan Zi River. The economic loss caused by water pollution in the Wuling district can be determined by its GDP of 85.5 billion Yuan (in 2013) and 1.2%, amounting to 1.026 billion Yuan (defined as a) which is also the economic loss caused by the Chuan Zi River. Because the Chuan project is located in the city center without industry and agriculture, it is assumed that the water pollution of the Chuan project area only causes risks to and loss of human health. From the literature, the loss of human health accounts for 23% of the total economic loss because of water pollution (defined as p_1) (Li et al. 2003). Thus, the human health loss due to water pollution on the Chuan Zi River can be calculated by $a \times p_1$. The proportion of the pollution of the Chuan project area to the total pollution of the Chuan Zi River estimated by Li (2010) is to be around 0.16 (defined as p_2) (shown in Table III). Hence, the saving of economic loss (defined as B_V) caused by the water pollution of the Chuan project could be determined by Equation 4.

$$B_V = \sum_{t=1}^{n} \frac{a \times p_1 \times p_2}{(1+r)^t} \quad (4)$$

Table III. The discharge of pollution of Chuan project (tons/year).

	Chuan project	**Total**	**Proportion**
BOD	58.34	359.88	0.16210959
COD	121.43	748.28	0.16227
NH_3-N	17.52	108.04	0.16216216

Source: Li 2010

3.5. Social benefits

Twenty job positions were created because of the Chuan project, which improved employment in the region. Fast economic growth can also help to improve employment. It is assumed that the employment effect of the project is the same as the effect of economic growth. That means economic growth contributing to improving employment can be regarded as a benefit of improving employment through a sponge city project. Employment elasticity, which is the ratio of employment growth to economic growth can be used in the study. If the employment elasticity is 0.1 that means an economic growth of 1% increases employment by 0.1% (Rawski 1979; Li 2003). In the literature, the employment elasticity of China is estimated to be 0.3 (Li 2003). Because of data limitation, it is assumed that the employment elasticity of China also applies to Changde city. The benefit of increasing jobs (defined as *J*) can be determined by Equation 5:

$$J = \frac{\frac{w}{W}}{\beta} \times Y \tag{5}$$

where β is the employment elasticity (0.3); w is the number of increasing jobs in the plant (20 persons); W is the total employment of Hunan province (40 million in 2011); Y is the GDP of Hunan province in 2011 (1,966 billion Yuan).

There is a wetland park in the Chuan project with an area of 0.15km^2. Before the park's construction, it is rare that people would spend time there because of the bad smell from the polluted river bank. Currently, around 5000 people come to this park every day for leisure activities. The wetland park is carrying out the function of recreation, which can be regarded as the social benefit of the Chuan project (defined as L), determined by Equation 6:

$$L = \sum_{t=1}^{n} \frac{d \times D}{(1+r)^t} \tag{6}$$

where d is the unit recreation value (28,358 Yuan/km^2), which is calculated through the value convention. The global average value of recreation caused by the wetland was estimated to be around 470680 Yuan/km^2 per year (Costanza et al. 1997). Recreation value is highly related with income, as consumers with higher incomes pay more for recreation. According to the World Bank Report (source:www.worldbank.org), the 1997 global Gross National Income (GNI) per capita world was 35,161.6 Yuan while the 2011 GNI per capital of China was 32,000 Yuan. The ratio of China's income to average global income is 0.9, and thus China's recreation value can be determined to be 428,358 Yuan/km^2. D is the area of the wetland park (0.15 km^2).

4. Economic result of the Chuan project

Table IV lists the results of economic analysis of the Chuan project. The initial investment of the Chuan project is huge, at 130 million Yuan. Spending 130 million on one water project is unaffordable to the Changde government. According to the interview with the Changde government officials, the Chuan project has the highest initial investment than other projects. The Chuan project is designed by a Germany company which is professional in wetland design so the cost is much higher. Because of benefits of successfully building and operating the Chuan project the local government to get more subsidies from the central government, the local government has the incentive to put high investment in the Chuan project.

Table IV. Results of economic analysis.

Items	All possible effects	Value (5 years, million Yuan)	Value (10 years, million Yuan)
Economic cost	Initial investment O & M cost	130 5.75	130 9.66
Environmental cost	N	N	N
Social cost	Residential resettlement	0.26	0.43
Economic benefits	Decrease of economic loss due to flood	1.6	2.68
Environmental benefits	Improvement in river water quality	152	254.98
Social benefits	Increase in jobs Increase in residents' leisure areas	3.3 0.26	3.3 0.43

Table V. Feasibility analysis of the Chuan project.

	5 years estimated period	10 years estimated period
Total cost	136	140
Total benefit	157.16	261.41
Ratio of benefit to cost	1.16	1.86
Economically feasible	Yes	Yes

Although the initial investment of the Chuan project is a large value, the environmental benefit is more than the initial investment cost. Either using the estimated period of 5 years or using 10 years, the environmental benefit contributes the major part of total benefits. It is shown in Table IV that the economic benefit and social benefit values are closed, but the environmental benefit is almost 40 times of other benefits. The environmental benefit emphasizes on the improvement of water quality which effectively promote area's economic development. As a result, the benefit of improving water quality is determined to be a large value.

Comparing all benefits and cost of the Chuan project, it could be concluded that the benefits are quite more valuable than the cost. It is shown in Table V that the Chuan project is economically feasible using both 5 years and 10 years as the estimated period. That means the water project of the Sponge City program is deserved to be promoted even though it required high initial investment.

The initial investment can be subsidized by the government and occurs at one time. However, the O & M cost is currently also subsidized by the government as there is not efficient economic model to cover the O & M cost. Although O & M cost is not a large amount, it occurs continuously. How to obtain a sustainable income to recover the O & M cost is still a question to the local government. The local government hopes to promote the city development through the Sponge City program but it neglects sustainable management of the water project. A sustainable way of the water project operation could significantly affect the Sponge City program.

Only one project is used to prove the economic feasibility of Sponge city program is the limitation of this research. As the Sponge city program has been implemented for short time, it is difficult to obtain the economic data of water projects. The Chuan project is a representative case in the Sponge city program since it is built in the city with serious water problem and the project has operated for a certain period. Other constructing projects have similar situations as the Chuan project. Hence the result of the Chuan project could show that Sponge city program could be economically feasible. The water projects could bring a large environment benefit of improving water quality and decreasing flooding pressure, so that the economic benefit can be higher than the economic cost even though the initial investment of water project is not a small amount. However, if there is not reasonable business model, the water project will have not a sustainable income to support the operation and maintenance. Being a social resources, water project is not very good profitable investment from the perspective of private investors. Meanwhile the local government is short of incentive to plan and develop a sound business model for the water project. The Sponge city program is issued by the central government, and is executed by the local government. The local government can obtain political achievement after the water project is completed construction and used for a while. How to keep the operation in a long term is always neglected by the local government.

5. Conclusion

The paper carries out an intensive economic analysis on the Chuan project, which is a demo project in the Sponge City program in China. Through examining all economic, environmental and social cost and benefits of the Chuan project, it is found that the total benefits caused by the project is much more than the total cost. It means the water projects in the Sponge City program is deserved to be promoted in China as it could improve the water environment of the city. However, no sustainable income to cover the O&M cost of the project, which can hamper the project's sustainable operation. Whether the Sponge City program can be implemented successfully depends on an effective cost recovery plan made by the local government or a reasonable business model for the water projects. If the financial problem is solved, the Sponge city program could largely help to improve the water environment and decrease the pressure of flooding.

6. Acknowledgments

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