A Study on Urban Drought and Water Shortage Risk Assessment and Management Measures in Jilin Province

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Abstract

It is well- known that water shortage seriously affect the cities' social and economic development and becomes a world-wide problem. Jilin Province is one of the most important provinces affected by drought and water shortage in Northeast China. Drought and water shortage has the characters of high frequency, influencing a broad range and causing great losses. Moreover, drought and water shortage has a tendency of occurring frequently, and the damages to social and economic system caused by it has been increasing during recent years, which due to the factors such as urbanization, population explosion, and so on, which cause a increasing demand of water resources This study presents a risk assessment model of urban drought and water shortage in which the four factors: hazard, exposure, vulnerability and emergency response and recovery capability forming the risk of urban drought and water shortage in Jilin Province are analyzed integratedly, by using Natural Disaster Risk Index method, Weighted Comprehensive Analysis, Analytic Hierarchy Process and the technology of Natural Disaster Risk Assessment from the viewpoints of climatology, geography, hydrology, disaster science, environmental science and so on.. Then, the risk of urban drought and water shortage is assessed and the risk map of urban drought and water shortage is developed based on GIS. Lastly, some strategies of managing urban drought and water shortage are proposed according to the theory of natural disaster risk management.

This study can be expected to raise public awareness of drought and water shortage risk, improve emergency response capability to drought and water shortage, mitigate the effects and losses caused by it, and provide theories and technological supports for taking comprehensive and active measures to fight with drought in Jilin Province.

Key words: urban drought and water shortage; urban drought and water shortage risk index; risk assessment; risk management; GIS; Jilin province

1. Introduction

Urban drought and water shortage seriously affect the social and economic development of cities has become a world-wide problem. Water is the indispensable foundation that guarantees the economy keeping on developing. With continuous increasing of population, the need of water is increasing. In these years, water resource shortage has become a restricted factor to economic development in many countries and region; water shortage threatens human lives and the city's development. Whether water resource is running off, and how the circumstance is being short of water are influenced by two factors: water use and water supply. Because of the randomicity of river flow and rain, water supply and water need have uncertain factors. Water shortage has a certain risk.

Until recently, no studies of combing methods and theories of risk management to do research on water shortage has been done[1-4]. In this paper, qualitative analysis on supplying and demanding water to the stage of the quantitative analysis is developed. Fuzzy decision method is used to evaluate the urban water shortage .The degree and type of water shortage of water using and supplying is also considered.

This article combines natural disaster principle, four factors: hazard, exposure, vulnerability and emergency response and recovery capability, and the method of using the urban drought and water shortage risk index (UDRI) to evaluate the urban drought and water shortage. The map and management measures of drought and the water shortage in Jilin Province are developed, based on the technique of the natural disaster risk management.

2. Study Area and Research Methods

2.1 Study Area

Jilin Province is located in the center of Northeast China, on the north temperature zone. Landform of Jilin Province is mountainous in the eastern, mound in the central, plain in the west. The main rivers are the second Songhua River, Mudan River, Hun river, Tumen river, yalu River and so on. The mean annual precipitation is 609.1mm, there is about 39.88 m^3 billion of water resource, and it means that every people can have 1518 m^3. Jilin province belongs to the middling degree region short of water; Changchun belongs to the heavy degree short region of water. Siping, Liaoyuan, sonyuan and so on belong to the heavy short region of water[5][6].

Because of the limited data, this paper takes 9 cities as the examples to study the risk of urban drought and water shortage in Jilin Province.

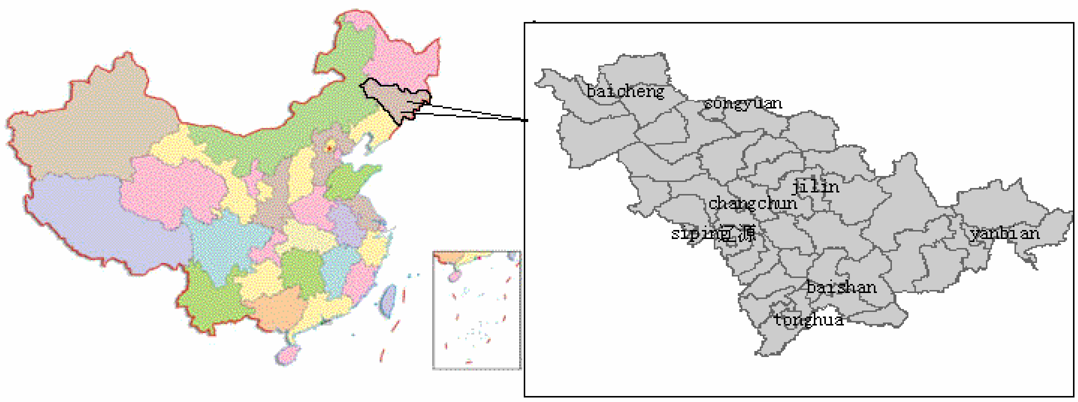

Fig .1 The area diagram of research area

Table1 The water shortage degree analysis for the divided area of administration

The ground grade of administrative area	The total deal of water resource（ten thousand	The water resource quantity of	The degree of water shortage

	stere）	average people （stere）	
Changchun	274566	392	Extreme degree of water shortage
Jilin	705835	1635	Middling degree of water shortage
Siping	164527	502	Heavy degree of water shortage
Liaoyuan	76254	614	Heavy degree of water shortage
Tonghua	553012	2463	Light degree of water shortage
Baishan	715102	5373	Do not be short of water shortage
Songyuan	138259	633	Heavy degree of water shortage
Baicheng	200904	1009	Middling degree of water shortage
A autonomy state of the korea nationality in Yanbian	1159849	4240	Do not be short of water shortage
Jilin province	3988308	1518	Middling degree of water shortage

2.2 The Research Methods

2.2.1 Natural Disaster Risk Index Method

Natural disaster risk is defined as both the possibility of natural disaster occurrence and the degree of damage caused by natural disasters during the following several years. Generally speaking, natural disaster risk is the result that hazard, exposure and vulnerability work integratedly[8~10]. Because emergency response and recovery capability also plays an important part in the formation of natural disaster risk, so it is also be considered. The natural disaster risk is formed by hazard (H), exposure (E), vulnerability (V) and emergency response and recovery capability(R), and can be expressed in mathematic formula as follows[10]:

$$\text{Natural Disaster Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \times \text{Emergency Response and recovery capability}$$

2.2.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process[11] (AHP) is a decision analysis method, which combines both quantitative and qualitative criteria in decision problems. Briefly, there are following five basic steps in applying the AHP in practice: (1) structure the decision hierarchy; (2) collect data by pair wise comparisons; (3) check consistency of material judgments; (4) apply the eigenvector method to compute weights; (5) aggregate the weights to determine a ranking of decision alternatives.

2.2.3 Weighted Comprehensive Analysis (WCA)

Weighted Comprehensive Analysis is used to assess the degree of the influence of each factor on the dependant variable. This method assumes that the degree of the influence of each factor j on a particular object i to be assessed is discriminated as the quantification value of the indicator j is different, the total of the influences on this object can be expressed by Eq. (1) [11].

$$CV_i = \sum_{i=1}^{m} QV_{ij}\ WC_i$$

Where CVi is the comprehensive value of the assessment object j, QVij is the quantification value of the indicator i with respect to the assessment object j (QVij ≥ 0), WCi is a weight on the indicator i (0 ≤ WC i≤1) and is computed by using AHP, and m is the number of assessment indicators. 2.3 The origin of the data

The data needed in this paper are obtained from 《The Jinlin’s statistical yearbook of the year in 2004》 [12] by Jilin statistic bureau, the comprehensive programming of the water resources in Jilin province and the result summary of the water resources of the Jilin water conservancy hall, and the disaster of 《The flood and the drought in Jilin province》 [13] by Jilin water conservancy hall.

3. The Conceptual Framework of the Urban Drought and Water Shortage Risk

3.1 Formation Mechanism of the Natural Disaster Risk

The western scholars in the economic field first put risk forward at the end of 19th century. In the economic field, risk means the uncertainty that be involved in the result of a certain activity, this kind of result includes three conditions: loss, profit, no loss and no profit [14]. Afterward, the risk is gradually introduced into the research field of natural disaster .The risk evaluation committee of the IUGS landslide research set define the risk to be the adverse affairs to health, property and environment, probability and the serious degree of the possible result [15]. Chinese natural disaster usually considers disaster risk as disaster activity and its possibility towards the damage of human lives and property [16].

According to the recognized definition of natural disaster risk, natural disaster risk (of a region, a family, or a person) is made up of four factors: hazard, exposure, vulnerability and emergency response and recovery capability [6].

$$R = H \cap E \cap V \cap C$$

Hazard represents an extreme natural event that affects human life, property or activity to the extent of causing a disaster with a certain degree of probability and severity. Generally, the higher probability and higher severity of an extreme natural event, the higher the damage degree, and the higher the natural disaster risk.

Exposure describes the number of people, and the value of property, structures and activities that will experience hazards and may be adversely impacted by them. Generally, the more number of people and value of property exposed to hazard factors e, the greater the level of loss that may be caused by them, and the higher the natural disaster risk.

Vulnerability denotes the degree of resistance of the asset & population against hazards. It decides loss degree caused by hazards. Generally, the higher the vulnerability, the greater levels of loss that may be caused by them, and the higher the natural disaster risk.

Emergency response and recovery capability denotes ability of managing natural disaster risk. It is made up of information, authority, institutions, partnerships, plans, resources and procedures to prevent and reduce the natural disaster risk.

3.2 Conceptual Framework of the Urban Drought and Water Shortage Risk Assessment

Urban drought and water shortage means that the city’s water supply can not satisfy the needs of it[17]. Whether water resources run short, and how the circumstance of being short of water is, are influenced by the two factors of water use and water supply. Because the randomicity of the river flow and rain, water supply and water need all pose the dicey factor. Water shortage has randomicity, and the short of water causes a certain risk. The water shortage would by all means make the national economy suffer an important loss. In order to avoid or mitigate the loss we need to adopt a series measure of engineering and not engineering from the two aspects of water supple and water need to control the water shortage risk. Urban drought and water shortage risk means that under the particular space time the city water supply and water use both exist uncertainty, which causes water shortage [18].

According to the formation mechanism of the natural disaster risk, this paper established the following concept framework of urban drought and water shortage risk as shown in Fig 2.

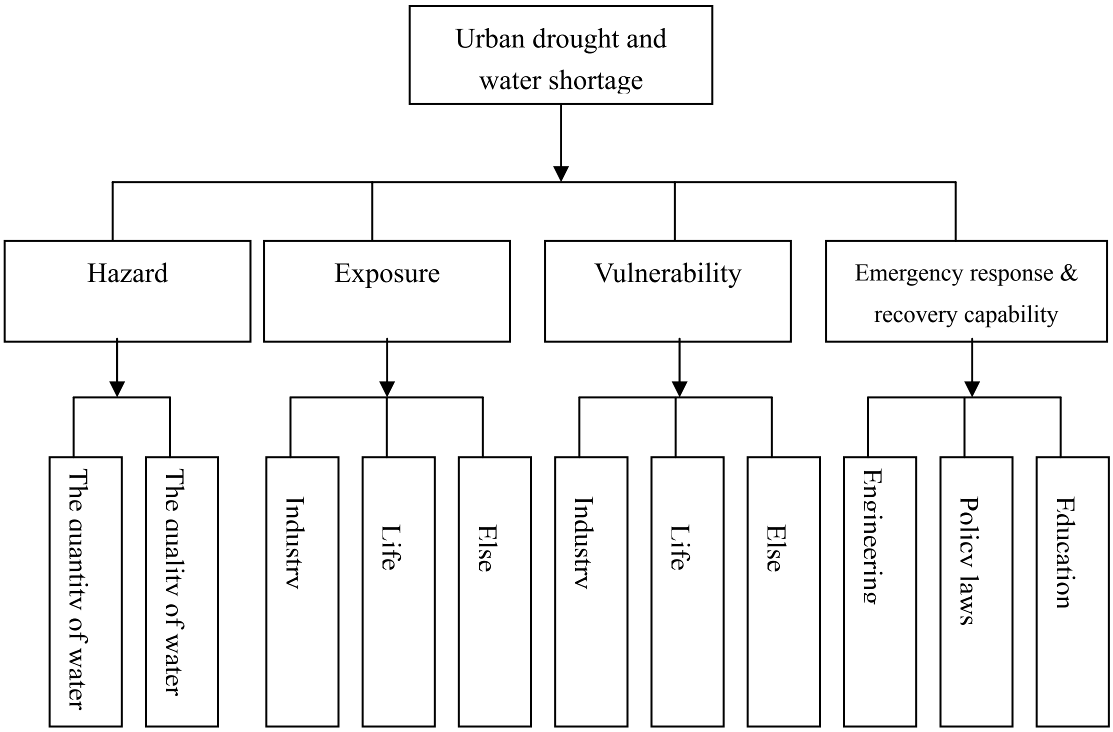

Fig.2 The conceptual framework of the urban drought and water shortage risk

4. Selection of the Indicators on Urban Drought and Water Shortage Risk Assessment

Quantification of the urban drought and water shortage risk is a new topic in the research of the urban drought and the water shortage risk, and is also a very important work. Indicator selection of risk assessment is the key process to assess degree of urban drought and water shortage risk. According to the conceptual framework of the urban drought and water shortage risk, based on the principles of the purpose, system, science, comparison, and operation on indicator system, with each city's actual circumstance and the degree of obtaining data, indicators of risk assessment system on urban drought and water shortage are divided into the comprehensive layer, system layer, indicator layer, and 24 indicators are selected to describe the urban drought and water shortage risk. The development of the concrete indicator system is shown in Table 2.

Table 2 The assessment indicators of city drought and water shortage risk

The gene layer	The auxiliary layer	The guide line layer
Hazard (h)	The quantity of water	The average person owns the water resources (h1)
		The average quantity of declining the water one year (h2)
		The coefficient of variation of rain one year (h3)
		The coefficient of variation of earth's surface water resource (h4)
		The depth of flow (h5)
		The drought index number (h6)
	The quality of water	The contrast of polluted path (h7)
Exposure (e)	Industry	The number of the industry business enterprise (e1)
		The mole number of the industry production value (e2)
	Life	Population density (e3)
		The population of using water in city (e4)
	Else	Farmland rate (e5)
Vulnerability (v)	Industry	Take the amount of water per unit GDP (v1)
	Life	The quantity of average person using water in living (v2)
	Else	Irrigation rate (v3)
Emergency response & recovery capability (c)	Engineering technique	Using rate of water resources (c1)
		Living dirty processing rate of water (c2)
		Industrial waste water processing rate (c3)
		The universality rate of using water (c4)
		The piping length of supplying water (c5)
	Education	The comparison of the student in school (c6)
	Policy laws	The fixed quantity of industry using water (c7)
		The fixed quantity of life using water (c8)
		The rate of consuming water (c9)

5. The Establishment of Risk Assessment of Urban Drought and Water-shortage

5.1 Urban Drought and Water Shortage Risk Assessment Model

Based on the conceptual framework of urban drought and water shortage risk and the formulation of the natural disaster risk mentioned above, the risk assessment model of the urban drought and water shortage can be described by the following formulas to make the comprehensive and objective assessment of the risk degree of urban drought and water shortage using weighted comprehensive analysis and *AHP*:

$$UDRI = DH \bullet DE \bullet DV \bullet DC \quad (3)$$

$$DH = A_{h1}W_{h1} + A_{h2}W_{h2} + A_{h3}W_{h3} + A_{h4}Wh_4A_{h5}Wh_5 + A_{h6}W_{h6} + A_{h7}W_{h7} \quad (3a)$$

$$DE = A_{e1}W_{e1} + A_{e2}W_{e2} + A_{e3}W_{e3} + A_{e4}W_{e4} + A_{e5}W_{e5} \quad (3b)$$

$$DV = A_{v1}W_{v1} + A_{v2}W_{v2} + A_{v3}W_{v3} \quad (3c)$$

$$DC = A_{c1}W_{c1} + A_{c2}Wc_2 + A_{c3}Wc_3 + A_{c4}W_{c4} + A_{c5}W_{c5} + A_{c6}W_{c6} + A_{c7}W_{c7} + A_{c8}W_{c8} + A_{c9}W_{c9} \quad (3d)$$

The $UDRI$ is urban drought and water shortage risk index, it means the degree of t urban drought and water shortage risk, the higher the value, the grater the urban drought and water shortage risk is more, DH , DE , DV , DC presents hazard, exposure, vulnerability and emergency response and recovery capability of urban drought and water shortage risk, repetitively, W is the weight coefficient on assessment indicators, A is the corresponding quantification value of indicators.

5.2 Calculation procedure

5.2.1 Quantification of risk Assessment indicators

The indicators identified for risk assessment of the urban drought and water shortage have a variety of units, e.g., yens, houses, and number of people. These indicators are scaled so that they are all unitless, and then they are combined. The theoretical foundation for indicator quantification is based on identifying and evaluating key factors related to the urban drought and water shortage risk and their contribution to the damage by them. In this paper, the assessment indicators of city drought and water shortage risk are quantified using the method of scaling value and point scoring method.

5.2.2 The calculated result of weights of risk assessment indicators

The Table 3 lists the weights of urban drought and water shortage risk assessment indicators calculated by AHP.

Table 3 The weights of urban drought and water shortage risk assessment indicators

Assessment Indicators	Weights
The average person owns the water resources (h1)	0.32
The average quantity of declining the water one year (h2)	0.20
The coefficient of variation of rain one year (h3)	0.18
The coefficient of variation of earth's surface water resource (h4)	0.13
The depth of flow (h5) runoff	0.06
The drought index number (h6)	0.06
The contrast of polluted path (h7)	0.06
The number of the industry business enterprise (e1)	0.11
The mole number of the industry production value (e2)	0.18
Population density (e3)	0.36
The population of using water in city (e4)	0.26
Farmland rate (e5)	0.09
Take the amount of water per unit GDP (v1)	0.30
The quantity of average person using water in living (v2)	0.54
Irrigation rate (v3)	0.31
Using rate of water resources (c1)	0.08
Living dirty processing rate of water (c2)	0.08
Industrial waste water processing rate (c3)	0.16
The universality rate of using water (c4)	0.16
The piping length of supplying water (c5)	0.04
The comparison of the student in school (c6)	0.08
The fixed quantity of industry using water (c7)	0.08
The fixed quantity of life using water (c8)	0.08
The rate of consuming water (c9)	0.08

5.2.3 The calculated results of UDRI

Table 4 shows the values of the urban drought and water shortage risk index calculated by the risk assessment model of the urban drought and water shortage (Formula (3)) and its calculation procedure mentioned above.

Table 4 The values of urban drought and water shortage risk index of Jilin Province

City	Changchun	Jilin	Siping	Liaoyuan	Tonghua	Baishan	Songyuan	Baicheng	Yanbian
UDRI	3.417	2.991	2.877	2.765	2.305	2.338	3.215	3.237	2.880

6. Assessment and Comparing Analysis on Urban Drought and Water Shortage Risk in Each Ground Class City in Jilin Province

Based on the above study, the values of UDRI listed in Table 4 are used as the criteria for making a comprehensive assessment and regional classification of the risk degree of urban drought and water shortage. In order to assess the risk degree of urban drought and water shortage, a criterion of risk assessment is created according to the three-grade system[19] based on the computed results of UDRI using the data in Jilin province as shown in Table 5. Then, according to the contribution rate, urban drought and water shortage risk are divided into 4 types: the type of resources, the type of using, the type of management and the type of hazard, exposure, vulnerability, and emergency response and recovery capability. If hazard ＞1 defines the type of resource; exposure and the vulnerability together ＞1 defines the type of using; emergency response and recovery capability＞1 defines the type of risk. Table 6 shows the degree and types of urban drought and water shortage risk see the Table 6.

Table 5 Standards of urban drought and water shortage risk assessment

UDRI	≤2. 50	2.50—3.00	≥3.00
The degree of risk	Low risk	Middling risk	High risk

Table 6 Degree and types of urban drought and water shortage risk

City	Chang chun	Ji lin	Sip ing	Liao yuan	Tong hua	Bai shan	Song yuan	Bai cheng	Yan bian
The degree of risk	High risk	Middli ng risk	Middli ng risk	Middli ng risk	Low risk	Low risk	High risk	High risk	Middling risk
The type of risk	The type of admixtu -re	The type of manage -ment	The type of resourc -e	The type of resourc e	The type of manage -ment	The type of manage -ment	The type of resourc e-e	The type of resourc e-e	The type of managem- ent

Base on the criterion shown in Table 5 and the values of UDRI listed in Table 4, the risk degree caused by the urban drought and water shortage are assessed and zoned (Fig. 4). The deeper colored area means the risk is bigger. The most shallow color part is not the study area.

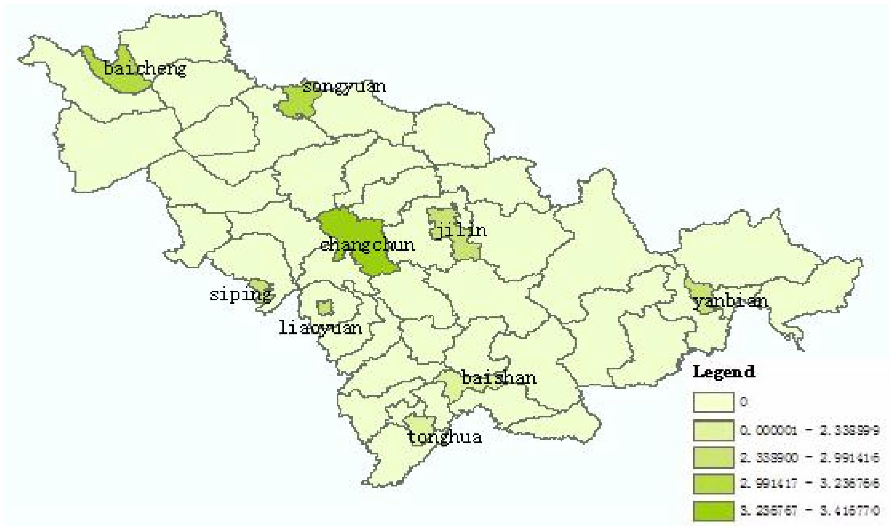

Fig.4 The risk map of urban drought and water shortage of the ground grade cities in Jilin province

The drought and water shortage risk in Changchun is greatest, because the population of using water is more and the distribution of the industry business enterprise is the wide; secondly is the Baicheng on the minimal amount of the year declining. The Tonghua and Baishan’s risk is the smallest because its water resource is a little more abundant.

Fig. 4 shows the comparison of contribution rate of indicators to the urban drought and water shortage risk in Jilin province. From the Fig. 4, it can be known that Changchun、Siping、Liaoyuan、Songyuan、and Baicheng are short of water, and are mainly restricted by hazard factor; Tonghua、Baishan and Yanbian are mainly restricted by Emergency response & recovery capability.

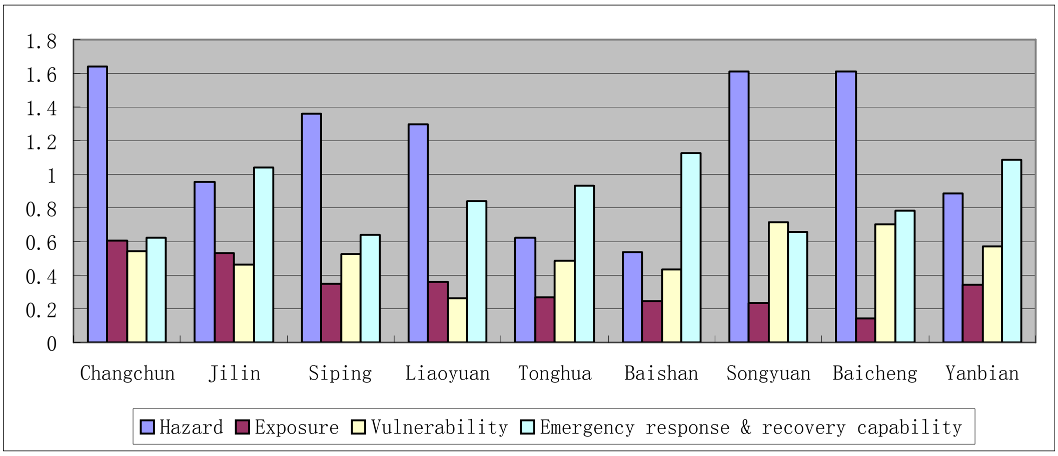

Fig.4 The comparison of contribution rate to the urban drought and water shortage risk of indicators in Jilin province

7. Risk Management Countermeasures on Urban Drought and Water Shortage

Urban Drought and water shortage is an chronic disaster under some influencing factors such as weather, hydrology, society and economy, it's adverse effect and results come about slowly, so it is apt to be ignored. Because the cause of water shortage in every city is different, we should take different measures and countermeasures according to different index of contribute rate in different cities, to mitigate risk of drought and water-shortage.

Measure to relax and relieve city's drought and lack water of risk are as follows:

7.1 Improved Water Resource's Using Rate

Organizing to order and actualize the plan of irrigation works project, increasing investment of irrigation works project advisably, digging adequately available potential water resource, reducing water resource lose, improving index of water resource's using; according that available water quantity set down plan of using water and using water ration, take timing, squarely to compute affording water; carrying out charge according to basic water price beyond plan and double price exceedingly.

7.2 Improving Sewage Resourced Degree, Advocating, Water's Circulation Using in building

Making sewage resourced, improving water resource using rate and constructing factory of sewage disposal that is core to make sewage resourced. Disposed Sewage is used to besides irrigation, some industry corporation, government and city site. Another approach is water's circular used in building. Water's circulation used in building indicates that kinds of drainage in buildings are used in buildings and residential area mix using water supply, such as washing WC, planting, washing car, watering road, doing cooling water and so on.

7.3 Developing Saving Water Industry, Adjusting Industry Configuration

Extending new high technology, producing and using water-saved equipments, taking water-saved techniques, and making great efforts to reduce water use. In order to use water scientifically, water resource should be collocated reasonably. It is necessary to build resource-saved city.

7.4 Innovating Water Price System, Building Price System of Water Resource in Reasonably

According to the principles: cost compensation, income in reason, burden fairly, and based on cost accounting to establish and adjust water price, practice different water price to different consumers, use economic measures to restrict consumers using water at will, in order to protect and use water resource in reason. If water price is too low, people will have mistake leading, going against saving water. Water price in reason is core to make water resource persisting. In America some researches indicate: when practicing charge according to water quantity in family using water, saving water 10%-30%, peak vale of city using water reduces 30%-50%; when water price advancing 5 times, consuming water quantity of great production value industry reduces 1/2.Above all, water price system is benefit for relieving water resource supplying and needing.

7.5 Strengthening Propagandization and Education, Advancing Citizen's Consciousness of Saving Water

Water is a kind of valuable and finite resource, in order to solving problem of water resource waste, we must strengthen propagandization of saving water, developing science popularization's education, advancing citizen's moral view of using water, forming common consciousness of saving water. At the same time, we should take some education on saving water to elementary and middle school students and hold it from callan, in order to make them understand water's value and the importance of saving water.

7.6 Compiling Emergency Pre-document of Drought and Lack Water and Put in Practice, Practicing Risk Management to Drought and Lack Water

In currently people are lack of necessarily estimated and forecasted ability to emergency of drought and lack of water, confronting its occurrence, we don't prepare well in psychology and substance, and we are so passive that we can't offset loss in economy and ecology. In order to avoid this effect and kinds of blindness in decreasing disaster's measure to project and non-project, it's necessary to compile emergency in making estimation to drought and lack water and to actualize risk management to it and to carry out against drought orderly, normal and systemic. Risk management based risk estimation emphasizes setting about, relieving, forecasting, forewarning before disaster, in order to relieve effect subsequently. So we should plant risk estimation, management theory and method in emergency to drought and lack water of chronic disaster; we should improve and perfect it, and set up perfect risk management system of drought and lack water, based on danger of drought and water shortage, vulnerability, harm, analysis and estimation to risk degree, we bring forward countermeasure systems reducing, avoiding, transferring and dispersing risk, compile emergency pre-document of drought and lack water, strengthen risk consciousness of drought and lack water, advance against drought ability, relieve effect and loss of drought disaster, make complete and active against drought.

For city with resource risk, finding source and saving water, advancing sewage resourced degree are better method; For city of use risk, we should make it at first that confirming and adjusting industry configuration; For city of management risk, we should emphasize particularly on unified management system, in advance using rate of water resource, increasing investment in order to make saving project and building better and make great effort in advancing saving water consciousness of citizens; For city of mixed risk, we should take mixed measures.

In a word, by advancing, practicing and mixing technology means, economy means, management system, public consciousness, policy indication, legal measure and so on, we can relieve drought and lack water risk of city and keep water resource persisting and developing.

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