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One thirsty world -- Analysis of the water resources

Junli Zhang[1,2,*], Qian Cheng[2] and Yan Wang[1,2]

[1] Xi'an Eurasia University, Xi'an, China
[2] Xi'an Jiao Tong University, Xi'an, China

* Corresponding author e-mail: 24200926@qq.com

Abstract. The living environment of human beings worsens, particularly the water scarcity is becoming more serious. It heavily affects the development of the nation and the survival of human beings. Firstly, this paper analysed the problem and developed a model that a region has the ability to provide clean water for its population, then predicted the future water resources and offered some measures to solve the problem. Firstly, we designed 5 influential principle indexes for water source and identified the controllable factors, then analysed the relationship between the various indexes. After that we developed the dynamic model to measure the water utilization rate and annual per ca-pita the surplus amount of water. First, analysed the pressure of world`s water resources and selected India where water is heavily overloaded as the chosen country for the aim of research. Second, it analysed the reasons of water scarcity from the aspects of physical scarcity and physical scarcity. First of all, according to the development of environmental factors of India, we built the prediction model of population and GDP, then applied the models of water utilization rate and annual per capita the surplus amount of water to predict the situation of water resources in the next 15 years in India. In the next 15 years, water scarcity worsens gradually and the increasing rate of water utilization comes up and annual per capita availability of water falls, which dramatically affects the stability of economy, society and environment in India. Firstly, we developed the policy intervention model, then set up multi-objective model based on the minimum of water utilization and the maximum of annual per capita the surplus amount of water, predicted the two situations that applied the intervention or not.

1. Introduction

According to figures released by the United Nations, global water use increased six times in the 20th century, the growth rate is twice the population growth. The United Nations educational, scientific and cultural organization says that the fresh water resources are totally adequate [1]. But about 1/5 of the world population has no access to the safe drinking water and 40% of people lack basic sanitation because of the uneven distribution and poor management and environmental changes and inadequate infrastructure, etc [2]. At present, there is already a shortage of fresh water in the Middle East, Africa, central Asia and parts of Latin America. The crisis of water scarcity has aroused world-wide attention and becomes a problem beyond politics and boundaries [3-5].

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2. The design and calculate of the basic index

2.1. The calculation of capitation water consumption per year
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$$d_{t1} = \alpha_{t1}\omega P_t + \alpha_{t2}(1-\omega)P_t \tag{1}$$

α_{t1} stands for urban annual domestic water consumption per person in this area, α_{t2} stands for rural annual domestic water consumption per person in this area, ω stands for the proportion of urban population, P_t stands for gross population, t stands for time variable.

2.2. The calculation of annual irrigation water consumption
The irrigation of water includes the water for crop growth, water losses in irrigation canal systems and field. Irrigation water consumption can be calculated by the following formula.

$$d_{t2} = \beta_t F_t \tag{2}$$

β_t stands for irrigation water consumption per hectare in this area, F_t stands for the amount of arable land in this area (unit: hectare), and t stands for time variable.

2.3. The calculation of annual industrial water consumption
Industrial water consumption refers to the direct and indirect water consumption during the industrial production, and includes water quantity, water quality and temperature [7]. The main applications are as follows: water as the raw material, directed used as raw materials or as a part of the raw materials; water for product processing; water for boiler and cooling. Industrial water consumption can be calculated by the following formula.

$$d_{t3} = \varepsilon_t G_t \tag{3}$$

ε_t stands for industrial water consumption per trillion Yuan of GDP, G_t stands for the total GDP (trillion Yuan) of this area, t stands for time variable. Industrial GDP is relevant stable in the whole GDP, and it doesn't produce variability except the financial crisis. So, it is very reasonable to use annual industrial GDP value to measure annual industrial water consumption.

2.4. The calculation of evaporation per year
Evaporation refers to in a certain period of time, the amount of water evaporated and scattered into the air. In general, the temperature is higher, the humidity is lower, the wind speed is faster, the air pressure is lower, and the evaporation is larger; whereas the evaporation is smaller. Areas having low rainfall, ground water resource and stream flow will suffer drought if there is a larger evaporation. The following formula will be the evaporation.

$$d_{t4} = E_t \tag{4}$$

E_t stands for annual evaporation in the area.

2.5. *The calculation of the water reused*

As a kind of renewable resources, water itself can circulate. In the moment of demand exceeding supply on account of serious pollution, it is an important to reuse the polluted water. More and more countries set up city's wastewater treatment plant and rainwater collecting facilities. Therefore, we can calculate the water can be reused by the following formula.

$$L_t = \sum_{i=1}^{3} \phi_{ti} d_{ti} \tag{5}$$

ϕ_{ti} stands for the treatment rate of domestic sewage of d_{ti}.

3. Model Construction

3.1. *Mathematical Model of Water Resource Utilization Rate*

Through the construction of above basic index, we can develop the mathematical model of the water resource utilization rate of this nation.

$$\eta_{\mathrm{t}} = \frac{Q_t}{M_t} \tag{6}$$

Q_t represents the total water consumption of the tth year, which removes the water consumption of repeating used from the total consumption of water for domestic use, water for irrigation, and water for industrial use, namely.

$$Q_{\mathrm{t}} = \sum_{i=1}^{4} d_{ti} - L_t \tag{7}$$

M_{t} represents the total available quantity of fresh water, which consist of the total annual runoff and technical collection for water resource, but eliminate the polluted water, namely.

$$M_{\mathrm{t}} = H_t + S_t - X_t \tag{8}$$

H_t is the average of the total annual runoff for the past 3 years, S_t represents indirect water resource collected by technical methods (e.g. seawater desalting and rainwater harvesting), X_t represents the unavailable water resource due to environmental issues and represents the time variable.

$$H_t = \frac{1}{3} \sum_{i=i-4}^{t-1} H_i \tag{9}$$

$$S_t = \mu_{1t} O_t + \mu_{2t} N_t \tag{10}$$

O_t is available water quantity for years, N_t is total annual precipitation, μ_{1t} is the desalination rate, μ_{2t} is the rainwater collection rate.

X_t can be calculated by the following calculation procedure

$$X_t = \sum_{i=1}^{3}(1-\phi_{\mathrm{it}})d_{it} \tag{11}$$

Having substituted the data into the mathematical model of water resource utilization rate [1], we can achieve the water resource utilization rate of the year. According to the index of the abundance degree of world water resource, when the resulting value is lower than 0.15, it means the area obtains rich water resource; when the resulting value falls between 0.15~0.25, it means the area has inadequate water resource; and when the resulting value is higher than 0.5, it means the area has water resource scarcity [2, 8].

3.2. Mathematical model of per capita amount of water resources surplus

The model of water resources utilization rate is not enough to indicate the surplus of water resources in that area, thus we need to establish a model of per capita amount of water resources surplus.

$$k_{\mathrm{t}} = \frac{(H_t + S_t - X_t) - (\sum_{i=1}^{4} d_{ti} - l_t)}{P_t} \tag{12}$$

k_{t} represents annual per capita amount of water resources surplus, meanwhile it is also the amount of untapped water resources.

3.3. Mathematical model of annual water consumption per capita

To measure the situation of water consumption per capita, we built up a model of it.

$$\mathrm{G_t} = \frac{\sum_{i=1}^{4} d_{ti} - l_t}{P_t} \tag{13}$$

4. The Prediction of the water resources in India in 15 years

The Prediction will be affected by GDP, the population, arable land, environmental changes, etc. The details are as follows.

4.1. The factor of population

Logistic model:

$$\begin{cases} \dfrac{dx}{dt} = rx(1 - \dfrac{x}{x_m}) \\ x(0) = x_0 \end{cases} \tag{14}$$

get: $$x(t)=\frac{x_m}{1+(\frac{x_m}{x_0}-1)e^{-rt}} \tag{15}$$

India's forecast results in 15 years are shown in table 8.

4.2. GDP Factor

For prediction of GDP, this paper collected India's GDP data in the last two decades and analyses the data and comes up with the fitting formula.

$$y=48.898x^2-68.243x+3588.2 \tag{16}$$

The analysis of the relevant factors through the literature review, the parameters are shown in Table 1.

Table 1. related parameters setting

Project	Data	Unit
Sewage treatment rate (ϕ_i)	0.39	%
Runoff per year (H_t)	19236	billion M³
Unused water resources (X_t)	7474	billion M³
Recycling water (S_t)	0	billion M³
water for life (α)	80	M³
β	3275	M³
ε	188.4	billion ton
P_t	1.267	billion people
F_t	1.6	billion hectares
G_t	2.07	billion dollars

Note: related data in India for 2010

In the assumption of the present increasing level of the science and technology and other factors (i.e. the increase of population and GDP and the increase of global warming and water contamination, etc.) and utilization of the water use rate model, the figures in India in the 15 years are shown in Figure 5.

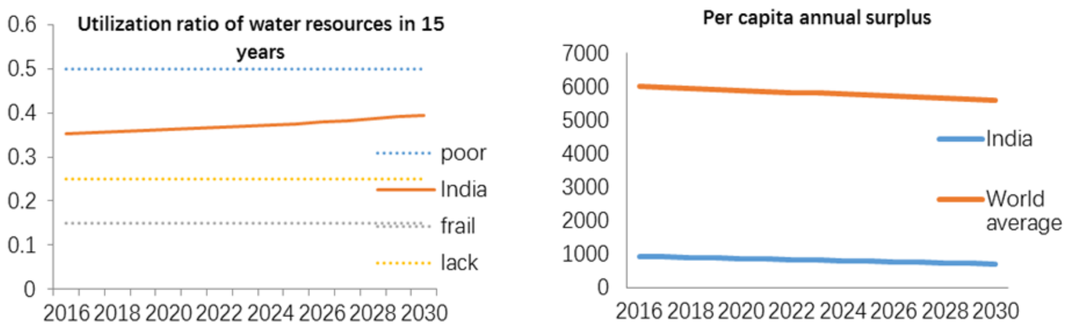

Figure 1. Utilization of water use rate in India in 15 years & Annual Per capita surplus amounts

Figure 1 shows it more obvious that the situation of water consumption rate changing. The growth of population and the development of industry exacerbate their impacts on environment, and in the next 15 years the water scarcity will be increasingly severe because the whole water resources consumption rate is on the rise. Substitute the model of annual per capita amount of water resources surplus, we can get the annual per capita amount of water resources surplus in the next 15 years.

5. The future of water resources in India

The reasons that are responsible for water scarcity in India are mainly uneven spatial and temporal distribution of water resources, large population (agricultural irrigation and industrial water use), low science and technology and the poor capacity of sewage treatment. We will deal with these reasons with Intervention Plan.

According to the solution in the question 4, the main impact factors are ε_t ,β, ϕ_{ti} , S_t , so we can set up intervention model as follows:

$$\begin{cases} \varepsilon_{\text{t}} = \lambda_{1t}\varepsilon_{\text{t-1}} \\ \beta_{\text{t}} = \lambda_{2t}\beta_{\text{t-1}} \\ \phi_{\text{it}} = \lambda_{3it}\phi_{\text{i,t-1}} \\ S_t = \lambda_{4t}S_{t-1} \end{cases} \tag{17}$$

Set up multi-objective mode based on the target of the least water resource utilization rate and the most annual water resource extra quantity per person.

$$\begin{aligned} &\max y_k = \sum_t k_t \\ &\min y_\eta = \sum_t \eta_t \\ &s.t. \begin{cases} 0 < \eta < 0.5 \\ k > 0 \end{cases} \end{aligned} \tag{18}$$

Solve the objective function, when annual rate of increase of ε_t is 5.0, annual rate of increase of β_t is 4.6%, annual rate of increase of ϕ_{ti} is 4.8 %and annual rate of increase of S_t is 15%, it will get the best result.

Then compare with results between after intervention and no intervention, as shown in Figure 2 and 3.

According to figure 2, it can be found that in this stage, India is lack of water resource. If there is no intervention, may be 20 years later, India will be in poor of water resources, and then it will present exponential deterioration. After intervention, beginning with the intervention, it will present recovery mode of the water resource, and it will reach the fragile in 10 years.

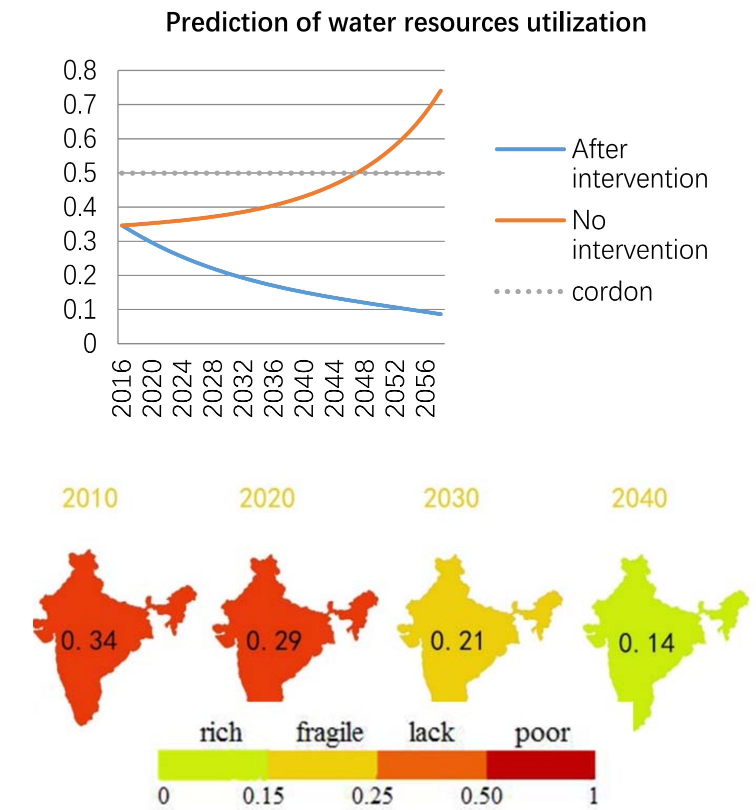

Figure 2. Prediction of water resources utilization

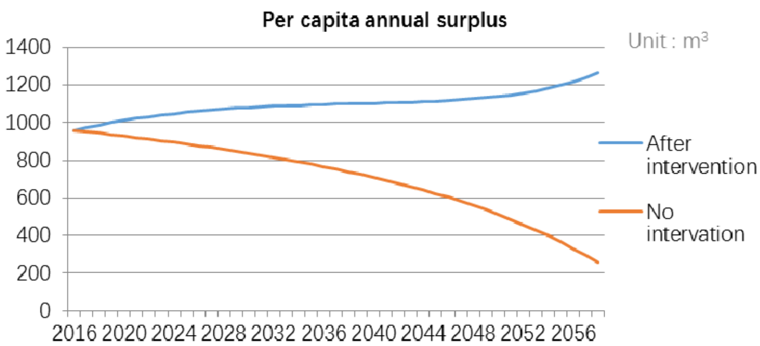

Figure 3. Per capita annual surplus

From the information illustrated in Figure 3, the application of intervention plan will lead to a result that the future water scarcity will not greatly affect India, and the per capita water resources in the amount of surplus will maintain a relatively stable level However, due to the large population base, the average per capita water resources will be lower than the world average level.

In the future, the water will become a crucial element, because the greenhouse effect will result in global warming and the temperature goes up, which Increase the amount of evaporation, by then, precipitation will be the only source of river recharge, and the spatial and temporal distribution of precipitation will directly affect the total amount of available water resources.

The establishment of this model is only based on the rational distribution of water resources and regulate and control it so as to achieve the purpose of alleviating water shortage problem.

That it is simple, universal, and easy to understand. The model excludes political interference and the dispute of interests in the country and it also can solve the problem of the uneven distribution of water resources, the low utilization rate of water resources and the low level of science and technology.

6. Conclusion

According to the data analysis, the water scarcity will still be serious in India in 15 years. The effects will be as follows if such model happens:

It still brings a severe threat to the sustainable development and social security in India. The water scarcity definitely affects the development of agriculture and does harm to the peasants' interests and restricts the development of manufacturing and slows down the urbanization. Intensifies the international disputes. In terms of cross-border rivers, India is down to Nepal and Bhutan and China. But it is up to Pakistan and Bangladesh. India has the potential disputes with the four countries of all except for Bhutan.

Deterioration of domestic water dispute. There is complicated, long-term and intense water dispute among states, within states, between upstream and downstream and between agriculture and industry. Chidambaram, the minister of Finance in India, even remarked that there are some civil wars among consumers of water for domestic, irrigating and industrial use.

Threaten of Public health. Drinking water problem is the biggest threat of India's public health, because 86% of India's diseases are directly related to the quality of drinking water. Sanitary conditions of groundwater that provide drinking water and domestic water for 90% of villagers are terrible. The ground water of 119 counties of 19 states contains much more arsenic than the standard. The arsenic groundwater has threatened 16 million people of eight counties in West Bengal. The groundwater in Bihar, Chhattisgarh and Uttar Pradesh also contains arsenic.

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