For office use only	Team Control Number	For office use only
T1 ________	**45985**	F1 ________
T2 ________		F2 ________
T3 ________	Problem Chosen	F3 ________
T4 ________	**E**	F4 ________

2016
ICM
Summary Sheet

Simulation of Water Supply and Demand Based on System Dynamics

Executive Summary

Water scarcity has become one of the most serious problems in the world. Without effective measures to solve water scarcity, the development of human being will be limited.

To evaluate the water scarcity of a country, we should come up with a criteria which is objective and comprehensive. Since the demand of water varies from countries, we build a **dynamic hierarchy evaluation model**. In this model, we classify the water scarcity into four classes and each class reflects a different degree of water scarcity. When the model is applied to India, we find that the scarcity lays between grade B and C which indicates that India suffers from heavy water scarcity.

To predict the degree of water scarcity in India in the future 15 years, we build a **system dynamics model** to simulate the behavior of the supply and demand of water. The system contains four subsystems and each subsystem contains its variables and parameters. Given the initial states of system, the model will simulate the system automatically. We can get the output of the model including parameters and indicators which we use to evaluate the water scarcity. Our prediction is that the water scarcity will become worse in the future 15 years.

We use cellular automaton to simulate the flow of water resource in region. After analyzing the result, we come up with a plan to exploit more undeground water to alleviate water scarcity. However, the plan is not sustainable.

In the next plan, we study the effect of the four schemes including saving waters, improving sewage treatment and promoting industrial structure. By analyzing the outputs of the system dynamics model, we come to a conclusion that the combination of the four schemes is most effective to solve water problem. And without intervention, water crisis will happen in India in 2021 when the underground water runs out.

Key words: Dynamic evaluation; System dynamics; cellular automaton; parameters

Contents

1 Introduction

1.1 Problem Background

Water is one of the most essential resources in the world that people cannot live without with. Humans require water resources for industrial, agricultural, and residential purposes. Agriculture accounts for 75% of total global consumption-mainly through irrigation, while industrial use accounts for about 20%, and the remaining 5% is used for domestic use.

The growth of population places burden on water scarcity. About one fourth of the world's population lacks access to clean water which threats their health severely. Fresh water are unevenly distributed, with much of the water located far from residents. About two million people die every year due to water-borne diseases from faecal pollution of surface waters.

Another reason for water scarcity is climate change, whose impacts are expected to combine to depress yields and increase production risks with unpredictable weather patterns. Some areas suffer from severe drought which lead to the contraction in agriculture output.

Pollution is another factor responsible for water shortage. Severe eutrophication has been discovered in many lakes and river which cause the death of fish and water degradation. Some industrial waste is discharged into river without being purified. About two million people die every year due to water-borne diseases from faecal pollution of surface waters.

Water management is one of a measure to solve water scarcity. Water saving and purified are important component in management. Since ocean occupy 77% of the world surface, if sea water desalination is highly developed, the water scarcity can be solved. So people are facing big challenge in the future water problem.

1.2 Problem Restatement and Analysis

Water scarcity has become one of the most serious problems in the world. ICM wants our team to measure the ability of a region to provide clean water to meet the demands of its population. We interpret this task as using a kind of criteria to indicate the water scarcity of a country. This criteria should be objective and universally applicable so that it can it commonly used in the different countries. Considering that different countries vary from the demand of water, we should come up with a dynamic classification to evaluate scarcity in different countries. Task two requires us to apply the evaluation model to India.

Since the supply of water resource is directly related to some dynamic nature of factors, the criteria must take the natural factors and physical factors into account. We combine natural factors and physical factors to build a water system. Considering the factors in the system are not independent which have mutual interaction with each other, we use the water system to simulate the demand and supply of water in real life. Getting the outputs from the water system, we use the model in task one to evaluate the water scarcity of a country.

In task four, we should come up with intervention plan to improve water situation. By changing some parameters of the supply and demand system, we can see the effect of these parameters. The plan should be made according by analysing the effect of parameters. Finally we can get the tendency of water capacity and see when the capacity will become so scarce.

2 Bold Assumption

(1) The issues outside India will not affect the water system in India.

(2) River is the only surface water in India ignoring lacks or iceberg, and its ability to provide water can be measure by its runoff

(3) The population in India will grow in the following 15 years without strong policy or disease to control the population.

(4) The main feature of water system can be indicated by some essential indicators.

3 Symbol Description

In the section, we use some symbols for constructing the model as follows.

Symbol	Description
w_i	The weight of the indicator x_i
X	The final criteria to evaluate water scarcity
S_Q	The sensibility of the variable Q to parameter P
S	The average sensibility of parameter P

P.s:Other symbol instructions will be given in the text.

4 Task One: Dynamic Hierarchy Evaluation Model(DHE)

There are two primary causes for water scarcity: physical scarcity and economic scarcity. Physical scarcity is affected by precipitation, river distribution, climate change, exploitable groundwater resources. Economic scarcity is affected by industrial structure, population, the management of water, technology development, consumption patterns. To evaluate the water scarcity of a country, we should come up with a criteria which is universal and objective.

Considering that the industrial structure and population vary from countries, the demand of water in every indicators also vary from each other. The same amount of water maybe be adequate in one country but inadequate in another country. Thus, the classification of demand vary from countries. From the analyse made above, we should build a dynamic evaluation to measure the water supply capacity of a country.

Step 1: The selection of indicators and classification: There are many factors that affect the supply and demand of water which makes the evaluation of water supply ability complex. In order to simplify the problem, we select ten essential indicators to measure the ability of a country to provide clean water. The indicators are selected from four aspects, including population, economy, environment and resources. Since the demand for water in different indicators varies from countries, we should have different classification od indicators according their demand of water. To classify the water supply capacity of a country, we classify the indicators into four classes as A,B,C,D, showing different classification of water scarcity in every indicators. 'A' indicates that the water is adequate water to meet the demand of people; 'B' indicators that the water is slightly inadequate; 'C' indicates that the water is moderately overloaded. And 'D' means the water heavily overloaded.The selection of indicators and their classifications are shown in the Table 1.

Table 1: The classification of indicators

#	Indicator	α_i	A	B	C	D
1	Supply water per capita(m^3)	α_1	900	600	400	200
2	Water use per capita(m^3)	α_2	1563	864	447	85
3	Water use per farmland(m^3/hm^2)	α_3	3300	4500	8550	10500
4	Industrial promotion water use($m^3/10^4$)	α_4	341	498	1128	1634
5	Urbanization rate(%)	α_5	30	45	60	75
6	Population density($person/km^2$)	α_6	10	100	150	250
7	Rate of cultivated land(%)	α_7	10	25	50	75
8	Water resources per capita(m^3)	α_8	3000	1700	1000	500
9	GDP per capita($)	α_9	898	3558	6887	10985
10	Sewage treatment capacity(%)	α_{10}	95	70	60	50

Step 2: Standardization: The dimension of indicators are different so they need to be dimensionless treatment. For the positive indicators, if the value of the indicator is x_1, then the standardized value $x_1^{'}$ should be:

$$x_1' = \frac{b_i}{x_1}, \tag{1}$$

where b_i is the lower limit of intervel.

If the indicator is negative, then the standardized value $x_1^{'}$ should be:

$$x_1' = \frac{x_1}{a_i}, \tag{2}$$

where a_i is the upper limit of the interval.

Step 3: Determine the weight of every indicator: All indicators become negative after standardization, so the smaller gap between the value of indicators and 1, the more serious water scarcity is. Since our purpose is to evaluate the water scarcity of a country, we should give greater weight to the indicator which indicates the water demand in this aspect cannot be satisfied. And the indicators that is adequate in water play little part in water scarcity. Thus, we used a 'S'−type function to describe the weight of indicators, which goes up rapidly in the middle, and slow down when the the value approach to 1. If the value of indicator is close to 1, the weigh of this indicator will approach to 1 which means that this indicator the important reason for water scarcity. The S−type function is describe in the Equation 3:

$$w_i(x_i) = \begin{cases} 2\left(\frac{x_i-a_i}{b_i-a_i}\right)^2, & c < x_i \leq b_i \\ 1-2\left(\frac{x-b_i}{b_i-a_i}\right)^2, & a_i \leq x_i \leq c \end{cases} \tag{3}$$

$$c = \frac{1}{2}(a_i+b_i), w_i(c) = 0.5$$

The S-Type function is shown in the Figure 1

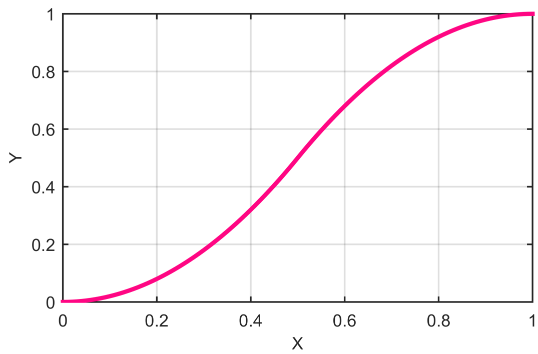


Figure 1: The weight function

where $w_i(x_i)$ is the weight of the i indicator, a_i is the upper limit of interval of the i idicator, and b_i is the lower limit of interval of the i indicator.

Step 4: Propose a synthetic evaluation function: After all the weight of indicator is determined, synthetic evaluation function should be proposed. Combine all the indicators and their weight, the function is described bellow:

$$X = \sum_{i=1}^{10} w_i(x_i)x_i \tag{4}$$

X is the final criteria to evaluate water scarcity of a country. X is a negative index so the bigger value of X means the more serious water scarcity.According to the classification of indicators, we use the boundary value of each indicators to calculate X and get four classification of X as 'A','B','C' and 'D'.

The boundary value of each classification is shown in the Table.

4.1 Strength and Weakness

- The weight of every indicator is not determine subjectively, but determine by a weight function which is make according the feature of indicators.
- Since the demand of water vary from countries, we use a dynamic evaluation model to evaluate the water scarcity of different countries.
- We choose some main indicators to simplify the problem, using these indicators to evaluate the water system. And when evaluating other systems, the evaluation model can be applied by changing the indicators and weight function.
- However, our model do not take into account of some natural disaster like flood and others. Only consider the state in a certain period.

5 Task Two: The Application of Model in India

India is one of the country with abundant water resources located in the south of Asia (Figure 2). However, it is the second-most populous country with more than 1.2 billion populaton[3]. Research indicates that water scarcity is becoming more and more serious in India in recent years. The average water resource amount per capita in India had drop from 1986 m^3 in 1998 to $1820m^3$ in 2001, and again drop to $1580m^3$ in 2010, far below the global average. Simultaneously, the demand for water is increasing. The total consumption of water in 1990 is 500 billions which grows to 761 billions in 2010.

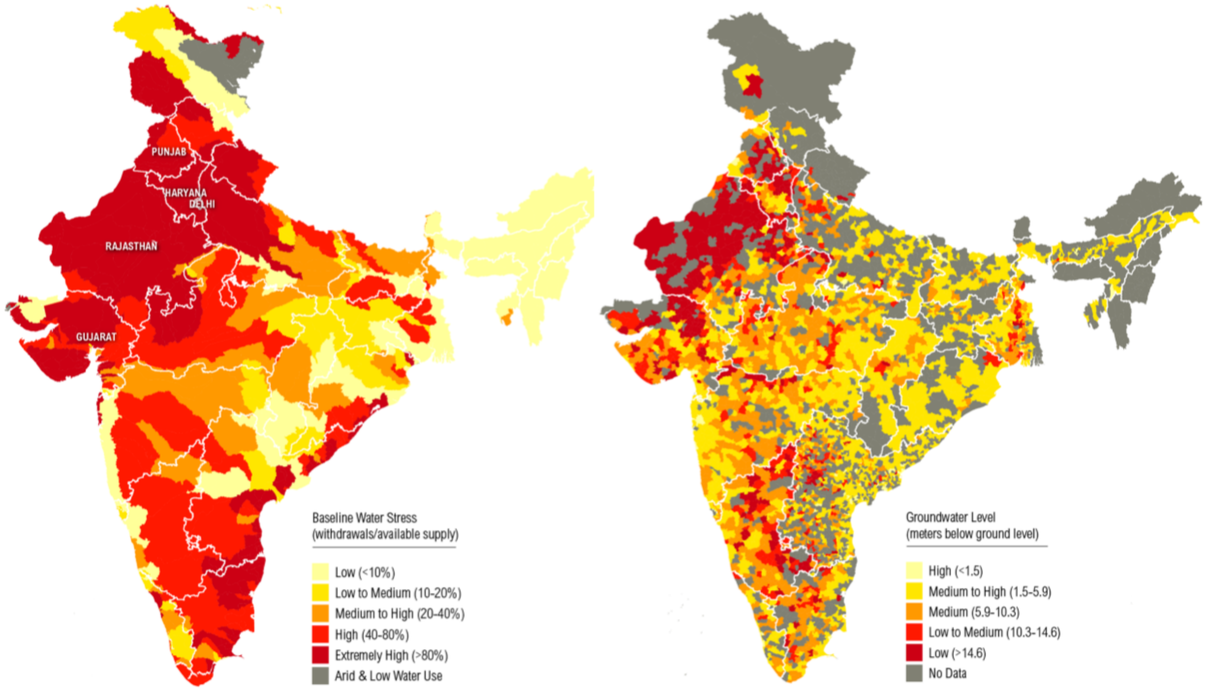
Meanwhile,the utilization rate of water is quite low, especially in agriculture. The water used in agriculture accounts for 91% of water consumption. The irrigation method in India is lag behind with low efficiency in water usage. Water pollution aggravates the water scarcity in India. About 70% of water is polluted and the sewage treated rate is only 31%[4].

To apply the Weighted Hierarchy Evaluation Model to evaluate the water supply ability of India, firstly, we collect data of 10 indicators of 2010 from India Statistic Bureau and the World Bank.

Secondary, we should make the classification of indicators for India. The value of the boundary of each classification should refers to the standard of world bank, the division of the city hierarchical structure in India, the measure of the wealth of India,and the research on the usage of land in India. Then we get the classification which is determined by the development of India. It is shown in the Table2. We use the boundary value of 'A' of every indicators to calculate the value of X and get the boundary value of 'A' grade water scarcity. Similarily, we can get the boundary value of 'B','C', and 'D' classification of water scarcity.

Thirdly, we standardize the data and use the Equation 3 to calculate the weight of every indicators. Finally, use the Equation 4 to calculate the water scarcity of India. The final result of X is 1.9173.

When put into the data of boundary value of ten indicators, we get four classifications of water scarcity. It is shown in Table 3



(a)Baseline Water Stress (b)Groundwater Level

Figure 2: The interaction between water subsystem and other three subsystem

Table 2: The classifications of indicators in India

#	Indicator	α_i	A	B	C	D
1	Supply water per capita(m^3)	α_1	900	600	400	200
2	Water use per capita(m^3)	α_2	1563	864	447	85
3	Water use per farmland(m^3/hm^2)	α_3	3300	4500	8550	10500
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Table 3: The classifications of indicators in India

Classification of water supply ability	A	B	C	D
Value	0.2471	0.9128	3.6000	10.0000

'A' is the most serious level of water scarcity which means water is heavily overloaded, and B is less serious, 'C' is moderately serious and 'D' is not serious.

We find that the value of scarcity in India lays between B and C classification which is less serious and moderately serious. The results shows that the water scarcity in India is not optimistic, but it has not become serious problem in India society in 2010.

6 Task Three: System Dynamics to Simulate the demand and supply system of water

The factors that affect the supply and demand of water is not constant but change over time and interact with each other, forming a system with perpetual motion and evolution.

Water, as a part of natural resources, is influenced by people activity and natural environment. Moreover, people activity and natural environment are closely connected with each other. Since the mutual restriction relations, the change of any factor will lead to the movement of the whole system. So it is difficult to tell the tendency of the system by the change of one factor. Meanwhile, people activity and environment are dynamic which change over time. The change of the factor and the interaction between them make the ability to supply water difficult to measure. Thus, a dynamic system should be established to describe the interaction between these factors.

System dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, economic, or ecological systems literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality. It is an approach to understanding the nonlinear behaviour of complex systems over time using stocks and flows, internal feedback loops and time delays[5]. It can simulate the system behavior according to the the internal structure and feedback loop of the water system. The internal feedback loop of water system is non-linear and complicated. Thus, we can use system dynamics to simulate the feed back loops and interaction in water system. The factors inside the system and their interaction runs the system and output some essential indicators of the water supply capacity.

In order to build a dynamic system, firstly we should determine the boundary of the system, that is to decide the research scope of the model. There is not definite boundary in reality system. In the sense of system, the boundary of a system is not a geographical concept. It is defined according to the purpose of modelling. So considering a boundary of water system means that we need to take into account of the important concepts and variables related to the water system. The water system is open where there is information input and output with other objects outside the system. India, as a country in Asia, also has information communication with the other parts of the world. For simply research, we define the boundary of the the system as the country border for India.

Water apply and demand system is a highly nonlinear system with multi feedback and multi variables. Except for the interaction between factors, the relationship between subsystem are interactional, each subsystem have mutual effect including positive effect and negative effect. It contains four subsystems including water subsystem, environment subsystem, society subsystem and economy subsystem.

6.1 Environment Subsystem

Sewage and green coverage are two components of environment subsystem. The variable to measure the quantity of sewage is the rate of sewage treatment. The system mainly studies the change of sewage discharge cause by the change of water supply, population, and economy and so on. The sewage water includes waste water produced by residents, industry and agriculture. Sums up the quantity of water produced by human is the total amount of sewage water. And water that is not treated will be the polluted water in the environment system which cannot be used for human activity. The amount of sewage water is affected by population, the acreage under irrigation, development of industry. The supply of water is affected by water treatment. Simultaneously, when the scarcity of water become more serious, the development of economy and growth of population will be limited.

The main parameters functions are listed below.

$\vartheta_S = \vartheta_D + \vartheta_W + \vartheta_R + \vartheta_G$

$\vartheta_T = \vartheta_A + \vartheta_I + \vartheta_E$

where ϑ_S is water supply, ϑ_D is desalination of water, ϑ_W is reclaimed water, ϑ_R is river runoff, ϑ_G is Groundwater ,ϑ_T is total water demand, ϑ_A is Agricultural water demand, ϑ_I is industrial water demand, ϑ_E is domestic water demand

6.2 Economy Subsystem

Economic subsystem is built to describe the demand for water in economic development, including agriculture, industry and resident. The water used in agriculture is mainly for irrigation and animal husbandry. The water used in industry is mainly as boiler water, cooling water, raw materials. And the water used in resident are used to meet the demand for people's daily life, like drinking, washing and cooking. Collecting data from Indian Water Bureau, we find the water used in agriculture occupied 83.3%[7]of total water consumption, so evaluate the total water consumption using the sum of water used in agriculture and industry.

The development of agriculture and industry is constrained by the supply of water. Moreover they interact each other. For example, the development of industry increase the demand for water, which lead to more severe water scarcity. However, industry are essential engine to promote the economy of a country. So the lack of water will limits the economy of the country.

The main parameters we choose in economy subsystem including GDP per capita, total fixed investment, the growth of total fixed investment. The relationship between parameters is shown in the function.

$\zeta_G = (\zeta_I + \zeta_R + \zeta_S) \times \zeta_O$

$\zeta_I = \zeta_F \times \zeta_C$

where ζ_G is Total GDP, ζ_I is GDP in industry, ζ_R is GDP in rural, ζ_S is GDP in service industry, ζ_O is Output div demand ,ζ_I is GDP in industry, ζ_F is Industry fixed investments, ζ_C is industry input output coefficient.

6.3 Society System

One of the main features of a society is population. When considering a society, we must take into account the permanent residents consisting of urban residents and rural residents. The population of permanent residents is decided by birth rate and death rate.Society system mainly studies how the water demanded in life influenced by the change of permanent resident population in India. And how the balance between supply and demand of water will be affected by the population. The main parameters in society system: permanent residents population: By referring to the newest data of World Bank, we determine its value as the newest population in 2015.

The real population growth rate: The population growth rate fluctuates every year, we determine the growth rate of India as the average growth rate from 2006 to 2015.

The relationship between parameters is shown bellow.

$\xi_P = \xi_R \times \xi_T,$

$\xi_N = \xi_B \times \xi_T.$

where ξ_P is Growth Population Per Year, ξ_R is Growth Rate of Population, ξ_T is Total Population, ξ_N is Newly-born=Birth rate, ξ_B is Birth rate.

6.4 Water subsystem

This subsystem includes underground water, sea water desalination, and river runoff. Underground water and river run off is influenced by precipitation. And water desalination is decided by the local technology. In the research of water resource in India, we focus on fresh water resource including surface water, underground water, river water and renewable water resources. The variables of water subsystem is supplement of water resource, including conventional water and renewable water resources. The former consist of surface water and underground water.

The main parameters in water subsystem are listed below:

- the quantity of underground water: The initial quantity of underground water is 1100 billion cubic meters in 2010. According to the data of underground exploitation in India, the average underground exploitation is 72 billion[2], with average growth rate of 7%. But the average water complemented by precipitation is only 43 billion cubic meters. Thus, the quantity of underground water in India decreases every year which is unsustainable.
- the quantity of sea water desalination: The initial quantity of sea water desalination in 2010 is 200 million cubic meters. With the construction of the third sea

water desalination projects, the quantity of desalinated water changes nonlinearly. According to the scale of the project, the quantity of desalinated water in 2015 is 280 millions cubic meters per year. The quantity of desalinated water in the following year is described by table function.

- the mean annual runoff: The annual runoff in India is 1869 billion cubic meters[1].(235 billion waters comes from overseas)
- the mean water demand of residents: Includes urban residents water consumption and rural residents water consumption. The mean water consumption of urban residents is 304L per day, and 177L per day for rural residents.
- the quantity of water demanded for productivity: the mean water used in unit farmland refers to the data in 2010. The growth of industrial water refers to ***Five-Year Plans of India***.

The relationship between parameters is shown below.

$$\psi_S = \psi_D + \psi_R + \psi_V + \psi_G,$$

$$\psi_T = \psi_A + \psi_I + \psi_S + \psi_O,$$

where ψ_S is Supplying water, ψ_D is Desalination of water, ψ_R is Reclaimed water, ψ_V is River runoff, ψ_G is Groundwater, ψ_T is Total water demand, ψ_A is Agricultural water demand, ψ_I is Industrial water demand, ψ_S is Service industrial water demand, ψ_O is Domestic water demand.

We construct frame to show their interaction which is shown below:

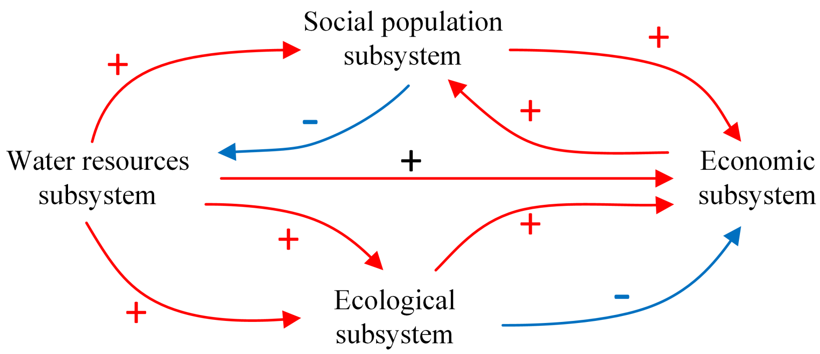

Figure 3: The interaction between four subsystems

Their interaction is shown in the Figure 4. We use $+$ to indicate that the development of one subsystem will improve the development of another subsystem. On the contrary, $-$ indicates the development of one subsystem has negative effect on another subsystem. This is the basic model of water system. A more detailed model should be built in specific region or country according the characteristic of the local situation of water supply and demand. The various internal factors and external influence factors are constantly changing, which leads to the nonlinear change of water apply capacity.

There are six feedback loops in this figure 4 including positive reinforcement loop and negative reinforcement loop. The first negative reinforcement loop in (a) indicates

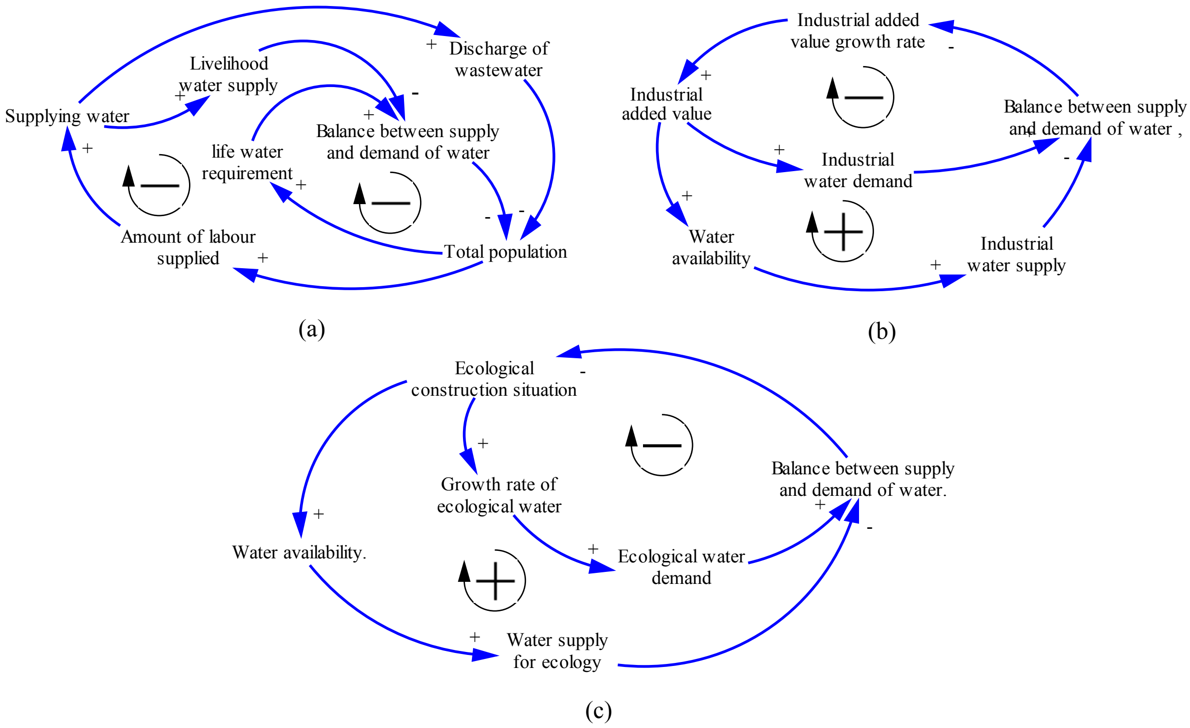

Figure 4: The interaction between water subsystem and other three subsystem

that the growth of labor supply will increase the supplying water, and the growth of supplying water will lead to the growth of discharge of waste water. However, the growth of discharge of waste water have negative effect on the total population. Thus, the growth of the three indicators will decrease the total population. This is a negative reinforcement loop. The other five casual loops act simultaneously but at different times they may have different strengths.

After the interaction between all indicators are determine, a system dynamics is built. The detail interaction of the water system is shown in the Figure 5.

6.5 The effectiveness test of system dynamics

The model should be tested to see if it is effective to emulate the water system. We choose India as our tested country. The effectiveness test includes the two parts. The first part is effectiveness test of the system's output. By comparing the output with the real data of indicators, if the output of system dynamics is close to the real data, that means our model can highly simulate the behavior of water supply and demand system. The other part of effectiveness test is sensitivity analysis. The means to change value of some parameters and see what effect will happen to the system.

6.5.1 The Effectiveness of the system output

We use 2010 as the initial year of the dynamic system . Then the dynamic system can simulate the behavior of water supply and demand system in the following year. It can out put some value of indicators which can be compared with the real value.

By comparing the output of the dynamic system and the real data, we can get the effectiveness of the system. We collect the real data from 2010 to 2014, and compare the data with the data output from the system. The data are shown in Figure 6.

By observing the Figure 6, we can see the the simulation fits well with real data. By simulating the system, can see that the population of India will increase in the following year. And the GDP will climb up simultaneously.

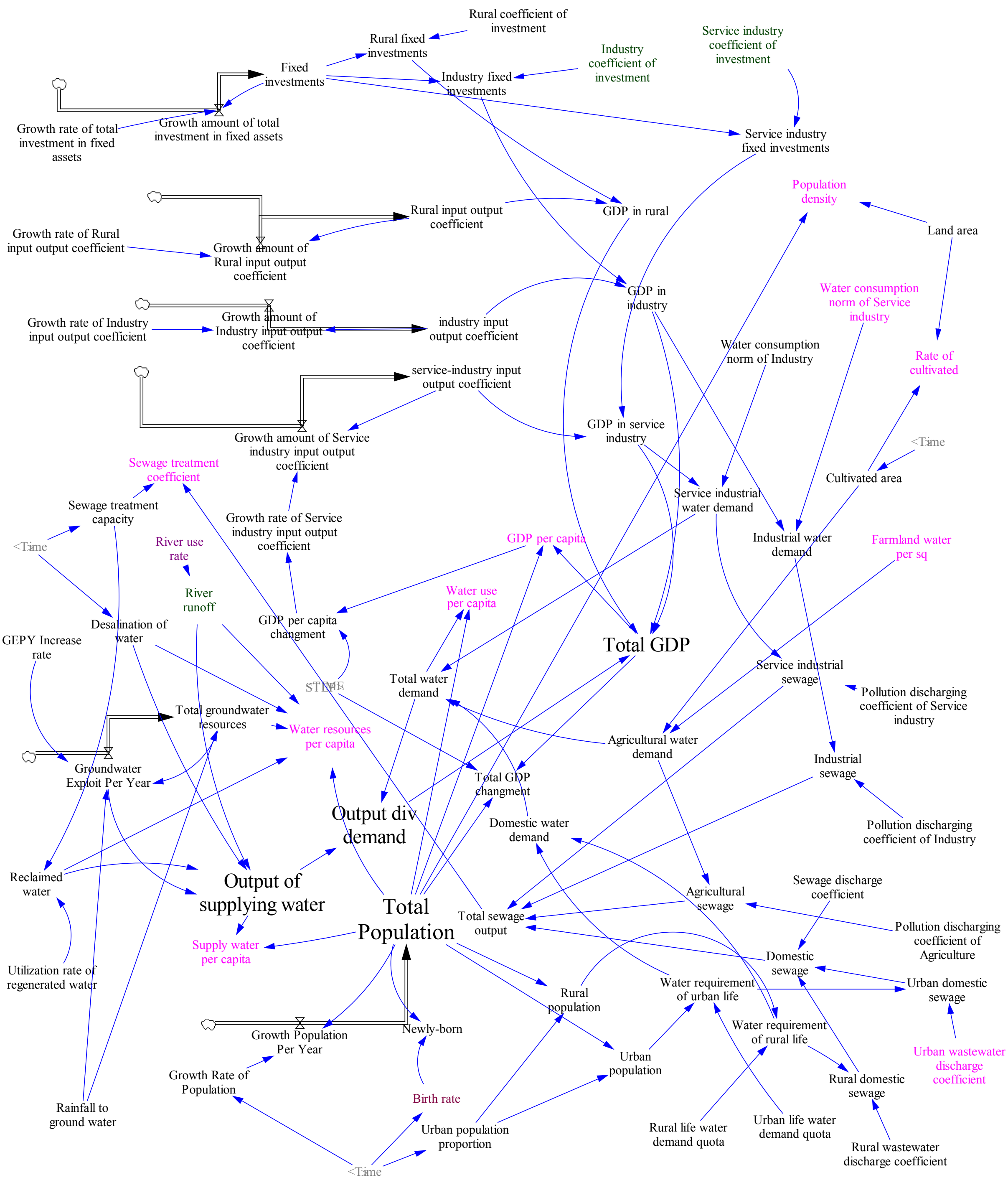

Figure 5: Water system with all the interaction between indicators

We can come to a conclusion that the system dynamics can simulate the behavior of the water supply and demand system. The output of the system dynamics is reliable.

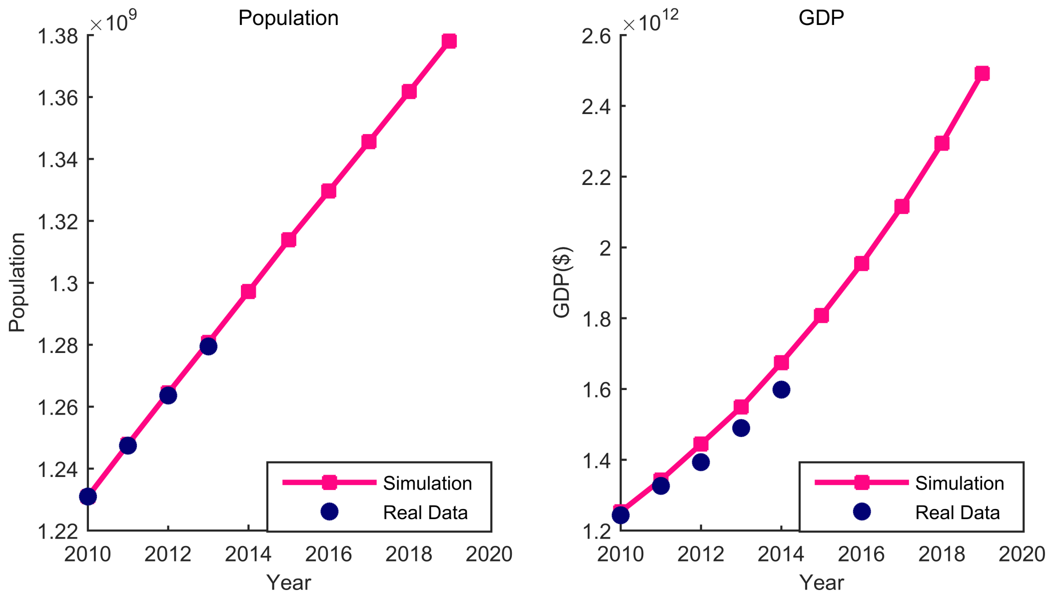

Figure 6: The interaction between water subsystem and other three subsystem

6.5.2 Sensitivity analysis

Since some parameters is difficult to assess, the value of the parameters may not be accurate Thus, we should test the sensitivity of the parameters to see if the system has strong robustness.

To test the sensitivity of parameters, we select 9 variables from water demand and supply system. Increase the value of each parameters by 10% and see the average effect on the variables. The formula to calculate sensitivity is listed below:

$$S_Q = \left| \frac{\Delta Q(t)}{Q(t)} \cdot \frac{P(t)}{\Delta P(t)} \right|, \tag{5}$$

where $Q(t)$ is the value of the variable in time t, and $P(t)$ is the value of the parament in time t, S_Q is the sensitivity of parament P, $\Delta Q(t)$ is the increment of Q during time t, and $\Delta P(t)$ is the increment of P during time t.

For all the variables, the average sensibility of P to Q is:

$$S = \frac{1}{n} \sum_{i=1}^{n} S_{Q_i}, \tag{6}$$

The result of average sensitivity of the parameter P for six variables is shown in the Figure 7.

By observing the Figure, we can see that by increase 10% of the parameter, the change of all variable is less than 20%. Two variables change more than 10% and the other change less than 10%. Thus, we can say that the variables is not sensitive to the parameters and our model have good robustness.

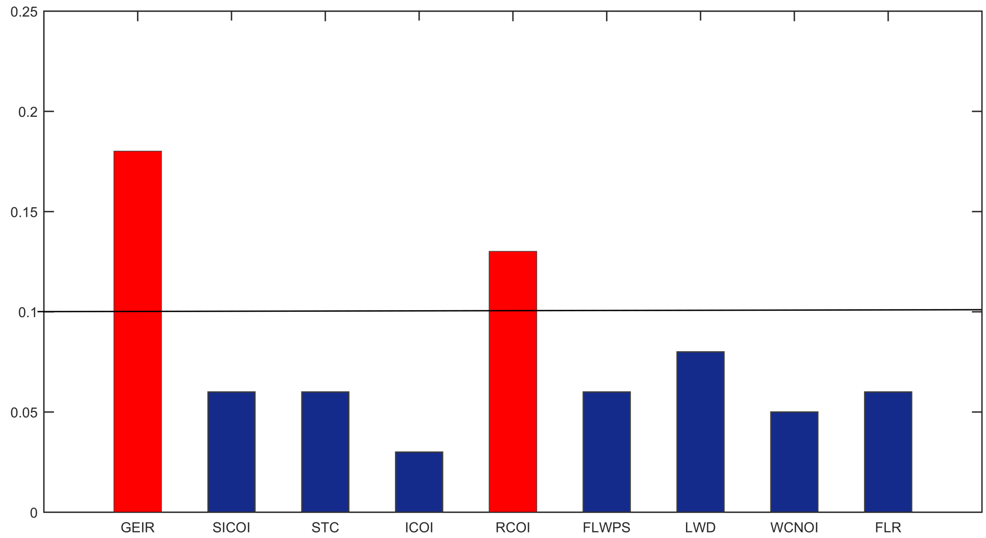

Figure 7: The average sensibility of variables

where GEUW is the growth of exploited underground water per, WPI is water productivity in industry, PISI is the proportion of investment in service industry, PF is the proportion of farmland, STR is sewage treated rate, DWR is the demand of water for residents, PII is the proportion of investment in industry, PIA is the proportion of investment in agriculture

6.6 System Dynamics to Simulate the Water Situation in India in 15 Years

In this part, we will use the model in task one to evaluate the water scarcity in India. The system dynamics will simulate the water situation in India in 15 years and all value of the indicators can be output from the system. The tendency of supply and demand of water is shown in the Figure 8

By observing the tendency of broken line in Figure 8, we can see the demand of water will increase in the following 15 years. The supply of water gradually increase from 2010 to 2020, experiencing a a sudden drop in 2021, and goes down until 2030. Because the supply of water decrease since 2021, the demand of water cannot be satisfy. Thus, the water problem would be very serious after 2021 in India. India government must take measure to solve the water crises.

Applying the model in task one to evaluate the water scarcity in 15 years. We get the tendency of water scarcity in 15 years. It is show in the Figure 9

By observing the Figure 9, we can see the the evaluation of water scarcity lays between grade B and C and gradually approach to grade C indicating that water scarcity will be more serious.

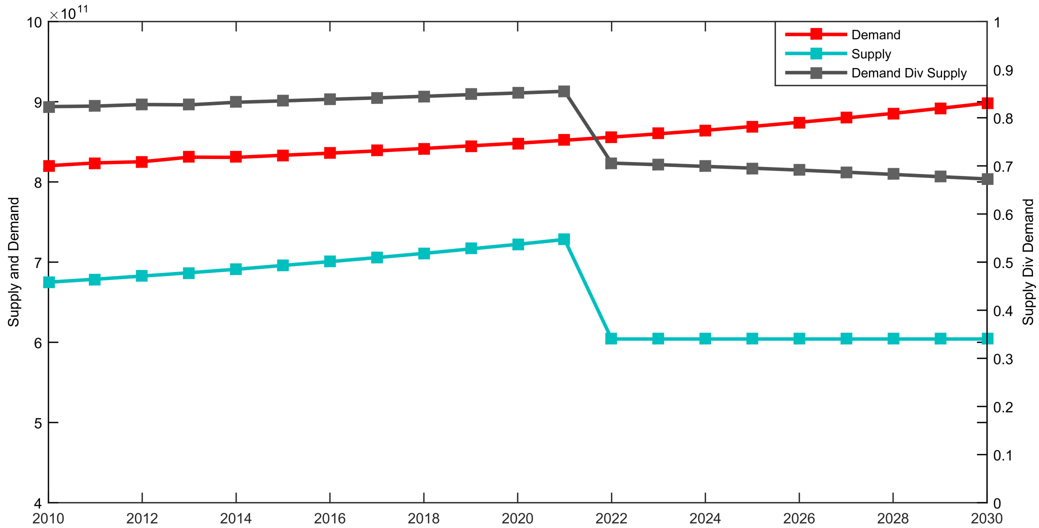

Figure 8: The average sensibility of variables

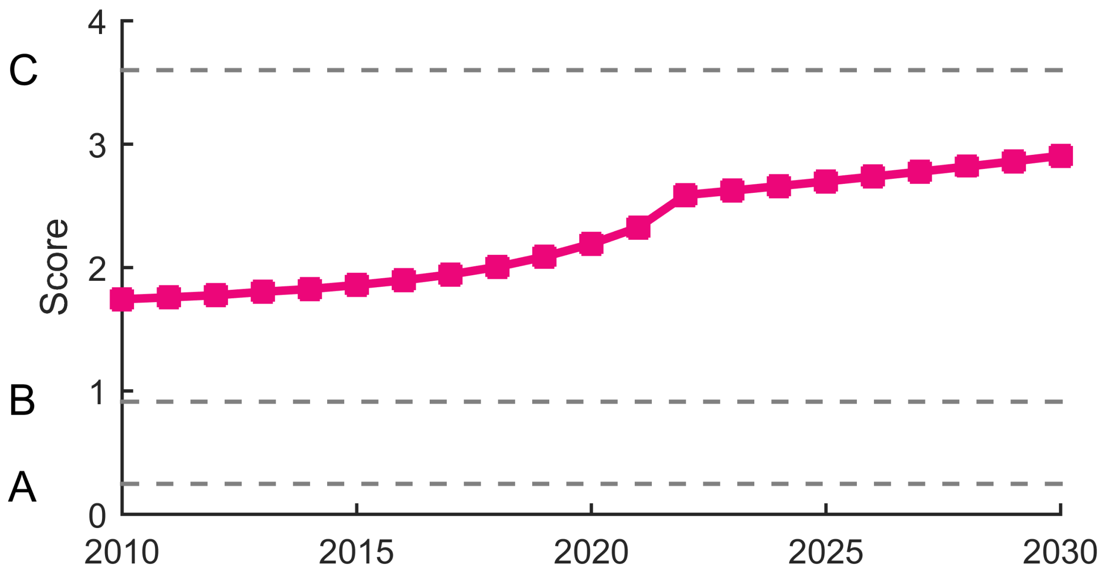

Figure 9: The average sensibility of variables

6.7 Strength and weakness

- The system dynamics model take full account of the interaction between indicators and subsystem. And the behavior of the water system and be simulate by the system dynamics model. Moreover, we can use system dynamics to capture the feature of water system and output the value of indicators. And use the model in task one to evaluate the water scarcity in a country.
- The supply and demand system is complex, however, we have a convenient software call Vensim to run the system and output the indicators.
- However, the value of some parameters are difficult to calculate or collect. And the system dynamics cannot used in optimization.

7 A Intervention plan for India

According to the result of task three, we can see that without intervention, water crisis will happen in 2022 in India. Therefore, we should come up with a intervention plan to prevent the crisis. Here we come up with four possible plans to intervene the water supply and use in India.

7.1 Plan one: Pumping more underground water

Underground water is one of the most essential water resource is India, accounts for about 33% of water supply. About 70% of irrigation land use underground water to grow crops, and water pumped from deep water well for irrigation is twice the amount of surface water. Thus, pumping more underground water may solve water scarcity.

To see the how underground water solve the demand of water in India, we use cellular automaton to simulate the influence of the groundwater supply. A cellular automaton consists of a regular grid of cells, each in one of a finite number of states, such as on and off[?]. According to the four classification of water scarcity, we define four states for each cell as 1,2,3,4 to simulate the water situation of a region. The grid can be in any finite numbers of dimensions. Thus, we used a square region and divide the region into grid according to the classification of water scarcity. An initial state is selected by assigning a state for each cell. We choose a initial time and use the initial classification as the initial state of of grid. The relationship between grids is not independent. If one grid in the region has water scarcity, and the grids around has less water scarcity, then there will be water transportation between them. There will be water redistribution in the grid and the grids around it. A new generation is created according to the a some fixed rule. The rule is listed below.

- Sum the 8 nearest neighbors of each cell (cells are four valued, 1/2/3/4)
- If the $sum < 16$ then the $state = state - 1$
- If the $sum > 24$ then the $state = state + 1$

- Otherwise the $state = state$

To see the effect by exploiting more underground water, we compare it with the normal situation without intervention on exploit underground water. The simulation of water consumption is shown in the Figure.10

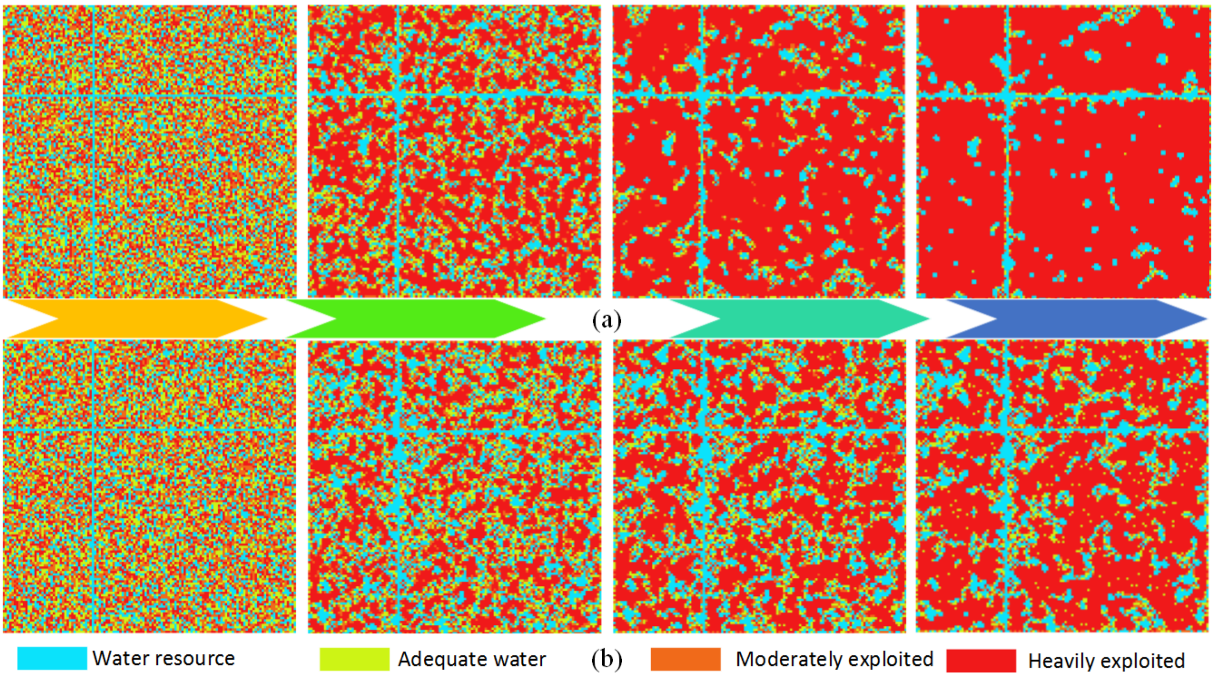

Figure 10: The average sensibility of variables

By simulating the water supply, we see that the water resource in this region will decrease and the water will be run out most grids. This indicates that many places will suffer from water crisis.

When increase underground withdrawal, the situation will be better. And less grids in the region suffer water scarcity.

By comparing the two situations in fig10, we come to a conclusion that the exploit underground water can alleviate water crisis. However, excessive exploitation of underground water will cause many problem.

- The underground water level decrease $0.5m$ per year. This is because water supplied by rain is far less than the water exploited by people.
- With the water level decreasing every year, the depth of well is becoming deeper and deeper, which makes the cost of exploitation higher.
- Geological disaster will be more common because the underground structure is changed. Besides, excessive underground water withdraw will cause soil salinization.

Thus, pumping more groundwater is unsustainable which will limit the demand of the coming generation. Thus, we should search for other plan to solve water scarcity.

7.2 Plan Two: A sustainable plan to solve water scarcity

Water problem should be solved in a long term without sacrificing the benefit of the coming generation. By analyzing the system dynamics model in task three, we get some parameters that are changeable by policy or activity of people. Some parameters maybe more sensitive than the other parameters. Thus, by making policy to change the value of this parameters, we can change water situation of the country. We choose the parameters whose sensitivity is more than 5%. Our plan is made based on the policy to change these parameters.

According to the sensitivity analysis in 6.5.2, we choose six parameters to improve water situation in India, including Water consumption per unit of cultivated land, water consumption for GDP growth in industry, living water, sewage treated rate, fix investment growth rate on industry, the decrease rate of cultivated land. We come up with five plans to solve water scarcity.

- The first scheme is to maintain the present development. This scheme is made to compare the influence of other scheme.
- The second scheme is to save water in cultivation, industry and residents. In this scheme, we will decrease the water used in industry and agriculture gradually until 50% of the initial value.
- The third scheme is to deal with the sewage. We will increase the investment on sewage treatment and promote the technology in sewage treatment.Besides, we will emphasize the importance of environment protection.
- The fourth scheme is to change the industrial structure in India. The water consumed in agriculture is the ten times as water consumed in industry. The service industry is booming in India, and we would like to promote the proportion of service industry to more than 40%.
- The fifth scheme is to combine the measure in scheme1,2,3,4, and to see that water situation will be.

More detail about the value of parameters in every scheme is listed in the Table 4.

Table 4: The values of parameters in four schemes

Adjust parameter	Normal	Save water	Sewage treatment	Industrial structure	Synthesis
Water consumption per unit of cultivated land(m^3/km^2)	438100	216100	438100	438100	216100
Water consumption for GDP growth in industry($m^3/\$$)	0.003	0.0016	0.003	0.003	0.0016
Living water(m^3)	79.6	40.3	79.6	79.6	40.3
Sewage treated rate (%)	30	30	50	30	50
Growth rate of fix investment on industry (%)	63.1	63.1	63.1	75	75
Decrease rate of cultivated land (%)	49	49	49	40	40

When changing the value of intervening parameters, we could get some output from the water demand and supply system. By evaluating the water scarcity of India after implementing the schemes, we can choose one of the best scheme and apply it to reality. The tendency of water scarcity is shown in the Figure 11.

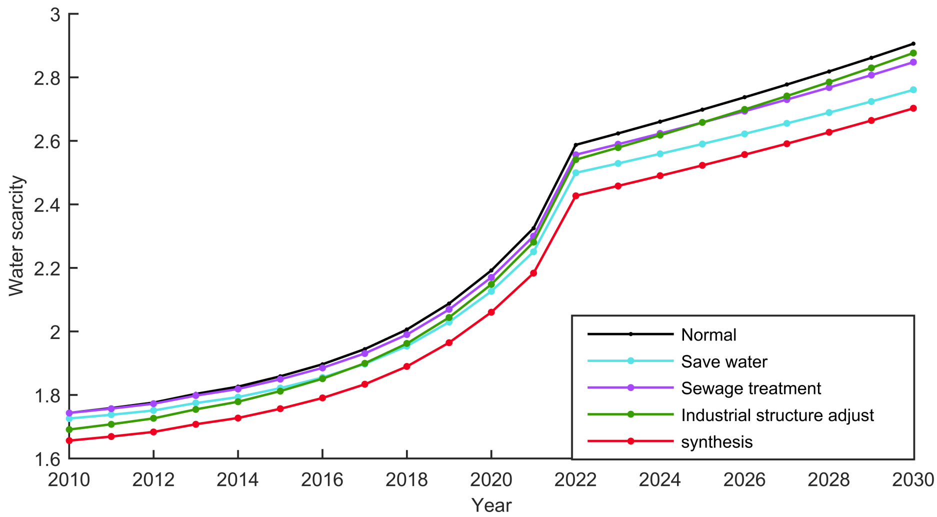

Figure 11: The Influence of Different Schemes

And supply rate of water demand is shown in the Figure 12.

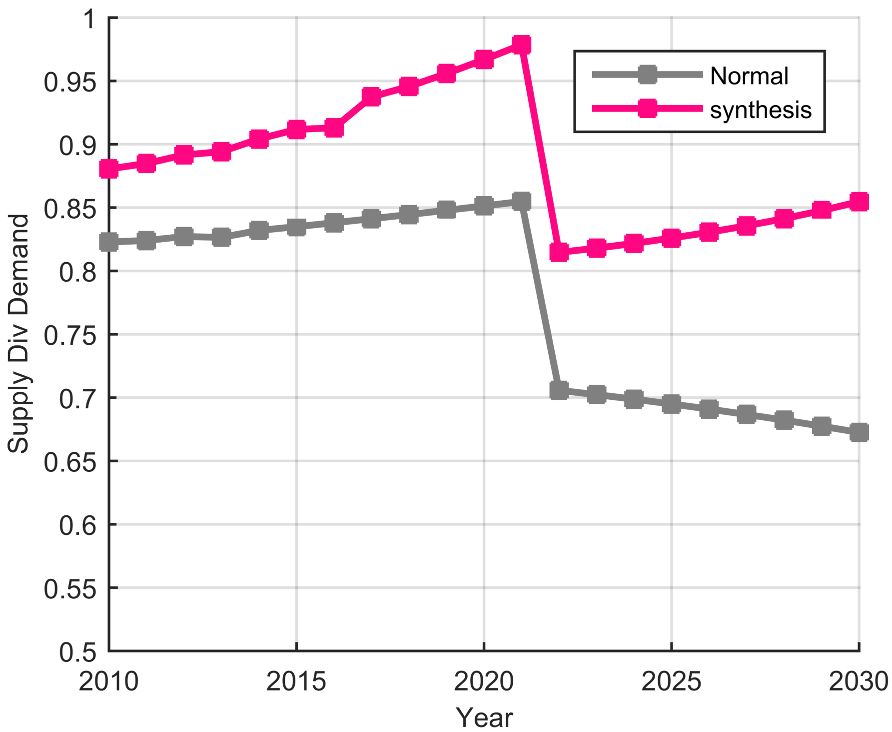

Figure 12: Supply and demand ratio

By observing the graph, we can see that the water scarcity is being improved after five schemes. And the most effective scheme is the synthesis scheme, that is to come the measure in other schemes, including save water, increase investment on sewage treatment, improve industry structure.etc. Thus, we come up with a sustainable plan to improve water situation in India. We should save water, develop sewage treatment, improve industrial structure to satisfy the demand of water in the future.

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Appendix

Variable Equation:

(01) Agricultural sewage=Agricultural water demand*Pollution discharging coefficient of Agriculture

(02) Agricultural water demand=Cultivated area*Farmland water per sq

(03) Birth rate = WITH LOOKUP (Time,([(2009,0)-(2020,0.02)],(2010,0.02159),(2011,0.021116),(2012,0.021116),(2013,0.020291),(2014,0.02),(2030,0.02)))

(04) Cultivated area = WITH LOOKUP (Time,([(0,0)-(4000,2e+006)],(2010,1.57006e+006),(2011,1.56979e+006),(2012,1.56546e+006),(2013,1.57e+006),(2014,1.56069e+006),(2030,1.50547e+006)))

(05) Desalination of water = WITH LOOKUP (Time,([(0,0)-(4000,4e+008)],(2010,2e+008),(2015,2.8e+008),(2030,3.7e+008)))

(06) Domestic sewage=(Rural domestic sewage+Urban domestic sewage)*Sewage discharge coefficient

(07) Domestic water demand=Water requirement of rural life+Water requirement of urban life

(08) Farmland water per sq=4381*100

(09) FINAL TIME = 2030
Units: Year
The final time for the simulation.

(10) Fixed investments= INTEG (Growth amount of total investment in fixed assets, 0.36786*1.24367e+012)

(11) GDP in industry=Industry fixed investments*industry input output coefficient

(12) GDP in rural=Rural fixed investments*Rural input output coefficient

(13) GDP in service industry=Service industry fixed investments*"service-industry input output coefficient"

(14) GDP per capita=Total GDP/Total Population

(15) GDP per capita changment=GDP per capita/DELAY1(GDP per capita , TIME STEP)

(16) GEPY Increase rate=0.05

(17) Groundwater Exploit Per Year= INTEG (IF THEN ELSE(Total groundwater resources > Groundwater Exploit Per Year*(1+GEPY Increase rate), Groundwater Exploit Per Year*GEPY Increase rate , -Groundwater Exploit Per Year+Rainfall to ground water),7.5e+010)

(18) Growth amount of Industry input output coefficient=Growth rate of Industry input output coefficient*industry input output coefficient

(19) Growth amount of Rural input output coefficient=Growth rate of Rural input output coefficient*Rural input output coefficient

(20) Growth amount of Service industry input output coefficient=Growth rate of Service industry input output coefficient*"service-industry input output coefficient"

(21) Growth amount of total investment in fixed assets=Fixed investments*Growth rate of total investment in fixed assets

(22) Growth Population Per Year=Growth Rate of Population*Total Population

(23) Growth rate of Industry input output coefficient=0.003

(24) Growth Rate of Population = WITH LOOKUP (Time,([(0,0)-(2020,0.014)],(2010,0.01374), (2011,0.01328),(2012,0.01286),(2013,0.01286),(2014,0.01286),(2015,0.012),(2030,0.012)))

(25) Growth rate of Rural input output coefficient=0.03

(26) Growth rate of Service industry input output coefficient=0.075*GDP per capita changment

(27) Growth rate of total investment in fixed assets=0.05

(28) Industrial sewage=Industrial water demand*Pollution discharging coefficient of Industry

(29) Industrial water demand=GDP in industry*Water consumption norm of Service industry

(30) Industry coefficient of investment=0.621

(31) Industry fixed investments=Fixed investments*Industry coefficient of investment

(32) industry input output coefficient= INTEG (Growth amount of Industry input output coefficient,2.38)

(33) INITIAL TIME = 2010
Units: Year
The initial time for the simulation.

(34) Land area=3.20145e+006

(35) "Newly-born"=Birth rate*Total Population

(36) Output div demand=Output of supplying water/Total water demand

(37) Output of supplying water=Desalination of water+Reclaimed water+River runoff +Groundwater Exploit Per Year

(38) Pollution discharging coefficient of Agriculture=0

(39) Pollution discharging coefficient of Industry=0.001

(40) Pollution discharging coefficient of Service industry=0.005

(41) Population density=Total Population/Land area

(42) Rainfall to ground water=4e+009

(43) Rate of cultivated=Cultivated area/Land area

(44) Reclaimed water=Sewage treatment capacity*Utilization rate of regenerated water

(45) River runoff=1.86973e+012*River use rate

(46) River use rate=0.2467*1.3

(47) Rural coefficient of investment=0.057

(48) Rural domestic sewage=Rural wastewater discharge coefficient*Water requirement of rural life

(49) Rural fixed investments=Fixed investments*Rural coefficient of investment

(50) Rural input output coefficient= INTEG (Growth amount of Rural input output coefficient,1.1)

(51) Rural life water demand quota=64.605

(52) Rural population=Total Population*(1-Urban population proportion)

(53) Rural wastewater discharge coefficient=0.0003

(54) SAVEPER =TIME STEP
Units: Year [0,?]
The frequency with which output is stored.

(55) Service industrial sewage=Pollution discharging coefficient of Service industry*Service industrial water demand

(56) Service industrial water demand=GDP in service industry*Water consumption norm of Industry

(57) Service industry coefficient of investment=0.231

(58) Service industry fixed investments=Fixed investments*Service industry coefficient of investment

(59) "service-industry input output coefficient"= INTEG (Growth amount of Service industry input output coefficient,3)

(60) Sewage discharge coefficient=0.15

(61) Sewage treatment capacity = WITH LOOKUP (Time,([(0,0)-(4000,200000)], (2009,1.9828e+007),(2050,1.2e+008)))

(62) Sewage treatment coefficient=Sewage treatment capacity/Total sewage output

(63) Supply water per capita=Output of supplying water/Total Population

(64) TIME STEP = 1
Units: Year [0,?]
The time step for the simulation.

(65) Total GDP=(GDP in industry+GDP in rural+GDP in service industry)*Output div demand

(66) Total GDP changment=((Total GDP/Total Population)/DELAY1(Total GDP/Total Population,TIME STEP))/TIME STEP

(67) Total groundwater resources= INTEG (Rainfall to ground water-Groundwater Exploit Per Year,1.1e+012)

(68) Total Population= INTEG (Growth Population Per Year,1.23098e+009)

(69) Total sewage output=Agricultural sewage+Domestic sewage+Service industrial sewage
+Industrial sewage

(70) Total water demand=Agricultural water demand+Industrial water demand+Service industrial water demand+Domestic water demand

(71) Urban domestic sewage=Urban wastewater discharge coefficient*Water requirement of urban life

(72) Urban life water demand quota=110.96

(73) Urban population=Total Population*Urban population proportion

(74) Urban population proportion = WITH LOOKUP (Time,([(0,0)-(4000,10)],(2010,0.3093), (2011,0.31276),(2012,0.31631),(2013,0.31994),(2014,0.32366),(2030,0.4)))

(75) Urban wastewater discharge coefficient=0.005

(76) Utilization rate of regenerated water=0.5

(77) Water consumption norm of Industry=0.003

(78) Water consumption norm of Service industry=505.424/10000

(79) Water requirement of rural life=Rural population*Rural life water demand quota

(80) Water requirement of urban life=Urban life water demand quota*Urban population

(81) Water resources per capita=(Desalination of water+Reclaimed water+River runoff/0.6+Total groundwater resources)/Total Population

(82) Water use per capita=Total water demand/Total Population