CASE STUDIES

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Ecological Risk Management of Drinking Water Project: The Case Study of Kunming City

Abstract   Following rapid infrastructure development and industrialization, the problems of water pollution and water shortage have become more severe. Whether there is safe drinking water in cities has attracted wide attention. The ecological risk management of drinking water project is an important means of ensuring the safety of a drinking water source. Based on ecological risk assessment and management theories, this paper establishes an ecological risk management model and assessment system with the aim of providing theoretical guidance and scientific basis for formulating a policy on the safety and protection of drinking water sources in a city. Kunming is one of the cities plagued by severe water shortage in China. Its ecological risk management of drinking water has attracted the attention of both the local government and the public. Using Kunming as the case study, this paper conducts a comparative analysis and assessment on three major reservoirs that face ecological risks. It highlights the existing problems and gives helpful suggestions.

Keywords: drinking water project, ecological risk, ecological risk assessment, risk management

1   Introduction

The continuous development of economy and society in China is followed by rapid expansion of urban infrastructure and rapid urban population growth. The demand for water among industry and households has increased significantly, which puts unprecedented pressure on municipal water supply. However, water safety management and ecological risk management are relatively lagging behind other fields of management. In fact, drinking water project plays an important role in the supply of water to

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industry, agriculture, and households. Any ecological risk will have profound impact on sources of drinking water, including rivers, lakes, reservoirs, and groundwater. Here are some examples:

The eutrophication of lakes and reservoirs: In 2007, Wuxi's waterworks was forced to shut down due to an outbreak of cyanobacteria (aka blue-green algae) in Taihu Lake.

Sudden water pollution incidents: In 2005, Songhua River was seriously polluted due to an explosion that occurred at the Jilin Chemical Industrial Plant.

Point source water pollution caused by toxic heavy metals or organic compounds: In 2008, the arsenic contamination of Yangzong Lake in Yunnan Province was caused by long-term effect of improper waste disposal of surrounding enterprises. Water-related information indicates that almost half of China's rivers and 90% of the water in the cities of China have been polluted in different degrees.

Nowadays, the main urban area of Kunming has a population of approximately 5 million people. It has less than 300 cubic meters of water resources per capita and has become one of the nation's 14 most water-stressed cities. There are seven reservoirs supplying drinking water for the Kunming municipal areas. Among these reservoirs, Songhuaba, Yunlong, and Qingshuihai reservoirs annually supply Kunming with 95% of its water demand. Due to the rapid development of economy and society and the effects of climate change, there is water pollution caused by domestic waste from villages and towns and rural non-point source pollution. The drastic increase in tourism and consecutive years of drought has complicated the situation. How to ensure water quality and annual per capita availability of water resources are two challenges facing the municipal government in Kunming. Currently, the drinking water protection area of the main urban area of Kunming covers a total of 1,849.29 km², of which 151.81 km² are a first class protection area, 1,006.04 km² are a second class protection area and 691.44 km² are a third class protection area (prospective protected area). This paper systematically examines and analyzes the ecological

risks and ecological safety management of three reservoir projects in Songhuaba, Yunlong, and Qingshuihai in Kunming. It provides theoretical guidance and scientific basis for local governments, research units and authorities concerned with other water-stressed cities to formulate policies on protecting sources of drinking water in the main urban area.

2   Literature review

2.1   The research and practice of the protection and ecological risk management of drinking water projects in foreign countries

The protection and management of drinking water projects in the United States (U.S.) have four characteristics: 1) priority is given to cooperation and coordination among institutions; 2) stakeholders play a dominant role; 3) non-profit organizations, government departments and the general public participate in supervision and management; and 4) public engagement is utilized. Germany has established a more comprehensive system of protecting drinking water sources. It implements several measures to protect the ecological system of the entire basin that the management of the first class water protection zone is fully enclosed (Ward & Michelsen, 2002). Singapore monitors both water quality and water quantity. Its implementation of an on-line hydraulic and water-quality monitoring system helps unify and standardize monitoring locations, frequency and parameters (Guo, Cui, & Zhao, 2009).

Ecological risk assessment is one of the important tasks in ecological risk management. It was evolved from health and safety risk assessment in the 1980s. It is widely used in developed countries such as the U.S. and the European Union and is regarded as an important basis for environmental decision-making. At present, many studies in foreign countries are related to model evaluation tools, the combination of qualitative and quantitative risk assessment, and ecological risk assessment using single variable or multivariable analysis (Yang, Wang, Li, Chen, & Huang, 2007).

2.2   The situation of establishing a regulatory framework for protecting and managing drinking water source projects in China

China has established a multi-level water regulatory system to protect drinking water source projects, which consists of national laws, administrative regulations, departmental rules, standards and local regulations. It promulgated Water Law of the People's Republic of China and Water Pollution Prevention and Control Law of the People's Republic of China. It also issued the Technical Guideline for Delineating Source Water Protection Areas, which highlights the technical requirements for protecting

different sources of water, such as rivers, lakes, reservoirs and underground water.

2.3   Literature review on the impact of ecological risks on drinking water source projects in China

There are many papers on protecting China's drinking water sources. But there is less of study on the impact of ecological risks on China's drinking water source projects. Ecological risks refer to the bad influence that uncertain hazards, accidents and human activities make on the natural environment, which endanger the safety and well-being of the ecosystem (Lipton, Galbraith, Burger, & Wartenberg, 1993).

Research on the goals and procedures of ecological risk assessment on drinking water projects: Yin (1995) suggested that ecological risk assessment could predict the extent and range of damage caused by pollutants to people and other vital living organisms. The procedure of ecological risk assessment on water environment can be divided into five parts: source analysis, receptor assessment, exposure assessment, hazard assessment and risk characterization. Research in this field has yielded stunning results (Yin, 1995).

Research on the impact of ecological risks on drinking water projects of rivers: the Delphi and Risk Assessment Code (RAC) were used to conduct ecological risk assessment in Lijiang River (Yang, Su, & Bai, 2007; Yang, Wang, Li, Chen, & Huang, 2007). Tang et al. (2008) studied heavy metal pollution in sediments and assessed potential ecological risks after dredging of external Qinhuai River, which provided theoretical basis for pollution control and ecological restoration in Qinhuai River. Yin, Xia, and Xia (2013) analyzed the impact of static, dynamic and other risk factors on the drinking water sources and the safety of ecological environment of Yangtze River in Suzhou section, and recommended a corresponding set of countermeasure techniques.

Research on the impact of ecological risks on drinking water projects of lakes: Li and Cai (2002) analyzed rainfall in flooding season and topographic factors of eight large and medium-sized cities along Lake Taihu and found the impact of ecological risk caused by flood hazards and the level of ecological risk of flood hazards in these cities. Wen (2005) summarized the ecological risk of Thousand Island Lake area and suggested objectives for ecological risk management in this area. He systematically recommended countermeasures for regional ecological risk management from the aspects of agriculture, forestry, towns, industry, tourism, non-native species, disasters, basins, ecological engineering technology and integrated management. Yang, Cheng, Yang, and Zhang (2008) analyzed and identified major ecological risk sources in South Lake Ecological Demonstration Area (EDA) in Tangshan and conducted an integrative landscape ecological risk assessment in EDA. Shi (2012) systematically examined the assessment

methods of the green drinking water source area (reservoir-type).

The literature review above shows that there are numerous studies and practice on projects and infrastructure, protection, formulation of laws and regulations of drinking water sources in China. However, most of the studies and practice are qualitative in nature without systematic analysis. Following a continuous and ever increasing demand for urban drinking water projects, there is continuous expansion of the boundary of drinking water area. To accommodate this situation, there is structural adjustment and the removal of plant industry, breeding industry, township and village enterprises. The great controversy between local economic growth and water source protection has created potential ecological risks and a great deal of problems. Under this circumstance, it is necessary to have detailed investigation into the identification, assessment and countermeasures of ecological risks. At present, there is a lack of systematic research on this field.

3 A model of ecological risk management on urban drinking water project

This paper develops a model of ecological risk management on urban drinking water project in accordance with the theory of ecological risk management and the procedures for ecological risk assessment. The model is shown in *Figure 1* and will be discussed below.

3.1 The scope and receptors of research

Defining scope of research varies in accordance with types of water projects. The research scope of a lake is defined as the subject and small watershed. The research scope of an underground water is defined by sources that supplement water to it and mainly considers how environmental factors on the ground (e.g., solid waste and domestic sewage) affect underground water. The research scope of a river is defined by river basin. The receptor refers to a risk bearer. An ecological receptor of water source can be categorized into groundwater systems, stream ecosystems, and lake ecosystems.

3.2 Assessment endpoint and assessment standard

Assessment endpoint refers to an explicit expression of the ecological value to be protected. The assessment goals include the quantity of water resources and the quality of water. Different types of water projects can choose different districts or areas for assessment and comparison. For example, research on a river can focus on upstream areas or a tributary that is less affected by human activity while research on underground water or lake can focus on an area with high quality water for comparison. This paper will compare the assessment results of different areas/districts in accordance with "Environmental Quality Standards for Surface Water (GB3838-2002)".

3.3 Source analysis

Source analysis includes identifying and describing the source of risks. This can determine the system for ecological risk index.

(1) Identification of risk sources. This will investigate the direct or indirect factors that affect water sources. These can be natural or human factors, sudden pollution accident or pollution with gradual or long-term effects. The ecological risk sources and factors threatening water sources are shown in Table 1.

(2) Description of risk sources. Description of risk source is the process of conducting qualitative or quantitative analysis on different types of risk sources within the scope of research. It estimates and calculates the degree of damage caused by different types of risk sources by determining the probability, intensity, change of time, and space of risk sources.
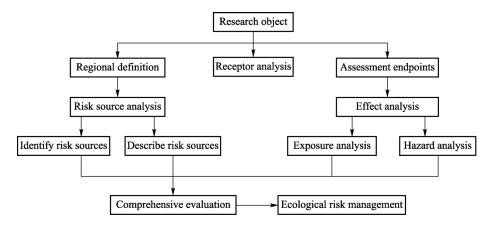

Figure 1. A model of ecological risk management on urban drinking water project.

Table 1

The Ecological Risk Sources and Threatening Factors in Water Sources

Category of risk	Threatening factor	Ecological risk sources
Incremental	Toxic and harmful substances	Point source (enterprise emission, chemical spill, market and town)
		Surface source (rural life, agricultural runoff, free-range livestock farming, soil erosion, transportation)
	Nutrient substance	Lake sediments
Probabilistic	Meteorological factors	Flood, drought, acid rain, atmospheric precipitation
	Sudden accident	Hazardous chemical spill, sudden appearance of cyanobacteria, algal blooms
	Water quantity	Rainfall, drawing water by factories

3.4 Effect analysis

Effect analysis is to study the external reaction of a water project in comparison to pressure under the joint action of several risk sources. It includes both exposure analysis and hazard analysis.

(1) Exposure analysis

Exposure analysis is the study of the distribution and flow of risk sources within the evaluation areas, and the exposure-response relationship for risk receptors (Lioy, 1995). The threatening reaction of each risk source to water source areas or to water projects is shown through a specific form. It can be analyzed through the changing pattern of water quantity or water quality and eutrophic conditions.

The changing pattern of water quality can be shown by its inter-annual variability while eutrophic conditions can be shown by the nutrient state index method TLI ($\sum$), of which the computation formula is shown as below.

$$\text{TLI}\left(\sum\right) = \sum_{j=1}^{m} W_j \cdot \text{TLI}_j. \qquad (1)$$

In the Eq. (1), TLI ($\sum$) is the comprehensive nutrient state index, W_j is the weight of nutrient state index of the jth parameter, TLI_j is the nutrient state index of the jth parameter (such as chlorophyll a (chla), total phosphorus (TP), total nitrogen (TN), transparency (SD), potassium permanganate index (CODMn)), and m is the number of evaluated parameters.

Generally, we use a series of consecutive numbers (0–100) to classify the nutrient state of lake (reservoir), the evaluation standard of nutrient state index is shown in Table 2.

(2) Hazard analysis

The purpose of hazard analysis is to compare the damage degree of risk sources to ecological system and its risk receptors. The stress generated by risk sources may affect or reduce the quality and function of ecological environmental factors that would endanger the normal development of economy. The hazardous effect brought by risk to water projects are residential water shortage in urban areas, the limited development of local economy, and damage to human health due to unqualified drinking water.

3.5 Integrated assessment on ecological risk

Risk assessment is a process that assesses the magnitude of harmful effects and the probability of its occurrence. It combines exposure analysis with hazard analysis to get the assessment result.

(1) The method of assessing ecological risks

According to the requirement of assessment endpoints, ecological risk assessment on a water project can use factor weighting methods or expert methods to calculate the ecological risk value. Risk value reflects the characteristics of ecological risk, such as intensity of risk sources, characteristics of risk receptors, and the degree of damage from risk sources to receptors. The integrated ecological risk value in a small area may be calculated by the formula below.

$$R_i = \sum p_{ij} W'_j. \qquad (2)$$

In the Eq. (2), R_i is the integrated ecological risk value of ith small area, p_{ij} is the jth ecological risk value in the ith small area; W_j is the weight value of the jth risk.

Table 2

Nutritional Status Classification and Corresponding Comprehensive Nutrition Index

Nutritional status classification	Score values TLI($\sum$)	Qualitative evaluation
Oligotrophication	$0 < \text{TLI}(\sum) < 30$	Excellent
Mesotrophy	$30 \leqslant \text{TLI}(\sum) \leqslant 50$	Good
Light eutrophication	$50 < \text{TLI}(\sum) \leqslant 60$	Slightly polluted
Middle eutrophication	$60 < \text{TLI}(\sum) \leqslant 70$	Moderately polluted
Severe eutrophication	$\text{TLI}(\sum) > 70$	Heavily Polluted

(2) Probability index of disaster

A disaster index is defined as the product of probability and weight, which describes the magnitude of the disaster and the degree of damage.

(3) Pollution risk index

Pollution risk index is calculated through the equivalent standard pollution index.

$$P_j = C_j/C_s. \qquad (3)$$

In the Eq. (3), P_j is the equivalent standard index of the jth pollution index, C_j is the value of measured thickness of the jth pollutants, and C_s is the standard value of environmental quality of the jth pollutant.

(4) The ecological risk index system

Finally, we determine the risk assessment system through the pollution sources, exposure and hazard analyses, which include types of risk, specific index of risk, pollution degree, weight and risk value of integrated assessment. Among them, pollution degree can be divided into four categories — very serious, serious, general, and not serious.

4 A case study on the ecological risk management of drinking water project in Kunming

4.1 Research scope

Since Songhuaba, Yunlong, and Qingshuihai reservoirs annually supply Kunming with 95% of its water demand, this paper selects water protection areas of these three reservoirs as scope of research.

4.2 Receptors and assessment endpoints

Songhuaba, Yunlong, and Qingshuihai reservoirs belong to the lake type of water source. The selected ecological risk receptors are an aquatic ecosystem. Changes in water quality are taken as the assessment endpoints because it is at greater risk of environmental pollution.

4.3 Analysis of risk sources

Similar to Table 1, the risk sources of Songhuaba, Yunlong and Qingshuihai reservoirs for the main urban area of Kunming are shown in Table 3.

4.4 The description of risk sources

4.4.1 Pollution of point sources

The water sources of the first class protection area of Songhuaba, Yunlong, and Qingshuihai reservoirs had no industrial point source or large-scale livestock breeding point source that produced or had pollutant emissions. These three reservoirs were formed by rivers from upstream, along which many enterprises discharged pollutant sin to reservoirs. There were seven firms in the manufacturing industry of non-metallic mineral and general equipment, and a large-scale livestock breeding farm located in Songhuaba in the second and third class protection areas.

Following the socio-economic development, villages were expanding and were joined together. A market town formed around the usual place of residence of a township government. Sewage and garbage from the town population became a point source of pollution. According to the survey information, there existed town gathering zones within the area of three water sources in the end of 2010.

Pollution emission sources in the three reservoirs are shown in Table 4. The most serious pollution emission source was in Yunlong reservoir, which was followed by Songhuaba reservoir and Qingshuihai reservoir. The point source of pollution from towns was the major source of pollution for the three reservoirs.

4.4.2 Surface source pollution

(1) Total amount of pollutants in storage

The total amount of surface source pollution in storage is shown in Table 5. We see from Table 5 that the total amount of surface source pollution in Songhuaba reservoir is greater than that of Yunlong and Qingshuihai reservoirs, and that the surface pollution (of Songhuaba reservoir) was more serious. The pollution degree of agricultural runoff and free-range livestock farming (correct font) is more serious.

(2) Soil erosion

The accounting method of the pollutant from soil and water erosion used in this paper was based on the study on the environmental capacity of water in the protection area of Songhuaba reservoir (Kunming Environmental Science Research Institute, 2011). Soil erosion existed in the three reservoirs in 2010, where there was mild erosion in

Table 3

The Risk Sources of Songhuaba, Yunlong, and Qingshuihai Reservoirs for the Main Urban Area of Kunming

Category of risk	Threatening factor	Ecological risk sources
Incremental	Toxic and harmful substances	Point sources (industrial enterprises, villages, and towns)
		Surface sources (rural life, agricultural runoff, free-range livestock farming, soil erosion)
Probabilistic	Meteorological factor	Drought

Table 4

Pollution Emission Sources in Water Source Areas (Year 2010)

	Water source	Point source type	Count	Sewage discharge /(million tons·yr⁻¹)	Pollutant discharge/(ton·yr⁻¹)			
					COD	TN	TP	NH
1	Songhuaba	Industrial enterprise	6	0.44	41.68	0.58	0.07	0
		Town point source	3	28.71	63.79	49.9	6.03	14.97
2	Yunlong	Industrial enterprise	1	0.05	2.68	0.02	0	0.02
		Town point source	2	78.84	175.2	137.04	16.55	41.11
3	Qinghaishui	Industrial enterprise	1	0.51	31.25	0.22	0	14.91
		Town point source	2	28.58	63.52	49.68	6	14.91
Total			15	137.13	378.13	237.44	28.65	71.23

Note: The industrial enterprises were located in the second class protection areas of the water source. There was no industrial point source and pollutant emission in the first class protection area of the water source. The data in 2010 was selected because its data presented a more complete accounting of pollution sources.

Table 5

The Total Amount of Pollutant of Surface Source in Storage (2010)

Name	Rural life pollution /(ton·yr⁻¹)				Agricultural runoff /(ton·yr⁻¹)				Free-range livestock farming /(ton·yr⁻¹)				Total /(ton·yr⁻¹)			
	COD	TN	TP	NH	COD	TN	TP	NH	COD	TN	TP	NH	COD	TN	TP	NH
Songhuaba	463	9.9	7.4	1.9	2020	317	3.4	55	1122	54.5	11	15	3606	382	22	71.8
Yunlong	341	7.3	5.4	1.4	1772	265	1.7	48.6	719	34.6	6.3	7.2	2832	307	13.4	57.1
Qinghaishui	199	4.2	3	0.8	1281	191	0.8	35.1	523	25.0	3.4	3.2	2004	220	7.2	39.1
Total	1003	21.4	15.8	4.2	5073	773	5.9	139	2365	114	20.7	25	8442	909	42.8	168

Songhuaba and Qingshuihai reservoir while there was moderate erosion in Yunlong reservoir.

4.4.3 Drought

The water supply of the three reservoirs came from rainfall within the basin. In recent years, the average water storage capacity of the three reservoirs was lower than their normal capacity due to drought. The average water storage capacity of the Songhuaba reservoir was 57% of the normal capacity while that of the Qingshuihai reservoir and Yunlong reservoir were 76% and 43% respectively.

4.5 Exposure analysis

(1) Analysis of water quality

With reference to "Environmental Quality Standards for Surface Water (GB3838-2002)" and based on the monitor data from the Environmental Monitoring Center in Kunming and the survey report on the basic information of the water protection area (Kunming Environmental Science Research Institute, 2013), changes in water quality were analyzed in Songhuaba, Yunlong, and Qingshuihai reservoirs from 2008 to 2014. The analytical results showed that the water quality of the three reservoirs were stable between the class II and III. However, there are some circumstances where the water of reservoirs had excessive

pollutants of total phosphorus and fecal bacteria, at a levels exceeding the legal limit.

(2) Analysis of eutrophic conditions

The statistical analysis indicated that the eutrophic condition of the three reservoirs in 2010 was in the middle nutritional level, and the comprehensive nutritional state index of the Songhuaba reservoir was the highest among the three reservoirs. There is a trend of eutrophication of water quality in the three reservoirs, indicating that all three reservoirs examined had the potential risk of eutrophication.

4.6 Hazard analysis

(1) Analysis of disaster (drought) probability

Due to the impacts of geographical conditions and its monsoon climate, Kunming has little temperature difference between seasons but does have distinct wet and dry seasons. It has the uneven distribution of water resources over time and space. The average annual precipitation is about 1,000 mm. More than 80% of rainfall is concentrated in the months of May through October every year. Kunming experiences a dry season from November through April in which there is less than 20% of rainfall. The regional annual precipitation is very unstable. According to historical weather data and information, Kunming experienced severe drought in 1960, 1963, 1979,

1980, 1984, 1987–1989, 1992, 1993, 1996, 2000, and 2009–2012. It keeps experiencing consecutive years of drought. Based on the data collected from 1960 to 2014, we find that the probability of drought disasters is about 25% in Kunming.

(2) Analysis of the pollution risk index

According to the monitoring results of recent years, the level of phosphorus, nitrogen and fecal bacteria in water exceeded the legal limits, which was the direct cause of water quality deterioration. In 2010, the pollution risk index of the Songhuaba, Qingshuihai, and Yunlong reservoirs were 1.76, 1.01, and 1.59 respectively. It meant that Songhuaba and Yunlong reservoirs were at greater risk from pollution. Meanwhile, Qingshuihai reservoir met the standard of value of environmental quality.

4.7　Analysis of emergency alert

At present, the drinking water project in the main urban area of Kunming has the feature of supplying water to the designated region. On the whole, there was an insufficient emergency water reserve project and a poor level of emergency protection in Kunming. Once the city's water sources or nearby sources were polluted, many counties would have the problem of severe water storage.

There are many blind spots in monitoring stations for drinking water projects in Kunming. It is only in the preliminary stage to meet the requirements for assessment in the quality of water projects. At present, only the water project in the Songhuaba and Yunlong reservoirs has established an automatic monitoring station. Other places are yet to establish automatic monitoring stations or mobile water quality monitoring network and are thereby unable to have real-time understanding of water-quality changes in water protection areas. In addition, there is no effective means of coordination and management in water source projects. The emergency response mechanism is not perfect and the capability of emergency alert is rather weak.

4.8　Integrated assessments of ecological risks

Using the above analysis on sources of pollution of reservoirs and considering the availability of data, we establish an ecological risk assessment index system of drinking water projects in the urban main city of Kunming. The expert method is used to determine the weight of each index. The integrated assessment risk values of the three reservoirs are calculated respectively, which are shown in Table 6.

It can be concluded from Table 6 that the primary sources of risks in the Songhuaba reservoir were water quality and agricultural runoff of surface source pollution. The primary sources of risks in the Yunlong reservoir were

Table 6

The Integrated Assessment of the Ecological Risks of the Three Reservoirs in Kunming

Category of risk	First grade indexes	Secondary indexes	Weight	Songhuaba reservoir		Yunlong reservoir		Qingshuihai reservoir	
				Pollution hazard degree	Compre-hensive value	Pollution hazard degree	Compre-hensive value	Pollution hazard degree	Compre-hensive value
Incremental	Point source	Industrial enterprise point source pollution	0.1	General	0.042	Not serious	0.019	General	0.042
		Pollutants in every-day life in towns	0.1	Serious	0.125	Very serious	0.061	Serious	0.125
	Surface source	Domestic pollution source	0.1	General	0.061	General	0.061	General	0.061
		Agricultural runoff	0.1	Especially serious	0.167	Very serious	0.148	Very serious	0.167
		Free-range livestock farming	0.1	Serious	0.042	Serious	0.111	Serious	0.125
		Soil erosion	0.05	General	0.042	Serious	0.056	——	0.000
	Internal source	Eutrophication	0.05	General	0.042	General	0.037	General	0.042
		Water quality grade	0.2	Serious	0.085	Not serious	0.012	General	0.049
Probabilistic	Meteorology	Drought	0.1	Serious	0.125	Serious	0.111	Serious	0.125
	Early-warning mechanism	Emergency drill	0.1	Not serious	0.042	Serious	0.111	General	0.083
Total					0.353		0.3254		0.322

pollutants in everyday life in towns and agricultural runoff. The primary sources of risks in Qingshuihai reservoir were agricultural runoff. Based on the analysis of the three reservoirs, the main ecological risks of water source were water quality, which was followed by agricultural runoff and pollutants in everyday life in towns. The Songhuaba reservoir was at greater ecological risk.

4.9 Ecological risk management strategies

4.9.1 Existing problems

Through the analyses and assessment of ecological risks facing the three major reservoirs of Kunming, we summarize the major problems in the protection and management of drinking water in the main urban area of Kunming as follows:

(1) Surface source pollution is still serious in rural areas and thereby intensifies the risk of water pollution.

According to the pollution emission statistics of water sources in 2010, in Kunming, the total amount of COD, total nitrogen, total phosphorus and ammonia nitrogen in the three major reservoirs respectively reached 8,441.67 tons, 908.61 tons, 42.49 tons, and 168.08 tons, and their proportion to the total amount of pollutants from surface sources were respectively 95.71%, 79.28%, 59.73%, and 70.24%. These proportions were much higher than the proportion of point source pollution emissions. Hence, the burden brought by surface source pollution has become the main pollution source in the water source area in Kunming. At the same time, following the development of the rural economy and the advancement of agricultural industrialization and changes in rural lifestyle, the problems of agricultural runoff and free-range livestock farming have become more distinct. The burden of nitrogen and phosphorus in Kunming is mainly attributed to the rural surface source pollution. Pollution encroaching into the reservoirs will lead to eutrophication, which may result in reducing the availability of reservoirs or losing the reservoirs.

(2) Rainfall precipitation is unstable in the areas and thereby increasing the probability of drought or consecutive years of drought.

Since the supply of urban water mainly relies on natural rainfall in the city of Kunming, rainfall instability would greatly threaten the water supply of the city and also reduce the ability for self-purification of water.

(3) Part of the water quality in the water source areas is difficult to reach the standard steadily and the safety of water quality is not optimistic.

According to the statistical results of water quality of the Songhuaba, Yunlong, and Qingshuihai reservoirs over the past seven years, the qualified rate of raw water quality in water source areas has failed to reach 100% and the water quality of reservoirs were fluctuating. Meanwhile, the monitoring data showed that there were inter-annual and monthly fluctuations of water quality. In other words, it has a potential eutrophication risk to reservoirs' water quality. For this reason, the safety risk of water quality should not be ignored.

(4) The emergency measures of reservoirs are not in place.

A corresponding set of emergency plans had been formulated for drinking water reservoirs of the city by 2012. Due to the lack of emergency monitoring equipment that was necessary, and the lack of a unified and standardized environmental monitoring system, environmental supervision and management was rather weak. The emergency drill to tackle a sudden accident in reservoirs was not performed as requested. Furthermore, alternate water sources are insufficient and are unevenly distributed in each county or district. Once the existing reservoirs cannot be used due to a sudden environmental event, it will directly affect the safety of drinking water for the local people.

4.9.2 Countermeasures for ecological risk management

4.9.2.1 Adjust industrial structure as the starting point, and strengthen the control of surface source pollution

(1) Optimize and adjust industrial structure and focus on promoting the control work on surface source pollution.

1) Since the water protection area mainly suffers from surface source pollution in Kunming, it is high time the government adjusts the structure of agricultural planting in the water protection area and vigorously implements the program of banning "flowers" and cutting "vegetables".

2) Give full play to the ecological environment in water source areas, and concentrate the land usage right to a leading firm engaging in organic agricultural production through guiding the reasonable transfer of land usage right. It will improve the level of specialization, scale and modernization of agricultural production. Organic agriculture will be well developed, and the pollution of pesticide and fertilizer will be reduced.

3) Raising poultry and livestock should be restricted. Raising poultry and livestock should be totally banned in the first class drinking water protection area and within 200 meters of the main inflow rivers. The scale of raising poultry and livestock in the second and third class of water protection areas should be limited. It is essential to close, remove and control the pollution sources and sewage outlets in protection areas for the sake of fully promoting the pollution prevention work.

(2) Implement the rural cleaning project and improve the effectiveness of ecological environment construction.

Based on the principles of reduction, harmlessness and recycling of rural garbage on everyday life, four measures can be introduced. Firstly, a system of waste collection,

transportation and disposition in the water protection areas should be established in accordance with local conditions. Secondly, the government can promote the use of solar energy in the program of rural clean energy engineering and strive to solve the energy problem faced by peasants in water source areas. Thirdly, three defense lines of "ecological restoration, ecological management and ecological protection" should be set up in the drinking water source areas. It can implement the countermeasures of returning farmland to forest and planting ecological forest in the first class protection areas, developing fruit forest and increasing water conservation forest in the second and third class protection areas. Fourthly, it can implement integrated management on serious soil erosion region by using small basin as a unit. In order to prevent damages to the ecological environment and slow down reservoir sedimentation, human activities such as rock cutting and stone digging should be banned.

4.9.2.2 Promote the construction of substitute project of water source

Government departments at all levels have addressed the problems of drinking water for some people and livestock through finding points of water sources, setting up pipe network and concentrating water lifting. In the long run, however, the construction of substitute project of water source is the safest way to solve the problems of agricultural irrigation and drinking water. Therefore, it is urgent for the government to promote the construction of a substitute water source in Kunming.

4.9.2.3 Establish and improve the security early-warning and emergency response mechanisms on water supply

It is important to establish the water supply security early-warning system, improve the integrated law enforcement system, promote the construction of monitoring system of drinking water sources and improve the ability of supervision on drinking water sources. It should strengthen the monitoring network of routine monitoring, mobile monitoring and dynamic monitoring, and have a real-time understanding of the situation of water quantity and water quality in water source. At the same time, it should establish a sound, fast, sensitive and efficient emergency response mechanism for a sudden water pollution event. Finally, it should establish the support system of technology, resources and personnel, implement major events reporting and processing system, and form an effective mechanism for emergency rescue.

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