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# The Comprehensive Evaluation of Reclaimed Water Effectively Utilization Policy in Tianjin, China

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## Abstract:

Increasing scarcity of freshwater resources and growing environmental awareness give rise to the use of reclaimed wastewater as an additional source of water supply. However, the amount of wastewater that can be reclaimed for reuse is subject to many factors, ranging from technical possibility to socio-economic and institutional conditions. Taking Tianjin in China as a case study, this paper provides a systematic framework for the analysis of waste water reuse potential under various driving forces and constrains. A linear programming model was used to analyze reclaimed wastewater reuse potential and the different reuse scenarios concerning environmental and economic development. In this paper we propose tentative policy proposals for meeting such challenges for economic development, water saving and water quality perfection. Through simulation and evaluation of introducing new advanced technologies and sewage plant in the catchment area, the simulation results suggest that the wastewater reuse can substitute 16 percent of freshwater under rational economic, financial and environmental constraints. The framework established in this study and the results of Tianjin case study help to give the optimal policy proposals of reclaimed water utilization. This study also provides a useful basis for the evaluation of specific wastewater reuse simulation for further research.

*Keywords: Reclaimed water reuse, Environmental policy, Socio-economic and environmental modelling, Simulation*

## 1. Introduction

Water resources are one of the most important things for human existence and social development. Also, with the increase of economic and population in developing countries, water scarcity and pollution problems are becoming more and more prominent recently. Wastewater reuse has drawn increasing attention worldwide as an integral part of water resources management. Such a move is driven by two major forces: scarcity of freshwater

resources and heightened environmental concerns[1-3]. Meanwhile economic considerations are also becoming increasingly important.

Reclaimed water reuse has been used in large municipalities in many parts of the world, especially in areas where the water resources are scarce and population and economic growth is rapid [4]. Tianjin is one of the typical areas in point.

Reclaimed water reuse practice can be traced back to several centuries ago. And there are a large number of studies on waste water treatment from technological and engineering aspects. Recently, many studies have been undertaken to protect the water environment and improve economic development. In Japan, Hirose and Higano [5] constructed simulation analysis to evaluate water purification policies in the catchment area of Lake Kasumigaura, Japan. Also, Mizunoya et al. [6] analyzed and assessed synthetic environmental policies to reduce environmental burdens by biomass technology. Studies about comprehensive environmental evaluation in China are mainly concerned with theories and theoretical model at national level. Another important research direction is systematic modeling of the costs and benefits of wastewater treatment and the optimal scale of the reuse under various technological, physical, socio-economic and institutional conditions. One of the noticeable studies as such is by Chu et al. [7], who applied a linear programming model to examine trade-offs between wastewater reuse supplies and demands, as well as the related costs and profits based on 342 cities in China.

However, there is rather rare research on reclaimed water utilization modeling and prediction. In most of these studies, conclusions are derived from simple data analysis and foreign experiences [8]. Research on construction and analysis of a comprehensive simulation policy that includes the introduction of current treatment technologies to control water pollutant emissions without deteriorating the socio-economic activities level are badly needed.

In the study, we selected Tianjin city as an objective region, and evaluated the various policies on reclaimed water promotion and water quality control with the consideration of economic benefits. Therefore, the significance of this study lies on the fact that Tianjin is a rapidly growing city in both population and economy while water scarcity is intensifying and water pollution deteriorating.

## 2. Current situation of the catchment area

Tianjin, one of four biggest municipalities in China, is located in northern China, near Beijing, capital of China, and the downstream of Haihe River basin.

There are 13 districts and 3 counties in Tianjin, the 3 counties are Jinghai, Ninghe and Jixian County. Tianjin's land area is 1,191,970 hectares. About the land usage, agriculture land accounts for the biggest part, 60.87%; construction land accounts for 32.13%; and unused land is 829.85ha, accounts for 7%.

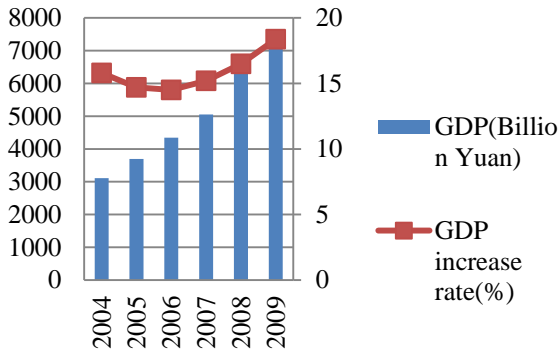
The total population in Tianjin in 2009 is 122.816 million, and with the urbanization process, the urban population increasing rate is much higher than rural population.



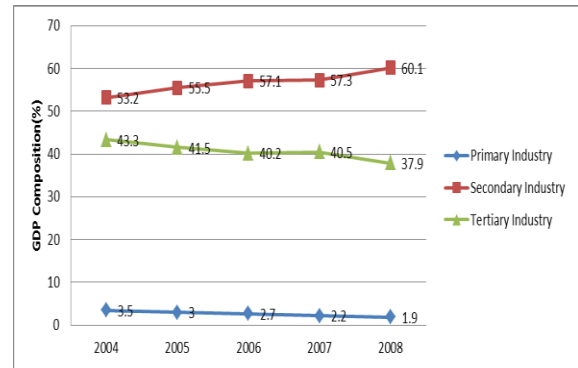
Fig.1 Location of Tianjin City, China

### 2.1 Economic development situation

From the following figures, we can see that Tianjin's GDP keeps a steady increasing trend; the increase rate is above 10% per year. Also, the three industries composition demonstrates that Secondary Industry is the monopoly industry while its composition steady rises; primary industry only contributes a little to Tianjin's economic, and its composition is low ; tertiary industry's GDP contribution declines year by year.



**Fig.2 GDP trend in Tianjin**

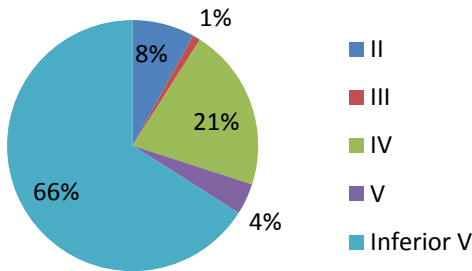


**Fig.3 Tianjin's GDP Composition Trend**

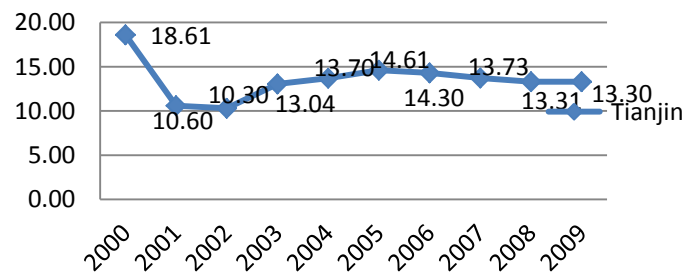
Source: Tianjin Statistical Year Book 2010

## 2.2 Water utilization and quality situation

Water shortage is a serious problem in Tianjin. The per capita water resources in Tianjin is 159.8 m<sup>3</sup> in 2008, it is only 1/13 of China average, and only 1/52 of world average. And a large part of its water supply relies on water transferred from Hebei Province.



**Fig.4 Water quality in Tianjin in 2008**



**Fig.5 COD emission amount in Tianjin (10000ton)**

Source: Tianjin Statistical Year Book 2010

Surface water quality in Tianjin is not enlightened; over 70% of surface water in Tianjin is in inferior V level. However, from the COD emission amount from 2002 to 2009, with the economic rapid development, COD amount has been controlled effectively, and the trend is declining.

## 2.3 Reclaimed water utilization situation

**Table1. Reclaimed water utilization(2008)** units:(10,000ton)

<b>Indexes</b>	<b>Tianjin</b>
Total amount of water resource	18.3
sewage discharge amount	6.82
sewage disposal amount	4.94
sewage disposal rate	72.40%
reclaimed water utilization amount	0.08
reclaimed water utilization rate	1.65%

Source: Tianjin Statistical Year Book 2010

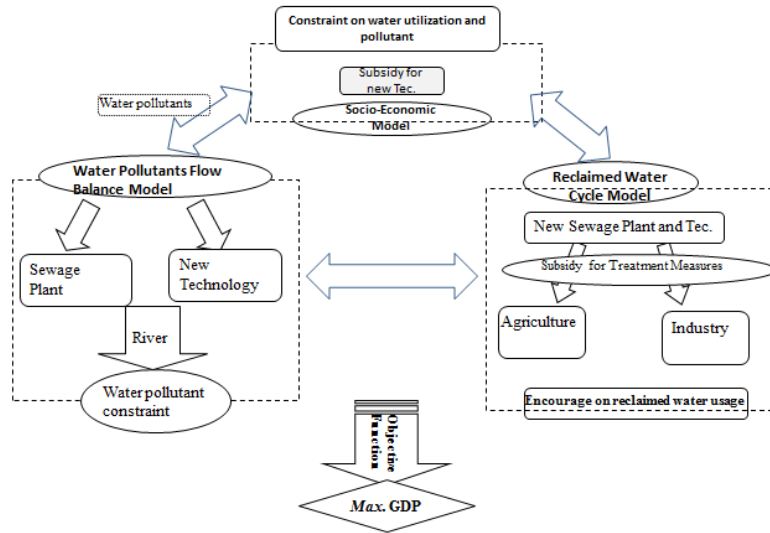
Furthermore, waste water reuse rate is really low, only 1.65% of reclaimed water is used in Tianjin. While the waste water disposal rate is 72.40%, a large amount of treated waste water has not been used.

From the current situation analysis, we can see that reclaimed water utilization rate is low, 1.65%; over 70% of surface water in Tianjin is in inferior V level, water quality is not well; and waste water treatment coverage proportion still needs to be improved. With the rapidly regional development, water scarcity is intensifying and water pollution is deteriorating. Thus, it is important to research on waste water utilization and recycles in order to solve water shortage and water pollution problems.

## 3. Research Model

My research aims to construct comprehensive evaluation model of effective reclaimed water utilization and optimal environmental policies in catchment area. The evaluation model is established based on our society and economic facts, and it should be simulated to reflect real social and economic development.

### 3.1 Skeleton of Simulation Model



**Fig.6 Model Framework of reclaimed water utilization and optimal environmental policies**

Regards to the research model, the object function is Maximize GDP, and there are three sub-models—reclaimed water cycle balance model, water pollution flow balance model and social and economic model.

### 3.2 Framework of Simulation Model

Regards to the simulation framework, the catchment area is divided into 18 areas based on these administration division.

**Table2. Tianjin’s regional division**

Index	Name	Index	Name
1	Heping District	10	Dongli District
2	Hedong District	11	Xiqing District
3	Hexi District	12	Jinnan District
4	Nankai District	13	Beichen District
5	Hebei District	14	Wuqing District
6	Hongqiao District	15	Baodi District
7	Tangu District	16	Ninghe County
8	Han'gu District	17	Jinghai County
9	Dagang District	18	Jixian County

And the water supply is divided into two types, freshwater and reclaimed water. Water demand resource is separated into 2 groups: household living water and industry water, and industry are divided into Primary industry, secondary Industry and Tertiary Industry.

**Table3. Classification of water supply and demand sources**

Index	Water supply	Index	
1	Freshwater	1	Primary Industry
2	Reclaimed water	2	Secondary Industry
		3	Tertiary Industry
		4	Household

**Table4. Integrated policies for the catchment area**

Source of water pollutants	Name of policy	Measurements
Industry	Reclaimed water reuse	I. Reclaimed water utilization subsidy in Primary and Secondary Industry
Household	Sewage system	II. Subsidization for the municipality to install more sewage system and sewage plant
Production	Reduction of the capital employed	III. Subsidization for industries to reduce working capital and thus adjust production

There are 3 policies proposals for the catchment area: firstly, the encourage policy for reclaimed wastewater reuse in Tianjin's Primary industry and Secondary industry; secondly, for household water utilization, we introduce new sewage system with new development technology ; and subsidization for industries to reduce working capital and thus adjust production.

## 4. Model structure

### 4.1 Objective function

The objective function was constructed to maximize the total GDP over the target term (t=11) in order to determine an optimal policy.

$$\text{MAX} \sum_t \text{GDP}(t)$$

in which, en: endogenous, ex: exogenous.



#### 4.1 reclaimed water cycle balance model

Total water supply amount is:

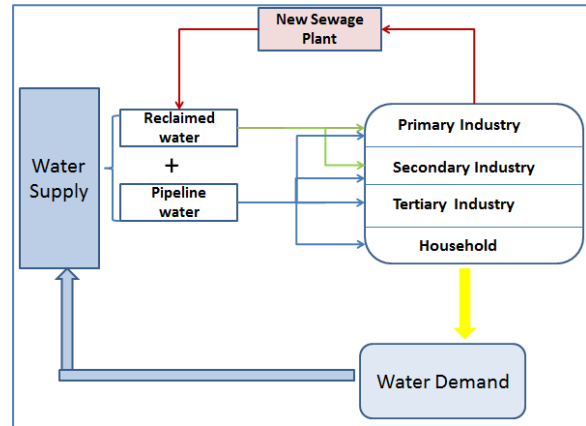
$$WS(t) = \sum_j \sum_m WSP_j^m(t) + \sum_j \sum_m WSR_j^m(t) + \sum_j WSP_j^l(t)$$

$WS(t)$ : water supply in time  $t$ ;

$WSP_j^m(t)$ : water supply from freshwater;

$WSPR_j^m(t)$ : water supply from reclaimed water.

$WSP_j^l(t)$ : freshwater supply of living water.



The Water Demand amount is:

$$WD(t) = \sum_j \sum_m Ew_j^m \cdot X_j^m(t) + \sum_j Ew_j^l \cdot z_j(t)$$

$WD(t)$ : Water demand in time  $t$ ;

$Ew_j^m$ : Coefficient of water demand of industry  $m$  in region  $j$ ;

$X_j^m(t)$ : Production of industry  $m$  in the area of region  $j$ ;

$$WS(t) \geq WD(t)$$

Waste water amount that discharged by industries' production and household utilization:

$$SPW(t) = \sum_j \sum_m Ep_j^m(t) \cdot X_j^m + \sum_j Ep_j^l \cdot z_j(t)$$

We assumed that the total sewage amounts except Primary industry have been disposed in sewage plant, including existing sewage plant and new established sewage plant:

$$SPW_j(t) = \sum_e SPW_j^e(t) + \sum_N SPW_j^N(t)$$

$SPW(t)$ : Water amount treated by sewage plant at time  $t$ ;

$Ep_j^m$ : treating rate of sewage water;

$SPW_j^e(t)$ : Water amount treated by existing sewage plant in region  $j$ ;

$SPW_j^N(t)$ : Water amount treated by new sewage plant in region  $j$ .

Therefore, the reclaimed water amount is decided by new established sewage plant, it has new technology to provide reusable water for Primary and Secondary industry.

$$RW(t) = \sum_j \sum_N \alpha \cdot SP W_j^N(t)$$

$RW(t)$ : Reclaimed water amount provided by sewage plant;

$\alpha$ : Reclaimed water recycle rate;

#### 4.2 Water Pollutant Flow Balance Model

The total water pollutant amount is discharged by economic and social activities:

$$TP^p(t) = \sum_j \sum_m Ep_j^{pm} \cdot X_j^m(t) + \sum_j Ep_j^{lp} \cdot z_j(t)$$

$TP^p(t)$ : The total net load of water pollutant p at time t

$Ep_j^{pm}$ : Coefficient of water pollution p of industry m in region j;

$Ep_j^{lp}$ : Coefficient of water pollution p of living water in region j;

P=1(COD); P=2(T-N); p=3(T-P).

#### 4.3 Social-Economic Model

In assumption, the new established sewage plant can provide reclaimed water. The sewage plant investment is proved by financial support and other social sources. The following is flow balance in the commodity market:

$$X(t) \geq A \cdot X(t) + C(t) + I(t) + B^{SP} \cdot I^{SP} + e(t) + T(t)$$

$$e_{min} \leq e(t) \leq e_{max}$$

$X(t)$ : Total product of industry in the study area(en);

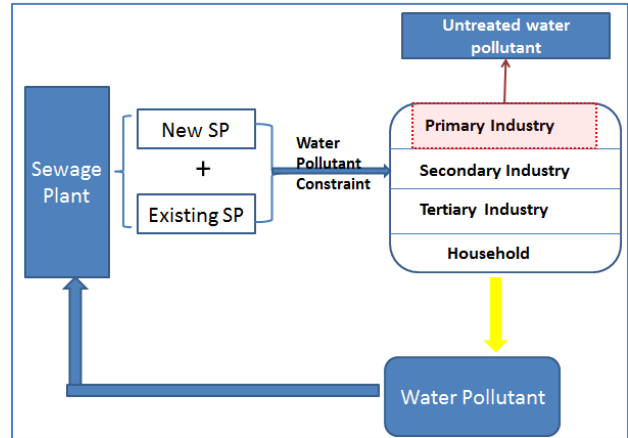
$A$ : Input-output coefficient matrix (ex.);

$C(t)$ : Total consumption at time t(en);

$I(t)$ : Total investment at time t(en);

$B^{SP}$ : Column vector of m-th coefficient that induced production by construction of sewage plant (ex);

$I^{SP}$ : Total investment for construction of sewage plant (en);



$e(t)$ : Column vector of net export(en.);

$T(t)$ : Column vector of transfer product between provinces in China(en.).

## 5. Simulation Results Analysis

### 5.1 Simulation case

In this study, we define the simulation case that COD water pollutants amount reduces 1000ton each year during the future 11 years from 2009. With integrated policies of new technology and sewage plant construction, we get the following results:

### 5.2 Objective function

Under the water pollutant constraint, as well as the new sewage plant construction encouragement each year, GDP in Tianjin can get steady improvement since 2010. And because of water pollutant limitation, GDP in 2020, 10135.28 billion Yuan, confronts with declining situation, less than 10188.57 billion Yuan in 2019. This demonstrates that the current technology and sewage plant cannot provide enough incentive power for both economic and environmental improvement.

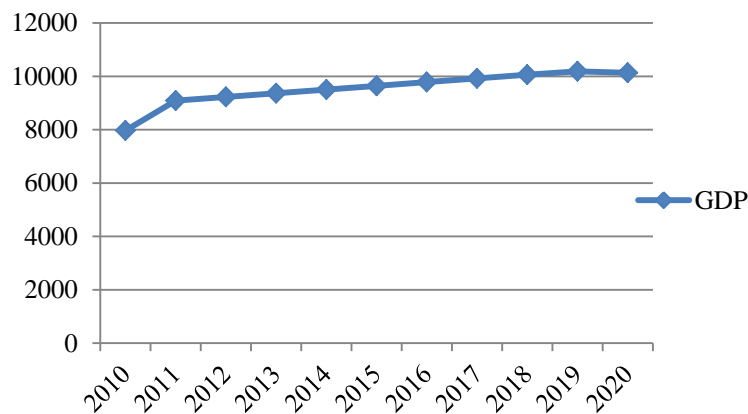


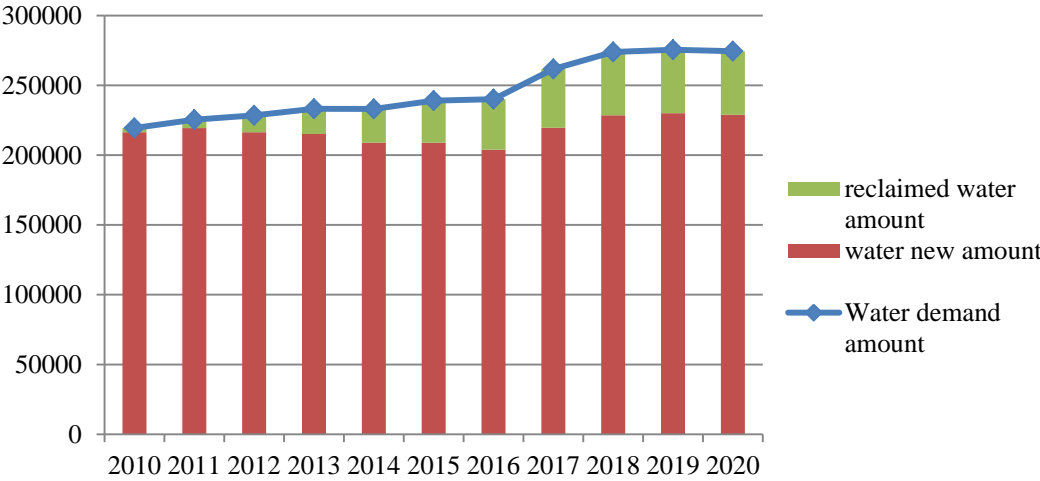
Fig.7 GDP changing trend from 2010 to 2020

### 5.3 Reclaimed water utilization trend

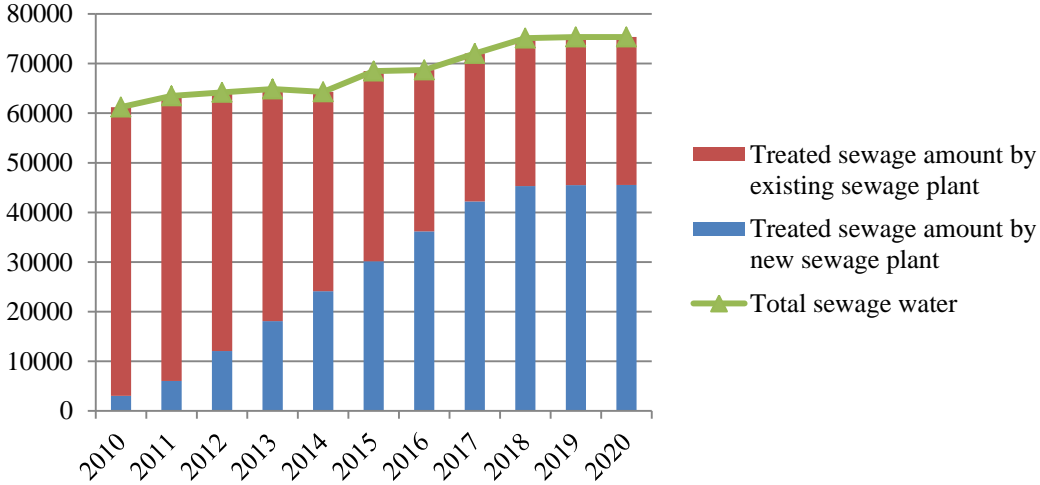
Through simulation, we get the reclaimed water utilization potential in Tianjin from 2010 to 2020. With the economic development and financial support in research area,

reclaimed water facilities are established and the total reclaimed water usage amount is growing significantly.

In 2010, only 1.4% water supply comes from reclaimed wastewater, and in 2020, its percentage rises to 16.59% while economic development and environmental protection. In 2020, total water demand is 27449.09million tons, and reclaimed water can save 4552.809 million tons freshwater for Tianjin.



**Fig.9 Reclaimed water substitution trend from 2010 to 2020**



**Fig.10. Treated sewage amount by new sewage plant trend from 2010 to 2020**

About the new established sewage plant disposal ability, we can see from above figure that the new sewage plant can get rapidly increase for its high waste pollution disposal

ability and financial support. In 2020, total sewage amount is 75351.59 tons, and over 60% waste water can be disposal by new sewage plant, and this can contribute a lot to water pollutant declination.

#### 5.4 New sewage plant construction and distribution

Also, from scenarios, we can get the distribution of new sewage plant in 18 regions of Tianjin.

Table5 shows the current sewage disposal capacity in Tianjin, large sewage plant is not distributed in each region. And the regions with bold letters are those who constructed new sewage plant. The simulation chooses to build new sewage plant in these areas lack of sewage disposal ability. Also, the new sewage plant construction is constrained by local government financial capacity and industry's development.

**Table5. Current sewage disposal capacity in Tianjin**

<b>Index</b>	<b>Name</b>	<b>Sewage Disposal Capacity</b>	<b>Index</b>	<b>Name</b>	<b>Sewage Disposal Capacity</b>
<b>1</b>	<b>Heping District</b>		10	Dongli District	3650
<b>2</b>	<b>Hedong District</b>		11	Xiqing District	16425
3	Hexi District		12	Jinnan District	2920
4	Nankai District		13	Beichen District	182.5
5	Hebei District	11388	<b>14</b>	<b>Wuqing District</b>	4380
6	Hongqiao District		<b>15</b>	<b>Baodi District</b>	730
7	<b>Tanggu District</b>	17520	16	Ninghe County	
<b>8</b>	<b>Han'gu District</b>		<b>17</b>	<b>Jinghai County</b>	
9	Dagang District	219	18	Jixian County	1095

The following table demonstrates the new sewage plant construction in different region, time and amount. From 2010 to 2020, there will be 19 plants being built. Wuqing District and Jinghai County construct 5 plants, there are short of wastewater disposal capacity. From this simulation results, we can also give policy proposals to prompt reclaimed waste water reuse and achieve economic optimal development.

**Table6. Sewage plant construction trend from 2010 to 2020**

<b>Region</b>	<b>1</b>	<b>2</b>	<b>7</b>	<b>8</b>	<b>14</b>	<b>15</b>	<b>17</b>
<b>Year</b>	<b>Heping District</b>	<b>Hedong District</b>	<b>Tanggu District</b>	<b>Han'gu District</b>	<b>Wuqing District</b>	<b>Baodi District</b>	<b>Jinghai County</b>
2010			★				
2011			★				
2012					★ ★ ★		★
2013		★	★				
2014						★	★
2015			★				
2016				★	★ ★		★
2017							★
2018	★						★
2019							
2020						★	
<b>Total</b>	<b>1</b>	<b>1</b>	<b>4</b>	<b>1</b>	<b>5</b>	<b>2</b>	<b>5</b>

## 6. Concluding remarks

According to this research, the following conclusions can be obtained. When we adopt new sewage technology and construct new sewage plant, 10,000 tons of COD can be decreased in water pollutants emission. While the economic development can be realized at 10135.28 billion Yuan, however, the economic increasing trend is slow down in the last years limited to technology capacity. Also, through simulation, we get the sewage plant construction distribution and cost-benefit analysis. The overall results suggest that reclaimed water utilization have great important meaning in the simultaneous pursuit of environmental preservation and economic development. And reclaimed water reuse have great feasibility and possibility to relief water shortage pressure, save energy, and perfect environment, and finally accomplish sustainable development in the study area—Tianjin, China.

## References

- [1]A.N. Angelakis, L. Bonoux and V. Lazarova, Challenges and prospective for water recycling and reuse in EU countries, *Water Sci. Technol. Water Supply* 3 (2003), pp. 59–68.
- [2]T. Asana and J. Cotruvo, Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations, *Water Res.* 38 (2004), pp. 1941–1951.
- [3]J.G. Chatila, Reclaimed waste water in some Middle Eastern countries: Pricing and perspective, *Canadian J. Development Studies* 25 (2004), pp. 481–497.

[4]Hong Yang, Karim C. Abbaspour. Analysis of wastewater reuse potential in Beijing. *Desalination* 212(2007), pp: 238-250.

[5]Fumiaki H., Yoshiro H. (2000), A simulation analysis to reduce pollutants from the catchment area of lake Kasumigaura. *Studies in Regional science*, Vol.30, No.1, 47-63.

[6]Mizunoya T., Sakurai k., Kobayashi S., Piao S.H., Higano Y. (2007), A simulation analysis of synthetic environment policy: effective utilization of biomass resources and reduction of environmental burdens in Kasumigaura basin. *Studies in Regional Science*, Vol.36, No.2, pp.355-374.

[7]J.Y. Chu, J.N. Chen, C. Wang and P. Fu, Wastewater reuse potential analysis: implications for China's water resources management, *Water Res.* 38 (2004), pp. 2746–2756.

[8]Dajun Shen, Bin Liu. Integrated urban and rural water affairs management reform in China: Affecting factors. *Physics and Chemistry of the earth* 33(2008), pp: 364-375