Research on Ecological Risk Assessment of Water Resources in Hilly Areas: A Case Study of Ya'an

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Abstract - **To address the problem of ecological risk of water resources in hilly areas, this paper establishes an evaluation index system for ecological risk of water resources in hilly areas on the basis of State-Pressure-Response model. Ecological risks of water resources in different districts and counties in Ya'an are calculated through collection, statistical analysis and expert evaluation of basic data of impact factors with Analytic Hierarchy Process and Fuzzy Comprehensive Judgment. Results are analysed through contrast analysis and cluster analysis, and then the level of risk is determined. Based on GIS platform, the thematic map of ecological risk level of water resources in Ya'an is drawn, which can help analyse the sources of ecological risk of water resources. Results show that the ecological risk level of water resources in Baoxing county is level I, which is alight risk; the risk level in Hanyuan County, Lushan County and Yingjing County is level II, which is a mild risk; the risk level in Shimian County, Tianquan County, and Mingshan County is level III, which is a moderate risk. And the risk level in Yuchengg district is level V, which is a severe risk. Ecological risk of water resources is closely related to population growth, human activities, industrial and agricultural production. The major risk sources include flood and drought, unbalanced temporal and spatial distribution of precipitation, development and construction of cascade hydropower stations, traditional farming and breeding, population growth, industrial pollution and so on.**

Keywords - Ya'an; Ecological Risk Assessment of Water Resources; Analytic Hierarchy Process; Fuzzy Comprehensive Judgment; MATLAB; GIS.

I. INTRODUCTION

Risk assessment and early warning is an inevitable trend of environmental management. Ecological risk assessment of water resources is an important field in researches on ecological science and an important part of environmental risk assessment[1]. Quantitative evaluation and comprehensive research on ecological risk of water resources are the current research hotspots at home and abroad[2]. Ecological risk assessment of water resources starts relatively late in China, and research on theory and technology is weak. Due to the lack of long-term and continuous field observation data, evaluation index system is established mainly from physical geographical elements and environmental background data. Then regional ecological risk is classified and spatial difference is analyzed, which mainly focuses on chemical ecological risk assessment of water environment[3], regional[4-5] and landscape ecological risk assessment[6]. Researches at broad are mostly based on plenty of field observation data. The functional changes and ecological risk of ecosystem are analyzed through qualitative method and semi quantitative method from the change of one or several biological individual and population, which is helpful for environmental management and decision-making[7]. Methods of assessment mainly include Analytic Hierarchy Process, Fuzzy Comprehensive Judgment[8] and Delphy Method[9]. Identifying regional risk sources, analysing the pressure state of water ecological system under the interference of various risk sources and evaluating its response mechanism and response characteristics are the main connotation of ecological risk assessment of water resources. There are only a few reports about domestic and foreign researches on the ecological assessment of water resources in hilly areas. Besides, there is no uniform standard of the selection of ecological risk assessment index and its evaluation methods. Therefore, it is very important to construct the index system of ecological risk assessment of water resources in hilly areas and its evaluation methods, which is also of great theoretical significance.

Located in the upper reaches of the Yangtze River economic belt, Ya'an is an important water source in Chengdu Tianfu district. With high mountain, steep slope, deep valley, fragile ecological environment and numerous ecotones, competitions among communities in Ya'an are very fierce. Greatly affected by external environmental factors, Ya'an is also an economy less developed area with prominent conflicts between human and land. The ecological risk of water environment in this district is emerging with the development of industry and agriculture, an increase in human activities, global climate change, Wenchuan earthquake on May 12th in 2008 and Lushan earthquake on April 20th in 2013. Based on State-Pressure-Response model, this paper establishes an evaluation index system for ecological risk of water resources in hilly areas by adopting the general principles and methods of ecological risk assessment and taking the specific circumstances of Ya'an water resources into consideration. Ecological risks of water resources in different districts and counties in Ya'an are calculated through collection, statistical analysis and expert evaluation of basic data of impact factors with Analytic Hierarchy Process and Fuzzy Comprehensive Judgment based on MATLAB software platform. Results are analysed through contrast analysis and cluster analysis, and then the level of risk is determined. Based on GIS platform, the thematic map of ecological risk level of water resources in Ya'an is drawn. This paper has established ecological risk assessment system of water environment in hilly areas and studied the evaluation model and methods of ecological suitability, which improves the deficiencies of theoretical researches on it. Besides, figuring out temporal and spatial distribution regularities of ecological risk of water resources and its main driving factors provides a scientific basis for the sustainable utilization and protection of water resources, which is of great practical significance.

II. MATERIALS AND METHODS

A. General Situation of Research Area

Ya'an is located in the western margin of Sichuan Basin, at 101 degrees 56 minutes to 103 degrees 20 minutes east longitude, and 28 degrees 51 minutes to 30 degrees 56 minutes north latitude. It has an area of 15314 km2 with six subordinate counties and two subordinate districts, namely, Yucheng District, Mingshan District, Baoxing County, Tianquan County, Lushan County, Yingjing County, Shimian County, and Hanyuan County with a total population of 155.4 million. It is the transition zone from Sichuan Basin to Qinghai-Tibet Plateau, mainly of mountainous region, which accounts for 94% of the total area of the city. The climate of this area is mild and rainfall is abundant, its river system belongs to the Dadu River, Qingyi Rive and Minjiang River basin. Besides, water resources are unevenly distributed annually, along with frequent drought and flood disasters.

B. Research Methods

① Establishing Evaluation Index System: Combining the current situation of water resources in hilly areas as well as social demands, and referring to the results of domestic and foreign relevant evaluation index system, this paper establishes an index system for ecological risk assessment of water resources in hilly areas from the indexes of natural factors and social factors like average annual precipitation, average annual evaporation, multi-year average runoff depth, total amount of water resources, total amount of water supply, production water supply, annual waste water discharge, per capita living water of urban residents, per capita living water of rural residents and eco-environmental water consumption and so on based on State-Pressure-Response model and the connotation of ecological risk assessment of water resources.

②Study on Evaluation Model and Evaluation Methods: According to the characteristics of ecological risk assessment of water resources in hilly areas, this paper uses Analytic Hierarchy Process (AHP) to determine key indexes' weights and Fuzzy Mathematical Method to develop ecological risk assessment model of water resources in hilly areas based on the constructed evaluation index system. Besides, it composes the calculating program based on Matlab platform. With the help of GIS platform, this paper draws the thematic map of ecological risk level of water resources to analyze the ecological risk sources of water resources and put forward related suggestions.

C. Data Sources and Data Inspection

Data in this paper is mainly from Yearbook of Ya'an and so forth. In order to make evaluation results more reliable and accurate, SPSS 13.0 statistical software is used to analyze data P-P and Q-Q statistically (see Table 1 and Table 2). Results show that data obeys normal distribution and can be further analyzed and calculated. What's more, accuracy and relevance among multiple variables (or factors) of objective things are calculated. Results are shown in Table 5 and Table 6.

III. RESULTS AND DISCUSSION

A. Evaluation Results

①Analytic Hierarchy Process (AHP): Evaluation scores given by AHP (see Table 3) is just a relative score, not a rank value. The rank is divided into five levels, roughly as follows: risk number not more than 2 belongs to level I, which is a relatively light risk; risk number not more than 3 belongs to level II, which is a slight risk; risk number no more than 4 belongs to level III, which is a moderate risk; risk number not more than 5 belongs to level IV, which is a relatively serious risk; and risk number more than 5 belongs to level V, which is s serious risk. Thus, the risk level of water environment in all counties and districts of Ya'an can be obtained. See Table IV.

② Fuzzy Comprehensive Judgment: The membership of natural factors and social factors in each county and district to each level is:

Shimian County: B1 = [0.23 0.20 0.41 0.16 0]
Hanyuan County: B1 = [0.43 0.21 0.2 0.16 0]
Baoxing County: B1 = [0.53 0.19 0.14 0.14 0]
Lushan County: B1 = [0.22 0.43 0.18 0.17 0]
Tianquan County: B1 = [0.22 0.22 0.41 0.15 0]
Yingjing County: B1 = [0.24 0.52 0.19 0.05 0]
Yucheng County: B1 = [0.20 0.16 0.17 0.16 0.31]
Mingshan County: B1 = [0.22 0.17 0.44 0.17 0]

TABLE I DATA STATISTICS OF NATURAL FACTOR

	N	Minimum	Maximum	Mean	Std. Deviation
Average Annual Precipitation	8	730.8	1732.0	1240	387.4647
Average Annual Evaporation	8	839	1573	1143.27	274.350
Multi-year Average Runoff Depth	8	737	1702	1215.00	339.456
Total Amount of Water Resources	8	5.8	42.9	23.075	15.3319
Total Amount of Water Supply	8	0.111	9.082	1.72138	3.036910
Eco-Environmental Water Consumption	8	0.005	0.007	0.00562	0.000744

According to the basic principles of Fuzzy Comprehensive Judgment, five numerical values in membership matrix represent the degree of membership risk level respectively, which is level I, II, III, IV, V. When the numerical value is greater, effect of risk level represented by this data in the matrix is greater. Therefore, risk level represented by the maximum value in membership matrix should be taken as the result of risk level (see Table V).

③Determination of Risk Level: In order to test the correctness of evaluation results, and reasonably determine the final risk level, the ecological risk level determined by these two methods is compared (see Table VI).

TABLE II. DATA STATISTICS OF SOCIAL FACTOR

	N	Minimum	Maximum	Mean	Std. Deviation
Per Capita Living Water of Urban Residents	8	66.7	175.7	99.988	34.5592
Per Capita Living Water of Rural Residents	8	3.5	33.0	15.038	10.1816
Production Water Supply	8	0.120	1.703	0.62925	0.557931
Annual Waste Water Discharge	8	60.25	2655.06	537.52	864.76077

TABLE III. EVALUATION RESULTS OF ANALYTIC HIERARCHY PROCESS

	Shimian County	Hanyuan County	Baoxing County	Lushan County	Tianquan County	Yingjing County	Yucheng County	Mingshan County
Risk Number	3.35	2.36	1.28	2.66	3.37	2.08	5.25	3.99

TABLE IV. RISK LEVEL

	Shimian County	Hanyuan County	Baoxing County	Lushan County	Tianquan County	Yingjing County	Yucheng County	Mingshan County
Risk Level	III	II	I	II	III	II	V	III

TABLE V. RISK LEVEL

	Shimian County	Hanyuan County	Baoxing County	Lushan County	Tianquan County	Yingjing County	Yucheng County	Mingshan County
Membership	0.41	0.43	0.53	0.43	0.41	0.52	0.31	0.44
Risk Level	III	I	I	II	III	II	V	III

TABLE VI. COMPARISON OF EVALUATION RESULTS

	Shimian County	Hanyuan County	Baoxing County	Lushan County	Tianquan County	Yingjing County	Yucheng County	Mingshan County
Analytic Hierarchy Process	III	II	I	II	III	II	V	III
Fuzzy Comprehensive Judgment	III	I	I	II	III	II	V	III

Table VI shows that in addition to Hanyuan County, the evaluation results of other counties and districts given by these two methods can match each other and have good consistency in data acquisition, statistics, evaluation and other aspects. Besides, they can inspect and complement each other.

In order to facilitate classified study, clustering method is applied to carry out the cluster analysis of comprehensive evaluation scores concluded by Analytic

Hierarchy Process (see Figure 1). When the distance of clustering recalibration is equal to 5, the research area can be classified into four categories, among which, Shimian County, Tianquan County and Mingshan County belong to the first category; Yucheng County belongs to the second category; Hanyuan County, Yingjing County and Lushan County belong to the third category, and Baoxing County belongs to the forth category.

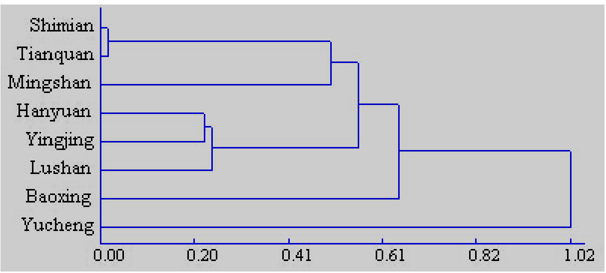

Fig.1. Results of Cluster Analysis

Combining Table VI and Fig.1 together, we can see that the ecological risk level of water resources in Yucheng County is level V; and that in Shimian County, Tianquan County and Mingshan County is level III; in Hanyuan County Yingjing County and Lushan County, the ecological risk level of water resources is level II, while that in Baoxing County is level I.

④The Production of Risk Thematic Map: Based on ARCGIS platform, the thematic map of ecological risk assessment of water environment in Ya'an is made,.See Figure 2.

B. Discussion

①An Analysis of Spatial Variability: The spatial variability of ecological risk of water resources is rather large. Hanyuan County and Shimian County in the southern part of Ya'an are located in the Dadu River basin, natural factors like rainfall, evaporation and others are very similar; but for social factors, the risk level of annual waste water discharge in Hanyuan County is level I, and that in Shimian County is level III.

The risk level of per capita living water of urban residents in Hanyuan County is level I, and that in Shimian County is level III. According to the evaluation results given by Analytic Hierarchy Process and Fuzzy Comprehensive Judgment, the risk level of Shimian County is determined as level III, and that in Hanyuan County is identified as level II. Although natural factors like rainfall, evaporation and others of Baoxing County, Lushan County, Tianquan County, Yingjing County, Mingshan County and Yucheng County in the northern part of Ya'an are very much similar, there are still big differences among social impact factors, which lead to big differences among evaluation results. Therefore, ecological risk of water resources is closely related to population growth, human activities and industrial and agricultural production.

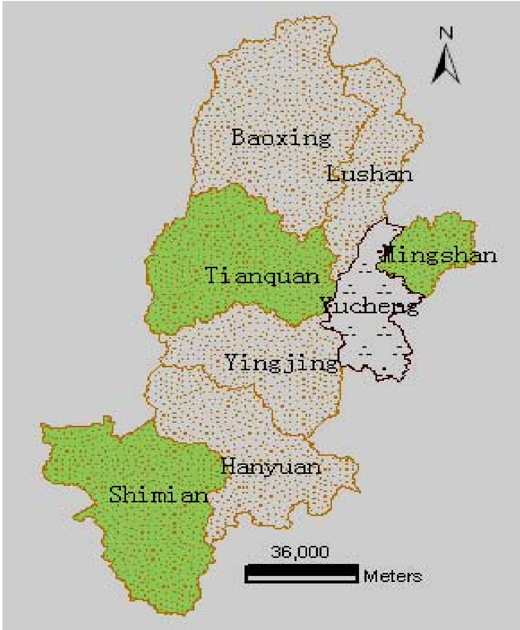

Fig.2 Results of Ecological Risk Assessment

② An Analysis of Ecological Risk Sources of Water Resources:

-a. The amount of average annual river runoff in this area is 18.069 billion m3, accounting for 5.8% of the total amount of that in Sichuan province. The average annual runoff depth in this area is 1184mm, annual per capita water resources is 12480m3, average unit water of cultivated land is 9740m3. Its inter-annual variability of river runoff is small, whose coefficient of variation is between 0.14 and 0.3. Besides, this area is rich in hydropower resources with 1108.4 kw theoretical reserves, the average of which is 726kw/km2. Among them, theoretical reserves of Qingyijiang River Basin are 4447000 kw, that of Dadu River Basin are 662.8 million kw and that of Minjiang River Valley are 0.54 million kw. But due to uneven spatial and temporal distribution of water resources, drought and flood disasters happen frequently accompanying with risks of natural disasters of water resources like drought, floods and so on.

-b. Spatial and temporal distribution of precipitation within this area is very uneven. Northern Counties in Qingyi River basin are located in the rainstorm areas of Mount Emei, which is one of the four famous heavy rain areas in Sichuan province. The average annual precipitation of Baoxing County and Lushan County is about 800-1200mm deep, while that of the rest places is mostly 1400-1800mm deep. Rainfall in summer happens mostly in forms of heavy rain and rainstorm. Southern

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Hanyuan County and Shimian County are in the shadow of dry hot valley in Dadu River, so its average annual precipitation is 600-800mm deep, while that in southwest mountainous area is up to 1000-1400mm. Because of crisscrossed mountains, strong dissected topography and uneven terrain in this area, chemical substances in original rocks and soil will run off into water environment under the erosion and leach of short-term heavy rainfall, which leads to a higher background value of water quality risk. For example, Fe and Mn in shallow groundwater in Mingshan County decrease gradually from northeast to southwest, which is closely related to a relatively higher background value of Fe and Mn in soil parent material and land type in Maohe village and Liao Chang village located in the northeast part of Ya'an.

c. 95% of Ya'an's hydropower resources concentrate in the rivers of main stream and tributaries of Daduriver and Qingyi river with a total length of 3118.3km. There existing 782 power stations of different sizes, among which, 25 are built every 100km. The layout of hydropower stations is dense. Constructing and operating storage and centralized emission of a large amount of water will not only lead to water reduction in natural rivers, a large increase in the number of dewatering sections and hydro-fluctuation belt of reservoir, but also change the hydrology, water regimen and water potential of natural rivers, thus causing new water and soil erosion and increasing the risk of eutrophication of surface water. It also has significant cumulated influences on rivers' ecological environment and destructs natural ecological environment and landscape. For example, when Tongtou hydropower station in Lushan County and Yucheng hydropower station in Yucheng County were in maintenance on October 15, 2008, water storage of two reservoirs was evacuated and a large amount of water was plunging. Therefore, sediment and organic sludge in river bottom flow down along the river, leading to excessive turbidity, ammonia nitrogen and coliform bacteria in river, which also causes serious water environment pollution of Qingyijiang River.

-d. Traditional farming and breeding still account for a considerable proportion in this area, the amount of pesticide and fertilizer use increases year by year, rural domestic wastewater, livestock breeding wastewater and household garbage are mostly discharged directly without harmless and resourceful treatment. Besides, large-scale farms and agriculture have to strive to develop in recent years, which also causes problems like sewage discharge and non-point source pollution, thereby increasing the risk of water quality. According to research, the amount of Level III, IV, V and inferior V water in medium-sized reservoirs of this area takes up 27.3%, 36.4%, 4.5%, 31.8% respectively of the total amount of tested water; the maximum over-standard rates detected in total nitrogen, total phosphorus, COD and ammonia are 69.4%, 38.9%. 41.7% and 22.2% separately. The amount of Level IV, V and inferior V water in small-sized reservoirs of this area takes up 27.3%, 36.4%, 4.5%, 31.8% respectively of the total amount of tested water; the maximum over-standard rates detected in total nitrogen, total phosphorus, COD and ammonia are 65.6%, 40.5%, 61.1% and 16.0% separately. The overall condition of small and medium sized reservoirs is organic pollution, in a state of mild or severe eutrophication [10]. Nutrients of nitrogen and phosphorus in reservoirs are mainly from farmland runoff, which takes up 93.48% of T, P inputs. Most of nitrogen and phosphorus deposited in the reservoir are in the form of particle adsorption, bringing potential hazards to the reservoir [11]. Fish cage culture reduces the DO value around the cage and increases the N, P and COD in the cage and surrounding water, making the water suffer eutrophication [12].

-e. With the increase of population, domestic waste water from urban residents and garbage pollution increase year by year. According to the survey, there is a sewage treatment plant in this area with a treatment scale of 5 million tons t/d. Only a part of urban domestic sewage can be discharged after being collected and treated by sewage collection system to reach the discharge standard, the rest are directly discharged into rivers. The total amount of the city's industrial and urban domestic wastewater discharge in 2013 is 4607.263 million T, among which, the amount of COD and NH3-N discharge is 13887.86t and 1636.934t respectively. A part of household garbage in this area is centrally collected and sent to landfill, the rest is simple treated or piled up in the open air.

-f. The fresh water consumption of per unit industrial added value in this area is 57.4m3/ million yuan, the effective utilization coefficient of agricultural irrigation water is 0.35. It shows that industrial structure of this area is mainly based on resource development, and its level of industrial and agricultural production and technology is relatively low [13]. The industrial types in this area and their proportions in the total value of the second industries are as follows: hydropower and electrometallurgical industry accounts for 45.1%, machinery manufacturing industry takes up 15%, mining industry occupies10.4%, chemical industry accounts for 9.3%; food and beverage industry and non-metallic mineral products take up 7.5% respectively; wood processing industry and paper industry occupy 3.2%; textile industry, clothing industry and leather industry account for 1.6%; the rest industries take up 0.4%. Thus, high energy consumption industry and machinery manufacturing industry are established on the basis of water energy resources and rely on the exploitation of preponderant mineral resources like pyrite, limestone, marble and granite. Together with chemical industry, these are the major second industries in this area. Mineral resources in this area are very rich, 30 kinds of mineral resources are exploited in this city. In the exploitation of coal, lead-zinc ore, Glauber's salt, marble mine, due to original exploitation pattern, indiscriminate digging, rampant disposal of wastes, a lot of wastes is piled up on the banks and beaches of the river or discharged into the river, which not only pollutes the water environment, but also clogs the river, causing frequent geological disasters, aggravation of water and soil erosion and increasingly serious water environment pollution. In stone processing, cutting machine is often used to process stone plates. In order to improve tools' service life, product quality, production efficiency and so on, clean water is often used to cool tools in time, remove debris and clean the surface. Cooling water is often added with organic coolant like saponified substances, Taigu oil, polypropylene, ammonium chloride and sodium nitrite. Its composition is complex and toxic. A lot of powder, silicon dioxide (SiO2), calcium carbonate (CaCO3) as well as a small amount of fine diamond abrasive grain, debris, sand washed down from the surface of blocks and mill floor, and pieces of product packaging materials are discharged into the river after rough handling or without treatment, making the original clean rivers into Milk River and resulting in aquatic biological extinction. A lot of white turbid liquid flows through the ground, making it seemingly covered with a layer of white paint. What's more serious is the infiltration of sewage into the ground, because it contains ammonium chloride, sodium nitrite and other substances. If people or animals drink this kind of water, they may suffer the risk of carcinogenicity, which makes a considerable part of groundwater unable for drinking. Besides, wastewater from stone processing will contaminate large tracts of arable land and water resources and seriously damage the ecological environment. In addition, enterprises secretly discharge industrial wastewater, illegally mines sand and rocks and washes them in the nearest river, leading to the deterioration of water quality. Events like ecological environment destruction occur from time to time. In recent years, resource-oriented industrial structure gradually changes, but structural pollution is still the focus influencing ecological risk of water resources in this area.

-g. Because of the change in land planting structure (like crop plantation is changed for tea, fruit and vegetable cultivation and so forth.), the rapid development of urbanization, andthe construction of modern agricultural park, rural land uses in this area is constantly changing. Under the influence of heavy rainfall in this area, accumulation effect of nutrients like N, P in soil changes, and the circumstances of water and soil erosion change, thereby affecting the change in ecological system of water environment. According to research, land uses in Fenjiang basin in Yucheng County have a significant impact on the accumulation of phosphorus in soil. Phosphorus adsorption capacity of soil in tea garden is extremely strong; while that in farmland, orchard, grassland soil and especially artificial woodland is relatively weak; Phosphorus loss risk of soil in artificial woodland, grassland and farmland is high, therefore, methods like compensation for P or maintenance of phosphate fertilizer should be adopted. Phosphorus content in soil in orchard, grassland and natural forest is low; but there is almost no risk of losing phosphorus in the soil of tea plantation [14].

-h. Because of Wenchuan 8.0 magnitude earthquake on May 12th in 2008 and Lushan 7.0 magnitude earthquake on April 20th in 2013, water conservancy facilities were badly damaged (for example, the city's 37 reservoirs, 993 Shan Pingtang(a small agricultural water storage project mainly used to solve the problem of water for production and living in the countryside), water diversion project of 8720km, 468 pumping stations, 2911 water kilns for water storage, embankment of 215.12km, 263ha fishing area and 30800ha area of soil and water conservation were seriously damaged, 101.58 million people lacked adequate drinking water because of the violent Lushan earthquake on April 20th). Water supply facilities in water plants and pipelines in Lushan County and other places were severely damaged, so source water can not get purified in time, residents had to take decentralized supplied water (like spring water, stream water, river water and water in swimming pool) as the main drinking water before the arrival of disaster relief materials (including bottled drinking water). In the few days after earthquake, the earthquake worsened the environmental health status (like human and animal excreta, garbage, chemicals), and rains caused the soil to pollute water sources. Therefore, the daily test results show that the qualified rate of water quality in the early stage after earthquake is very low. Continuous monitoring of tap water and table-water in Lushan County shows that the qualified rate is under 50% mostly. Indexes like turbidity, ammonia nitrogen, total coliforms, Escherichia coli exceed the standard. Earthquake also further deteriorates the geological conditions of this area, slope materials within this area move strongly. Under the influence of heavy rainfall in this area, risk of secondary geological disasters like collapse, landslide and debris flow increases, water and soil erosion becomes serious, which results in the deterioration of ecological risk of water environment.

IV. CONCLUSIONS AND SUGGESTIONS

① Ecological risk of water resources in hilly areas is a comprehensive response to the complex changes of primary environment, secondary environment (such as human activities, land use patterns), earthquake, climate change and so on.

② Natural factors and human factors both affect the ecological risk level of water resources in hilly areas. Among them, average annual precipitation, total amount of water resources, annual waste water discharge and eco-environmental water consumption all influence the ecological risk level of water resources in hilly areas.

③ Based on water resources, water environment and water ecosystem in hilly areas, the reduction in ecological risk of water resources in hilly areas should be made by combining current situation and the major problems of water resources in hilly areas and its quality, and comprehensively applying biological, ecological and other related technologies. Besides, it constructs the ecological clean small watershed as space unit, and takes comprehensive control measures to solve problems of water and soil erosion, dewatering sections of cascade hydropower stations, non-point source pollution in rural areas, medium and small sized enterprises and large-scale pollution discharge of livestock and poultry according to local conditions. Combining total amount reduction and process control, pollution abatement and recycling, technical study and engineering application, pollutant management and ecological civilization construction together to reduce load pressures of water pollution so that water resources, water environment and water ecological system can evolve to an orderly direction by depending on self regulation and self organization ability of ecosystem. It will also improve and restore the water quality of contaminated water in rivers, reservoirs, and under the ground. Besides, it can improve the ability of water resources to resist external interference and its carrying capacity, promoting sustainable development of regional society, economy, resources, and environment.

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