Water Resour Manage (2008) 22:621–633
DOI 10.1007/s11269-007-9182-z

A Risk Assessment Model of Water Shortage Based on Information Diffusion Technology and its Application in Analyzing Carrying Capacity of Water Resources

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Received: 19 September 2006 / Accepted: 16 April 2007 /
Published online: 2 June 2007

Abstract A risk assessment model for water shortage was constructed from the risk analysis method based on the information diffusion theory. The application of this model was demonstrated in the city of Jinhua in Zhejiang Province, China. The study indicates that the present model is more stable and effective when compared with the traditional model, based on analytical results from a small sample. The risk assessment result was used to analyze the carrying capacity of water resources from an ecological angle. The author advances that the carrying capacity of water resources should be defined as the maximum bearing capacity of water resources for human activity in certain stages of social development under the sound circle of the ecological system. Further study on Jinhua was also performed in the paper, and the result indicates that water shortage in this city is not of the relevant type of water source and can classified in terms of water quality type as well as water conservancy. In order to verify the result of the theoretical investigation in the present paper, the author also simulates the dynamic changing process of carrying capacity of water resources under the condition of enforcement of the future policy in the city. The simulation uses the model of system dynamics (SD), according to the historical data of the city over twenty years and the governmental standard for comprehensively building a comfortable society by 2020. The paper simultaneously indicates that the primary scheme of unilaterally pursuing the fast development of the economy at the expense of environment and the secondary scheme of taking environmental protection as the primary goal via slowing of development of the economy are undesirable for Jinhua. Furthermore, a scheme of simultaneously giving consideration to both economic development and environmental protection should be the preferred scheme. However, if the present amount of water supply is constantly maintained in the near future, the requirement for water supply will not be satisfied under the balanced considerations of economy and environment. The carrying capacity of water resources in this region can be effectively improved only under the

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situation of not only strengthening the investment in environmental protection but also increasing income and reducing expenditure year after year.

Keywords Water shortage · Information diffusion · Risk assessment · System dynamics · Carrying capacity of water resources · Guaranteed rate

1 Introduction

The carrying capacity of water resources is a concept with twin attributes involving nature and society. Obviously, this means the system is complex and large scale, involving numerous factors including population, resources, environment, ecology, society, economy, technology, etc. These factors interact as both cause and effect, restrict each other and act not only as a positive feedback but also as a negative feedback. Unquestionably, the answers to several important questions about the exact amount of population that can be supported by water resources, whether or not the sustainable development of social economy can be successfully achieved, and whether or not the sound circle of the ecological system can be smoothly realized, should wholly depend upon policy parameters such as economic measurement, development speed, strategic policy, and so on. The choice of policy parameters is a rather difficult problem, and the problem can be effectively solved through a mathematical method derived from system dynamics (abbreviated as SD).

Carrying capacity of water resources is the basic standard of measurement for water safety (Xia and Zhu 2002). Thus, it can be closely related with the phenomena of risk-bearing. However, the calculated result of system dynamics normally has nothing to do with the risk factor. Therefore, in the present paper, the risk factor for water shortage is designed to introduce the study on carrying capacity of water resources based on system dynamics. It is obvious that water shortage should be closely related to the sharp increase of water consumption from human activity, and that this phenomenon appears only from the beginning of the 1980s. Therefore, the data that can be used in the risk assessment for water shortage is rather limited. This makes the risk assessment for water shortage an issue under the small sample condition. One of the methods of dealing with this small sample issue regards is to regard the small sample as fuzzy information, and then optimally treat the information using information diffusion technology (Huang 1997; 2001). A result with a higher reliability for risk assessment can be achieved using this method (Huang 2002a).

2 Risk Assessment Model for Water Shortage

Information diffusion refers to transforming a traditional data sample point into a fuzzy set. The principle of information diffusion is an affirmation: when a knowledge sample is given, it can be used to compute a relationship. The result deduced directly from this sample is called “non-diffusion estimation.” When and only when this sample is incomplete, there must be an appropriate diffusion function and a corresponding arithmetic formula, which makes the diffusion estimation closer to the real relationship than the non-diffusion estimation. As the purpose of information diffusion is to search for useful information and enhance the identification precision of the system, technology of this kind is thus called Fuzzy Information Optimization Processing Technology (Huang 2002b).

Information diffusion is a processing method of abstract mathematics that can deal with the sample using a set numerical method (Huang 2000; 2002a). A single-valued sample can be transformed into a set numerical-valued sample through this technology. The simplest model is the normal diffusion model. If the index field of water shortage can be represented as $U = \{u_1, u_2, ..., u_m\}$, then the information carried by a single-valued observation sample of x_i can be diffused into each point in the field U according to the following equation:

$$f_i(u_j) = \frac{1}{h\sqrt{2\pi}} e^{-\frac{(x_i-u_j)^2}{2h^2}}, j = 1, 2, ..., m \tag{1}$$

Where h is the diffusion coefficient, which can be determined according to the maximum and minimum values of the samples and the sample number in the set (Huang 1997; 2001; Chatman 1986). If we let:

$$C_i = \sum_{j=1}^{m} f_i(u_j) \tag{2}$$

Then the related attaching function of the fuzzy subset can be represented as follows:

$$\mu_{x_i}(u_j) = f_i(u_j)/C_i \tag{3}$$

The function of $\mu_{x_i}(u_j)$ can be called the normalized information distribution of sample x_i.

A good result for risk analysis can be obtained through treatment of the function of $\mu_{x_i}(u_j)$. If we let $x_1, x_2, ..., x_n$ to be the n specified observation values, then the function can be called the information quantum diffused from the sample of $X = \{x_1, x_2, ..., x_n\}$ to the observation point of μ_j. This can be represented as follows:

$$q(u_j) = \sum_{i=1}^{n} \mu_{x_i}(u_j) \tag{4}$$

The physical meaning of the above function is that if the observation value of water shortage can only be chosen as one of the values in the series of $u_1, u_2, ..., u_m$ then the sample number with the observation value of u_j can be determined to be $q(u_j)$ through the information diffusion from the observation set of $x_1, x_2, ..., x_n$, in regards to all values of x_i as the representatives of the samples. It is obvious that the value of $q(u_j)$ is generally not a positive integer, but it is sure to be a number no less than zero. Furthermore, let:

$$Q = \sum_{j=1}^{m} q(u_j) \tag{5}$$

In fact, Q should be the summation of the sample number on each point of u_j. It is easy to know that the function should be the frequency value of the sample appeared on the point of u_j, and the value can be taken as the estimated value of the probability. This can be represented as follows:

$$p(u_j) = q(u_j)/Q \tag{6}$$

It is also obvious that the probability value transcending of u_j should be as follows:

$$p(u \geq u_j) = \sum_{k=j}^{m} p(u_k) \tag{7}$$

The value of $p(u \geq u_j)$ should be the required value for the risk assessment.

3 Analysis for Carrying Capacity of Water Resources

The term "Carrying Capacity," which originally came from dynamics and was later used in bionomics, refers to "the maximum amount of biological individuals viable under certain environmental circumstances." As early as 1921, Park and Burgess used the term in population research for the first time. With the intensifying contradiction between social development and shortage of resources, UNESCO put forward the concept of "Carrying Capacity of Resources" in the early 1980s. The Xinjiang Soft Science Research Group for Water Resources (1989) in China first advanced a new concept of carrying capacity of water resources. However, an explicit definition of this concept has generally not been acknowledged at home and abroad up until now. Some believe that carrying capacity of water resources means the ability to continually support a sound social system (Hunter 1998; Ofoezie 2002), whilst others considered the concept as a threshold value for the ability to support human activity (Harris and Kennedy 1999; Li et al. 2000).

Although water resources are limited, the exact amount of water resources that can be supplied by the environment is still unknown for the present investigation (Clarke 2002; Beuhler 2003). In fact, water resources that can be supplied by any water body including rivers, lakes and groundwater have a threshold value. If this limitation is rashly broken, a vicious circle will appear in the ecological system (Falkenmark and Lundqvist 1998). Therefore, the author advances that carrying capacity of water resources should be defined as the maximum bearing capacity of water resources for human activity in certain stages of social development under the condition of the sound circle of the ecological system.

Carrying capacity of water resources can be calculated according to the following equation derived from system dynamics (Motohashi and Nishi 1991):

$$BW(K) = BW(J) + DT \times BWR(JK) \tag{8}$$

Where: BW represents the bearable volume of water use, and J, K and JK denote the preceding time, current time and adjacent time intervals, respectively. DT means the step length of simulation; BWR represents the rate of change of bearing volume of water use, which includes the increased amount of water owing to the newly built retaining works and the improvement of reproduction availability. Total carrying capacity of water resources (also means total bearing volume of water use) for one region can be represented as BW_T, in which the subscript symbol of T is the leading character of "Total." BW_T can be divided into three parts as the bearing volume of water use for agriculture (BW_A), the bearing volume of water use for industry (BW_I) and the bearing volume of water use for human and domestic animals (BW_{PS}), which can be represented as follows:

$$BW_T = BW_A + BW_I + BW_{PS} \tag{9}$$

It is obvious that the relative reliability of the rate of change of bearing volume of water use (BWR) should be the key factor for calculating the carrying capacity of water resources. However, BWR also has non-determinacy to some extent, owing to the non-determinacy of future water shortages. In order to simplify the analysis, we assume that the non-determinacy of water shortage can only be related with the non-determinacy of natural precipitation. Therefore, estimation of the probability distribution of the annual precipitation in the studied region becomes a kernel for the risk assessment of water shortage. At present we also assume that the natural precipitation in the studied time interval should be a stationary Markov process. From this the probability distribution in the studied time interval can be regarded as unchanged.

The annual precipitation can be notated as x and the risk for water shortage can be represented using the probability distribution of $p(x)$. Thus, we can estimate the discrete expression of $p(u_j)$ for $p(x)$ using the normal diffusion model under the small sample condition (as seen in Eq. 6). The expected value for this distribution is also the average risk value for water shortage and can be represented as follows:

$$\mu = \frac{1}{m}\sum_{j=1}^{m} \mu_j p(u_j) \tag{10}$$

The rate of change of bearing volume of water use (*BWR*) is solely composed of μ described above, and other water sources. Under the assumption of the stationary state of the Markov process, μ is unchanged in the studied time interval, and therefore *BWR* only shows the variations of other water sources. In other words, only with the consideration of the uncertainty of other water sources can the risk of water shortage be fully assessed. Unfortunately, there are too many non-determinacy factors in the social system, and these are not considered in the present paper.

4 Case Analysis

In this section, Jinhua is chosen as an example to introduce the detailed usage of the related model.

4.1 Risk Assessment for Water Shortage in Jinhua

Jinhua is located in the middle of Zhejiang Province. The total area of the city is 10,918 km^2 and the total population of the city is 4.492 million. The city has a mid-subtropical monsoon climate with a combination of rain and heat. Jinhua and the surrounding area is a combined agricultural region which is comprehensively developing in several fields such as agriculture, forestry, livestock farming, fishery and other sideline manufacturers. This merits the city's name of 'second granary of Zhejiang Province.' In recent years, the city's government has decided upon the strategic objective of becoming a key city in the Midwest of the Zhejiang Province. The three strategic policies of promoting industrialization, quickening of urbanization and advancing of unitization of town and county have been strongly enforced. Distinct improvement in economic growth has been achieved in the city.

Unfortunately, distribution of precipitation in Jinhua is not homogeneous in space and time. Moreover, there also exists a phenomenon of river pollution, and water storage projects are also lacking in the city. The above situation is not ideal, and makes a problem the water shortage a real possibility. Serious drought in 1996 led to 160 thousand people and 80 thousand domestic animals in the city suffering from a lack of drinking water. The direct economic loss was nearly 170 million Yuan. The situation became even worse in 2003. During that summer, record high temperatures appeared and drought ran through from summer to autumn. Precipitation from July to October was just 124 mm, which is just 30% of the regular precipitation. Even though water demand was strong the affluent Yiwu residents could only sit and watch as polluted water from the river went past their doors. Water from the Jinhua River that had been used for generations was left abandoned by the city's government in 1998, and water from the Shafan reservoir was used as s water supplying source for the urban district of the city – all at a huge expense. The government of Yiwu County also provided funds in November 2000 of about 2 hundred million Yuan for permanently purchasing fresh water resources of 4.999×10^7 m^3 each year from the reservoir in Dongyang County. This became the first business for water rights after the Ministry of Water Conservancy advanced the theory of water rights and the water market. Even with this policy, the supply of water in Yiwu still needs restrictions in terms of time-sharing, sectioning and step-downs. It is obvious that the problem of water shortage has become a bottleneck for comprehensively building a comfortable society in 2020.

A set of [0, 2000] on the space of one-dimensional real numbers can be regarded as the field of x_i according to the actual information of annual rainfall over 26 years from 1980 to 2005 measured by the Jinhua Station. The continuous field of [0, 2000] can be transformed into a discrete field through equidistantly selecting the points. Considering the requirement for calculating accuracy, 101 points were selected to form the discrete field, which can be represented as the following:

$$U = \{u_1, u_2, ..., u_m\} = \{0, 20, 40, ..., 2000\}$$

Risk assessment for water shortage in Jinhua can be obtained using Eqs. 1–7, as shown in Table 1.

During the calculations, the unity was selected as 1 year. Hence, line 1,400 in the table means that the probability under the condition that precipitation is larger than 1,400 mm in Jinhua is p=0.6581 in each year henceforth. Put another way, precipitation in Jinhua under the risk level of low-water year can be estimated to be encountered every 3 years (recurrence interval is equal to $1/(1-p)$).

The amount of rainfall in each year has an important influence on the utilization of water resources in Jinhua. Precipitation of the future low-water year in every 5 years is calculated as only 1,276 mm, and precipitation of the future low-water year in every 10 years is also only 1,151 mm. Both of these are worked out through the interpolation method using the risk analysis model, according to the actual information over 26 years from 1980 to 2005 measured by the Jinhua Station.

4.2 Analysis for Carrying Capacity of Water Resources in Jinhua

The average annual precipitation of Jinhua is 1,503 mm, with the city being located in a humid area. Therefore, compared with that of a dry area (Verschuren et al. 2000), water shortage of the city is related not to the type of water source but to the type of water quality and the type of water conservancy project. This includes water shortage caused by water

Table 1 Risk assessment for water shortage in Jinhua

Annual rainfall (mm)	Surpass probability
900	1
1,000	0.9965
1,100	0.9469
1,200	0.8597
1,300	0.7782
1,400	0.6581
1,500	0.4934
1,600	0.3221
1,700	0.1919
1,800	0.0906
1,900	0.0308
2,000	0.0014

pollution, and shortage of water storage projects. Therefore, protection of water sources and new construction of water storage projects such as reservoirs with large or middle scales should be the most considered index (Toledo 2006). Several indexes that have important influence on the carrying capacity of water resources in Jinhua were selected according to the principle of simplicity. These indexes include summation of population, total output value of industry and agriculture, gross domestic product, investment in environmental protection, amount of sewage discharge, length of polluted river, total required volume of water use, amount of additional water produced from increasing income and reducing expenditure, amount of water supply, and bearing volume of water use.

The index system involved in the study on carrying capacity of water resources for Jinhua can be divided into five subsystems – population, agriculture, industry, environmental protection and water resources. As considered by system dynamics, there exists a mutual relationship of cause and effect between one subsystem and another subsystem, as well as between one factor and another factor, inside a certain subsystem. Moreover, this relationship forms a closed feedback structure. Therefore, cause and effect diagrams and flow diagrams of the system can be determined according to the index system and the feedback structure of the system. However, these diagrams simply explain the logical relationship among each variable in the system. The quantitative relation among each variable of the system cannot be demonstrated using these diagrams. Thus, the special language of DYNAMO is required to build an equation of system dynamics. Variables used by system dynamics may include level variables, rate variables and auxiliary variables. The related equation should be the level equation, the rate equation and the auxiliary equation, respectively. The equation of system dynamics is organically grouped by the above dynamic equations. It fully reflects the dynamic variation process of the carrying capacity of water resources. The level equation is the key equation here, as it quantitatively describes the cumulative time process of the dynamic systematic variables.

In the present paper, the field investigation work was conducted along the main rivers of Jinhuajiang, Dongyangjiang and Wuyijiang. The related data and information for water resources and social economic systems since 1980 was comprehensively collected by the author according to the actual situation in Jinhua and the requirement for the SD model, with ecology as the guiding ideology. The equations of system dynamics for the five subsystems of population, agriculture, industry, environmental protection and water resources were built according to the characteristics of water resources in Jinhua. More than 100 variables and parameters were selected in the model. The model also includes nine level equations, nine rate equations and numerous auxiliary equations. Three step functions, three table functions, four ramp functions and eight clip functions were also used in the model. The model is operated using the PD+ (Professional Dynamo Plus) software. The testing time for the historical review is 26 years (1980~2005) and the terminal time for the simulation is the year 2020, with a step length of 1 year. The structure of the model was proved to be reasonable through the analyses on parameter error and sensitivity, and can reflect the actual characteristics of the carrying capacity of water resources in Jinhua. Therefore, it can be used to forecast the dynamic development process of the system after the future policy parameters are enforced.

The total amount of water resources in Jinhua is 86.03×10^8 m^3, of which the amount of underground water resources is 20.24×10^8 m^3. In order to discuss harmonic development of the carrying capacity of water resources and social economy in the region during the future 20 years, several indexes were selected as the policy parameters, according to historical data and the standard of comprehensively building a comfortable society. These indexes included agriculture, industry, GDP, increment speed of investment in environmental protection, irrigation quota for agriculture, water consumption amount per unit output value of the thousand Yuan for industry, and amount of sewage treatment. Furthermore, three development schemes were further simulated using the SD model. The three schemes can be represented as the primary scheme with economic development as the main goal, the secondary scheme with environmental protection as the main goal and the middle scheme of balancing economic development and environmental protection. The detailed analyses on the carrying capacity of water resources under the three schemes are represented as follows.

4.3 Application of the Method on Guiding of Economic Development

4.3.1 Scheme Only for Economic Development (High Scheme)

The objective of quadrupling the GDP of the city can be easily realized by 2016 if this scheme is selected. The value of GDP would reach 3,051 hundred million Yuan in 2020 (as shown in Table 2 and Fig. 1). An affluent society might be achieved in 2010 with the value of GDP more than 3,000 dollars per capita. However, unilateral pursuit of fast development of the economy leads to increases in the amount of sewage discharge as well as a decrease in the investment in environmental protection. Therefore, the amount of sewage discharge would increase to 33,400 ten thousand tons in 2020. Also, the percentage of river length below class III (polluted percentage of river length (PPRL)) would reach to 43.7%. Unrestrained flowing of sewage could be clearly seen everywhere and the ecologic environment would be seriously damaged, as shown on Fig. 2. At the same time, the total industrial output value of the city would reach 7,061.5 hundred million Yuan in 2020 owing to the rapid development of industry. However, a series of measures including the adjustment of industrial structure, separately supplying water of different quality and

Table 2 Variation of the main indexes in the three schemes for carrying capacity of water resources in Jinhua

1	2	3	4	5	6	7	8	9	10
High scheme	2000	81.6	1,260.0	544.4	2.1	13,030	17.3	24.7	24.9
	2005	125.5	1,938.7	837.6	2.8	15,440	20.4	26.2	27.0
	2010	193.1	2,982.9	1,288.8	3.8	17,580	22.9	29.1	27.7
	2015	297.1	4,589.5	1,982.9	5.1	22,980	29.9	32.4	29.4
	2020	457.1	7,061.5	3,051.0	6.8	33,400	43.7	37.2	30.1
Middle scheme	2000	81.6	1,260.0	544.4	2.1	13,030	17.3	24.7	24.9
	2005	117.1	1,808.9	781.6	3.0	13,090	16.9	25.7	27.0
	2010	168.1	2,596.9	1,122.0	4.4	9,741	11.5	27.9	29.2
	2015	241.3	3,728.2	1,610.8	6.3	5,884	5.2	30.1	32.4
	2020	346.5	5,352.3	2,312.5	9.0	4,887	2.4	32.9	34.8
Low scheme	2000	81.6	1,260.0	544.4	2.1	13,030	17.3	24.7	24.9
	2005	109.1	1,686.2	728.5	3.3	12,380	15.8	25.3	27.0
	2010	146.1	2,256.5	974.9	5.0	7,766	8.4	26.9	30.7
	2015	195.5	3,019.6	1,304.7	7.7	1,775	0	28.1	35.5
	2020	261.6	4,041.0	1,745.9	11.9	0	0	29.6	39.4

Where: 1. Scheme, 2. Year, 3. Gross agricultural output value (10^8 yuan), 4. Gross Industrial output value (10^8 yuan), 5. Gross domestic product (10^8 yuan), 6. Investment of environmental protection (10^8 yuan), 7. Sewage discharge (10^4 t), 8. PPRL (%), 9. Total water demand (10^8 m^3), 10. Bearing volume of water use (10^8 m^3)

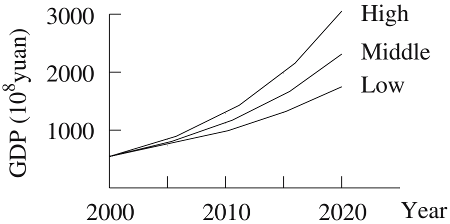

Fig. 1 Simulation curve of gross domestic product (GDP) in the three schemes

improving the price standard of water were executed to decrease the industrial water consumption amount per unit output value of ten thousand Yuan from 35 m^3 per ten thousand Yuan to 20 m^3 per ten thousand Yuan. However, water requirements for industry sharply increase and would reach 17.7×10^8 m^3, a value that would exceed the value of water consumption for agriculture. This makes the total requirement for water supply as high as 37.2×10^8 m^3. Because of lack of investment, measures that increase income and reduce expenditure and regenerative use of water would be restricted. The ability to supply water to the city would be massively reduced. It also can be observed that the simulation curve would intersect in 2008 as shown on Fig. 3, which means that total bearing volume of water use already cannot satisfy the requirement for total water supply. A contradiction between demand and supply for water resources would happen at that time. Total bearing volume of water use would be 30.1×10^8 m^3 in year 2020. A huge shortage of 7.1×10^8 m^3 for water resources would exist at that time.

4.3.2 Scheme Only for Environmental Protection (Low Scheme)

This scheme takes environmental protection as the primary goal. Therefore, investment in environmental protection increases year after year and so the amount of sewage discharge gradually decreases. Sewage treatment rates would reach 100% in 2017. Thus, the percentage of river length below class III would also gradually reduce year after year. The percentage would decrease from 17.3% in 2000 to 8.4% in 2010 and would finally decrease to zero in 2015. This means that the stream length with inferior water quality would disappear owing to the great efforts of the city on environmental protection. Picturesque scenery of green hills and clear waters would appear around the city and the ecologic environment of the city will be completely changed, as shown in Fig. 2. Because of the slowing of industrial development, the requirement of water for industry would be just 10.1×10^8 m^3 in 2020, which is 7.6×10^8 m^3 less than that of the primary scheme. Therefore, the total requirement for water supply would be only 29.6×10^8 m^3, far below the maximum bearing capacity of water resources for human activity as shown on Fig. 3. Although this scheme has an

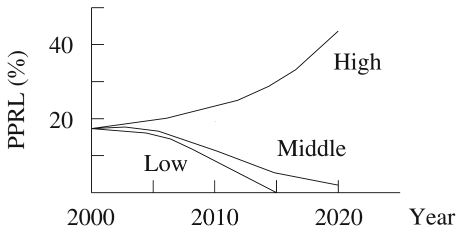

Fig. 2 Simulation curve of polluted percentage of river length (PPRL) in the three schemes

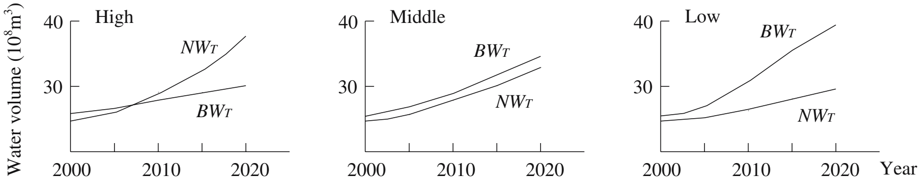

Fig. 3 Simulation curves of total requirement for water supply (NW_T) and total bearing volume of water use (BW_T)

outstanding effect on balancing the demand for water against supply, slowing down of resource development and restricted development of industry and agriculture will occur. This is owing to the decrease of investment in industrial fixed assets and less investment in agricultural capital construction. Therefore, the objective of quadrupling the value of the GDP of the city in 2020 cannot be successfully achieved under this scheme, even though a comfortable society could still be established in the year, as shown in Table 2 and Fig. 1.

4.3.3 Scheme Balanced with Economy and Environment (Middle Scheme)

It is obvious that environmental pollution is unavoidable during the process of economic construction. However, we cannot blindly develop the economy at the expense of environment. Also, the consumption for resources cannot exceed the regenerative ability of the ecological system. The homogeneous development of economy and environment should be the final objective for the city. The relationship between economic development and influencing factors such as population, resources and environment in Jinhua are carefully considered in the middle scheme. Optimization regrouping on resources, environment, industry and market are performed through weighing of the advantages and disadvantages from an ecological angle. The scheme indicates that the objective of quadrupling of value of GDP of the city in year 2020 could be easily realized if several measures are properly executed. These include the inviting of outside investment, quickening of the construction of the industrial park, timely adjustment of the industrial structure and vigorous support of superior industries. These superior industries are shown in Table 2 and Fig. 1, and include small commodities in Yiwu County, metal fittings in Yongkang County, construction in Dongyang County, floriculture in Jinhua County and rock crystal in Pujiang County At the same time, the amount of sewage discharge would also decrease year after year and the percentage of the polluted river length would reduce to 2.4%, which leads to a suitable living environment (Fig. 2). Total bearing volume of water use could reach 34.8×10^8 m^3 at the time, which can fully satisfy the total requirement of 32.9×10^8 m^3 for water supply. The equilibrium of supply and demand for water resources will be achieved, as shown in Fig. 3.

4.4 Suggestion for Future Policy Parameters

According to the above discussion, the primary scheme of unilaterally pursuing the fast development of economy at the expense of the environment and the secondary scheme of environmental protection as the main goal via slowing of the economy are both undesirable for Jinhua. Furthermore, the middle scheme of simultaneously giving consideration to both economic development and environmental protection should be the chosen scheme. In order to realize the mutual benefits between economic development and environmental protection, the increment speed of agriculture, industry and GDP is suggested at 7.5%,

Table 3 Irrigation quota for agriculture and water consumption amount per unit output value of ten thousand yuan for industry in different years

1	2	3
2005–2010	670–680	30–35
2011–2020	660–670	25–30

Where: 1. Year, 2. Irrigation quota for agriculture (m^3/mu), 3. water consumption amount per unit output value of ten thousand yuan for industry ($m^3/10^4$ yuan)

respectively. The increment speed of investment in environmental protection is also selected as 7.5%. The irrigation quota for agriculture and water consumption amount per unit output value of ten thousand Yuan for industry in different years is shown in Table 3.

Transcendental probability can be described not only as the recurrence interval but also as a guaranteed rate, which means the ability to reach a certain required percentage. If the current amount of water supply from 1998 to 2005 is constantly maintained in the near future, then the guaranteed rate for satisfying the total required amount of water supply of 27.9×10^8 m^3 in 2010 would be just 0.1962 according to Eqs. 1–7 of the risk assessment for water shortage. This is still true when the middle scheme with the mutual benefits of economy and environment is selected, which means that equilibrium of supply and demand for water resources can only be achieved in 1 year among the 5 year average. Furthermore, the guaranteed rate for satisfying the amount of water supply of 32.9×10^8 m^3 in 2020 would be nearly zero. Therefore, three powerful measures represented as the following must be adopted in order to attain the equilibrium of supply and demand of water resources in the city. The three measures are: (1) increase of income: the amount of reservoir storage for newly built retaining works should reach 1.5×10^8 m^3 per year from 2007 and the amount should reach 2.5×10^8 m^3 per year from 2015; (2) reduction of expenditure: the amount of water resources from reduction of expenditure in each year should be 1% of that of the total bearing volume of water use through special measures of adjusting industrial structure, economizing of water use, separate supply of different quality water, and improvement of the price standard of water; (3) improvement of the reproductive availability of water: the amount of water that can be reproduced and used again should increase 0.3×10^8 m^3 in each year through the employment of effective measures such as advanced technology and the recycling of sewage treatment.

5 Conclusion

Several conclusions represented can be obtained according to the simulation result and theoretical analysis described above. They are as follows:

(1) Information diffusion technology is an effective method of risk assessment for water shortage.
(2) Carrying capacity of water resources has the characteristic of non-determinacy and therefore must be calculated on the basis of the risk assessment for water shortage.
(3) Some knowledge can be obtained through the case analysis on Jinhua based on the present method:

    (a) Precipitation of the future low-water year in each 5 years for the city will be just 1,276 mm and the value will be just 1,151 mm for the future low-water year in each 10 years.

(b) The primary scheme of unilaterally pursuing the fast development of economy at the expense of environment and the secondary scheme environmental protection as the primary goal via slowing economic development are both undesirable for Jinhua. Furthermore, the middle scheme of simultaneously giving consideration to both economic development and environmental protection should be the preferentially chosen scheme.

(c) If the current amount of water supply is constantly maintained in the near future, then the requirement for water supply cannot be easily satisfied at the time according to the risk assessment for water shortage, even when middle scheme is selected. The contradiction between demand and supply for water resources will become greater.

(d) At present, the water shortage of Jinhua is not due to the type of water source, and should be down to the type of water quality and the type of water conservancy projects. The carrying capacity of water resources of the region can only be improved through the strengthening of investment in environmental protection year after year and newly building water storage project. These projects include the building of reservoirs with large or middle scales, as well as the simultaneous adjustment of the industrial structure and creation of a society that naturally saves water.

Acknowledgments This work was supported by Zhejiang Provincial Science and Technology Foundation of China (No. 2006C23066).

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