Study on Carrying Capacity of Resources in Danjiangkou Reservoir Area based on GIS Technologies

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Keywords: Carrying Capacity of Relative Resources, Sustainable Development, Mid-Route of the South-North Water Diversion Project, Danjiangkou Reservoir, GIS.

Abstract: The environmental health and green development of the water source area of Mid-Route of the South-North Water Diversion Project (SNWDP) is not only essential for ensuring that "The clear water is sent to Beijing", but also an important prerequisite for sustainable development of society and economy in the water source area. Based on national geographic survey data, basic surveying and mapping data and statistical yearbook data, this paper used the model of relative carrying capacity of resources to estimate and analyze the carrying capacity of relative natural resources (CCRNR), carrying capacity of relative economic resources (CCRER) and carrying capacity of relative resources (CCRR) and their spatial-temporal changes in the Danjiangkou Reservoir area of the water source area of the Mid-Route of SNWDP from 2009 to 2015 by Geographic Information System (GIS) technologies. The results were shown that: (1) CCRR increased significantly compared with that in 2009. However, CCRR in the study area was still overloaded in 2015. (2) CCRNR was rich, but decreased from 2009 to 2015. (3) CCRER was in a overloading state, which increased obviously from 2009 to 2015. The improvement of CCRER was the main reason for the sustainable growth of carrying capacity in the study area. Therefore, the countermeasures including making rational use of natural resources, developing economic resources and controlling population quantity were proposed to promote the sustainable development of society, economy and ecology in the study area.

1 INTRODUCTION

The "China's National Land Plan Outlines (2016-2030)" clearly states that China adheres the matching of the national land development with its carrying capacity, the coordination of agglomeration development and balanced development, and the promotion of development and protection to achieve the high-efficient and sustainable spatial development of national land and harmonious regional development. As a basic essential to support the system of nature, economy, and society, resources and environment are playing a significant role to the sustainable development of a country or a region.

Even since the early 1980s, UNESCO has proposed the concept of carrying capacity of resources. The resources carrying capacity of a country or region is the maximum population size that the area can sustain utilizing the energy and other natural resources, as well as the conditions of intelligence and technology given the grantee of the material living standards complianced with its socio-cultural rules. Therefore, the carrying capacity of resources and environment is an important basis for evaluating regional sustainable development (Feng, 2017). However, this concept only considers the carrying capacity of natural resource homogeneously, ignoring the complementarities between natural resources and economic resources. At present, extensive research have conducted by researchers on CCRR in the provinces and cities such as Xinjiang, Shandong, Changsha, etc., as well as in Yangtze River Basin in China (He, et al. 2003; Huang, et al. 2010; Jing, 2006; Liu, 2002; Zhang, 2018; Yang, 2018), and single aspects such as cultivated land area, crop sowing area and water supply amount are selected as the key elements to estimate the regional CCRNR in the research. Due to the differences of environment, location and development level among each region, inconsistencies between the results and the actual situation is possibly existed led by this evaluation method.

The Middle Route of SNWDP is the key project related to the national economy and people's livelihood, which can effectively alleviate the water shortage in the north and support the sustainable

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development of economy and society by supplying water to Beijing, Tianjin, Hebei, Henan and Hubei provinces for urban domestic and industrial use and for agricultural and other usages (Wang. et al. 2005).

The Middle Route of the South-to-North Water Diversion Project is to divert water from the Danjiangkou Reservoir in the upper and middle reaches of the Hanjiang River, the largest tributary of the Yangtze River. The main canal is excavated at the head of the project in Xichuan County, Henan Province, on the east bank of the Danjiangkou Reservoir. Channels are excavated at the edge of the central and western regions, passing through the Yellow River through tunnels, going north along the west side of the Beijing-Guangzhou Railway, and flowing to the water delivery project of Tuancheng Lake in the Summer Palace in Beijing. The main water canals span the four provinces and municipalities of Henan, Hebei, Beijing and Tianjin. The water-receiving areas are 14 large and medium-sized cities along the line. This project focuses on solving the problem of water shortages in Henan, Hebei, Beijing, and Tianjin, and providing water for production, living, industry and agriculture for more than a dozen large and medium-sized cities along the route. The total area of the water supply is 155,000 km^2, the total length of the main water canal is 1,277 kilometers, and the Tianjin branch line is 155 kilometers long.

After the Danjiangkou Dam was heightened, the normal water level of the Danjiangkou Reservoir reaches 170 meters to guarantee the future water diversion amout. Appropriate compensation projects have been carried out in the middle and lower reaches of the Han River to ensure the industrial and agricultural development, shipping and environmental water in the transferred area while transferring water to the northern region.

To guarantee a good natural ecological environment of Danjiangkou Reservoir area, which is a water resource area of water diversion, is the basic premise to ensure the high-quality water supplying for the regions of Beijing, Tianjin, Hebei, Henan, etc. Thus, in order to provide suggestions for the sustainable development of water source area, this paper analyzed the resource carrying status in Danjiangkou Reservoir area, estimating CCRR of the productive land area considering various aspects based on GIS technologies.

2 STUDY AREA

The study area located at the Danjiangkou Reservoir and its surrounding cities and counties in the middle route project of SNWDP with the range of 109.4°~111.9° E and 32.2°~33.8° N crossing Henan Province and Hubei Province, with the total area of 17292.22 km^2 including 7 administrative units which are Danjiangkou City, the districts of Maojian and Zhangwan, as well as the counties of Xixia, Xichuan, Yunxi and Yunyang (Figure 1).

The reservoir area is located in the subtropical zone, with mild climate and abundant rainfall. The average annual precipitation is about 1000 mm and the average temperature is 15.6-16.0℃. The surrounding mountains are high and steep, with mountains and hills accounting for 97%. The plant species are various, and resources are abundant. By the end of 2015, the inhabitant in the study area was 34477,000, with a gross product of 220.93 billion US dollars. The eco-environmental status between the Danjiangkou Reservoir, which is the water source of the Middle Route of SNWDP, and its surrounding areas, has a direct impact on the quality of water transfer and project benefits. However, with the development of economy and society, the contradiction of man-land relationship around the reservoir area has become increasingly prominent. The correct analysis and evaluation of the comprehensive carrying capacity of the study area is of great significance for coordinating and solving the contradiction between human-land relationship around the Danjiangkou Reservoir area and promoting the sustainable economic and social development of the region near the Middle Route of SNWDP.

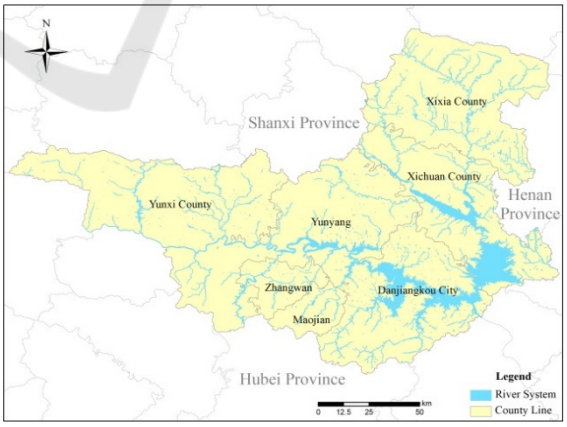

Figure 1: The location of the study area.

3 DATA SOURCE AND RESEARCH METHODS

3.1 Data Source

3.1.1 Geoinformation Data

The first China Geography Census is an important survey of national conditions, and it is a basic task for understanding and grasping national conditions to formulate national policies. We fully investigated the current situation and spatial distribution of various geographical national conditions, and mastered China geographical national conditions. The first China geography census has been accomplished in 2015, while high precision land cover data were achieved. The objects of this census were the natural and human geography elements of the land surface of the whole country (excluding Hong Kong, Macao Special Administrative Region and Taiwan). Census content included two parts. The first was the basic information of natural geographic elements, including geographic information such as topography and landforms, vegetation coverage, waters, deserts and bare land, such as categories, locations, scopes, and areas, and their spatial distribution. The other part was the basic elements of human geography Situation, including geographic information such as railways and roads, residential areas and facilities, geographic units, etc., which are closely related to human activities, and their spatial distribution status. This census adopted the China Geodetic Coordinate System 2000 (CGCS2000) and the 1985 national elevation datum, using remote sensing images with a resolution better than 1 meter acquired by airborne and satellites platforms such as Worldview, Quickbird, Pleiades and Geoeye.

1:50000 Digital Line Graphic (DLG) extracted water system, road, residential area, vegetation, soil quality, and other information about land surface from aerial and satellite Digital Orthophoto Map (DOM). It adopted the 1980 Xi'an coordinate system and the 1985 national elevation datum. This research extracted 5 classes of landcover including cultivated lands, forests, grass lands (including wetlands), construction lands and watersheds from the 1:50000 DLG of 2009 and the first national geographic condition census of China by joining processing. Due to the different contents and standards of the data collected from two timelines, this paper consistently processed the basic geoinformation of 2009 based on the achievements of the first national geographic condition census of China in 2015.

3.1.2 Thematic Data

The Gross Domestic Product (GDP) and permanent population data used in this paper was from "China Statistical Yearbook", "Statistical Year book of Shiyan City" and "Statistical Year book of Nanyang City" and "the Statistics Communique on National Economy and Social Development" in 2010 and 2016 (National Bureau of Statistics of China, 2010; National Bureau of Statistics of China, 2016; Hubei Provincial Statistics Bureau, 2010; Hubei Provincial Statistics Bureau, 2016; Henan Province Bureau of Statistics, 2010; Henan Province Bureau of Statistics, 2016).

3.2 Research Methods

3.2.1 Indicators

The sustainable development is a comprehensive ecosystem composed by the subsystems of nature, economy and society (Hao. et al. 2004), thus this paper took natural and economical resources as the main carrying resources. The natural resources were represented by the productive land resource area of ecological footprints, such as the areas of cultivated land, forests, grass lands, construction land and watersheds, while the economical resources were represented by Gross Domestic Product (GDP). Moreover, CCRNR, CCRER and CCRR were calculated taking the livable cities as the referencing area.

Livable city refers to the comprehensive evaluation of the city's suitability for living. Its characteristics are: beautiful environment, social security, civilization and progress, comfortable life, economic harmony, and high reputation. The "GN China Livable City Evaluation Index System" consists of 7 first-level indicators, including the ecological environment health index, urban safety index, convenience index, living comfort index, economic wealth index, social civilization index, and city reputation index. It is composed of 48 second-level indicators and 74 third-level indicators (Zhang, et al. 2016). The ranking of China's top ten livable cities in 2015 are Shenzhen, Zhuhai, Yantai, Huizhou, Xinyang, Xiamen, Jinhua, Liuzhou, Yangzhou, Jiujiang.

3.2.2 Methods

CCRNR were described as the following,

$$C_{rl} = I_l * Q_l \quad (1)$$

where, C_{rl} is CCRNR, Q_l is the area of productive land resources of the study area, $I_l=Q_{p0}/Q_{l0}$ is the index of carrying capacity of natural resources, among which Q_{p0} is the population size of the referencing area, and Q_{l0} is the area of productive land resources of the referencing area.

CCRER were described as below,

$$C_{re} = I_e * Q_e \quad (2)$$

where, C_{re} is CCRER, Q_e is the gross of the economical resources of the study area, $Ie=Q_{p0}/Q_{e0}$ 为 is the index of carrying capacity of the economical resources, among which Q_{e0} is the gross of the economical resources of the referencing area.

$$C_s = w_1 * C_{rl} + w_2 * C_{re} \quad (3)$$

where, C_s is CCRR, according to the details of the research $w_1=w_2=0.5$ were defined.

The calculation method of productive land resources area in formula (1) is proposed by the Canadian ecological economist named Rees and his students in 1992 and 1996 (Wackernagel, 1996). Considering the above the area of productive land in the study area were calculated using the model as the following,

$$A = \sum_{i=1}^{5} \alpha_i \times r_i \times y_i \quad (4)$$

where, i expressed the mutually-exclusive productive land including cultivated lands, forests grasslands (wetlands), construction lands and watersheds; a_i was the area of productive lands of the class i actually occupied; r_i is the equivalence factor, where the equivalence factor of the productive land of a certain kind of creature equals the average productivity of the productive land of this kind of creature in the world divided by the average productivity of productive lands of all creatures in the world. Moreover the equivalence factor of different classes of productive lands were defined as the followings, cultivated land and construction land were 2.8, for forests was 1.1, grasslands was 0.5, and watersheds were 0.2 (Wackernagel, 1996); y_i represented the yield factor, which expressed the Ratio between the average productivity of a certain productive land in the study area and the world average productivity of similar lands, where, the value was determined as 1.66 for the cultivated land, the value was taken as 0.19 for the grassland (wetland), 0.91 for forests and 1.0 for the watersheds (Wackernagel, 1996).

3.2.3 Estimated Criteria

By comparing the calculated CCRR with the actual resource-carrying population of the study area, the carrying status of the area relative to the reference area at different time periods can be obtained, including the following three states:

Overload status: population size of the actual carrying capacity of resources (P) was greater than the CCRR (C_s), or $P-C_s>0$;

Surplus status: population size of the actual carrying capacity of resources (P) was smaller than CCRR (C_s), or $P-C_s<0$;

Critical status: population size of the actual carrying capacity of resources (P) was equal to CCRR (C_s), or $P-C_s=0$.

4 RESULTS AND ANALYSIS

4.1 Spatial-temporal Changing Characteristics of the Carrying Capacity

Based on the method in section 3.2, considering the livable city as the referencing area, CCRNR, CCRER and CCRR were achieved by the calculation taking the 2009 and 2015 as the referencing year (Figure 3 to Figure 8).

The features of the comprehensive carrying capacity of relative resources of the study area could be concluded. Firstly the entire CCRR were at the overload status in the year of 2009 and 2015. Thereinto only in Yunxi and Xixia Counties, CCRR were greater than the actual population size carried in 2009, which indicated the population of two counties were under the surplus status (Figure 7 and Figure 8). On the contrary, the rest regions were under the overload status. Secondly comparing to the year of 2009, Danjiangkou City, Yunyang District and Xixia County were under surplus status relatively during 2015. All the regions showed stable changing trend comparing the year of 2015 with 2009, except Danjiangkou City, Yunxi County and Yunyang County. Thirdly, judging from overload/ surplus population size, the carrying capacity of all the rest of the regions had been enhanced comparing to the population size except the counties of Yuanxi, Xichuan and Xixia.

CCRNR of the regions appeared under the surplus status with a declining trend in 2009 and 2015, except the districts of Zhangwan and Maojian (Figure 3 and Figure 4). CCRER of all the seven regions were under the overload status in 2009, while 6 regions maintained the same status except Zhangwan District in 2015 (Figure 5 and Figure 6). In general, CCRER in 2015 was greater than it was in 2009, which indica-

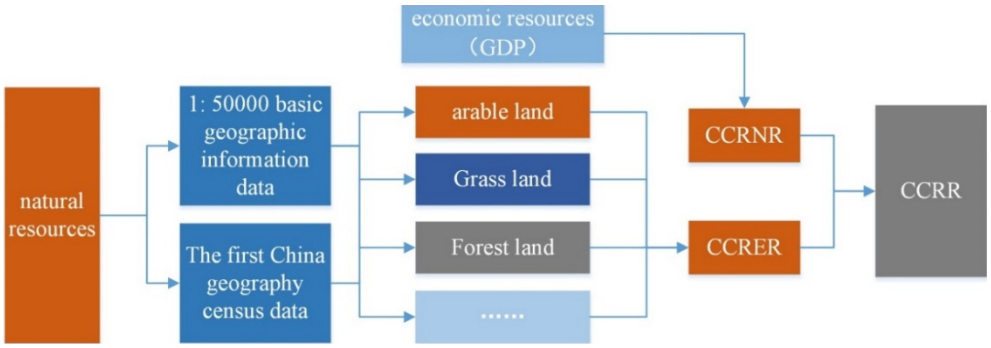

Figure 2: Calculation flow of comprehensive CCRR.

ted a rising trend. CCRNR were all above CCRER in the study area in the two time periods, which also showed a much big exceeding with regards to their contribution to CCRR (Table 2 and Table 3).

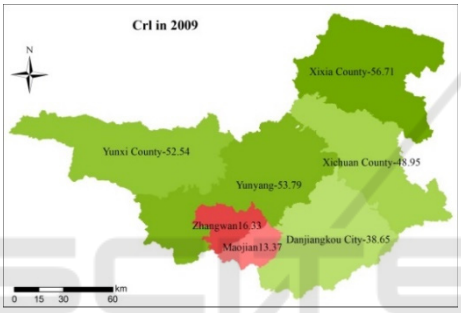

Figure 3: Spatial pattern of C_{rl} in 2009.

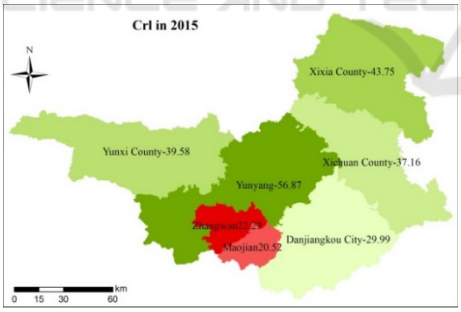

Figure 4: Spatial pattern of C_{rl} in 2015.

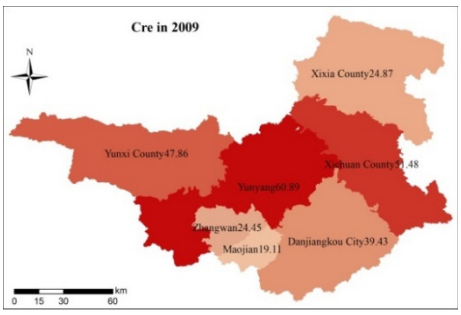

Figure 5: Spatial pattern of C_{re} in 2009.

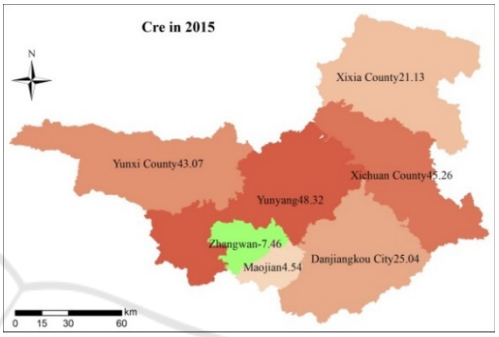

Figure 6: Spatial pattern of C_{re} in 2015.

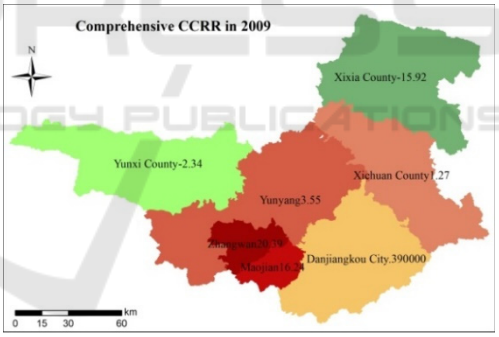

Figure 7: Spatial pattern of comprehensive CCRR in 2009.

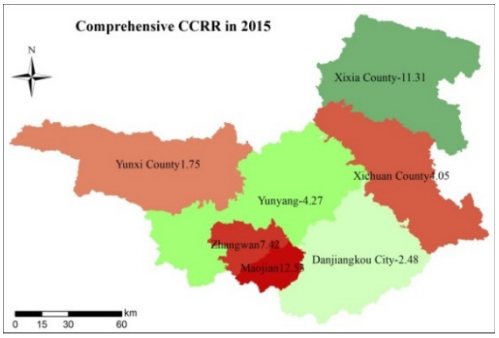

Figure 8: Spatial pattern of comprehensive CCRR in 2015.

4.2 Driven Forces Analysis

In general, CCRR and CCRER gradually increased in Danjiangkou Reservoir area and in the surrounding cities of Middle Route of SNWDP, while CCRNR presented a declining trend. The reasons were the water storage of the first and second phases of the Danjiangkou Reservoir and the conversion of farmland to forests project, which reduced the cultivated land area of the study area from 3454.73 km^2 in 2009 to 2300.33 km^2 in 2015, with a total reduction of 33.42%. Besides, the productive land, such as construction land, water area, woodland and grassland increased by 180.79 km^2, 204.07 km^2, 113.43 km^2 and 565.33 km^2 respectively. Although the cultivated land and construction land have the greatest impacts on productive land, due to the significantly shrinking of the cultivated land area in the study area, CCRNR reduced. In 2015, the GDP of the study area achieved 141.394 billion Yuan, with an increase of 190% compared with 48.08 billion Yuan in 2009. This was closely related to the optimization of industrial structure, economic restructuring, and stimulation of potential productivity and expansion of domestic demands brought by the start service of the Middle Route of SNWDP.

Danjiangkou City is the water diversion source for the four Northern provinces and the water input source for the downstream of the Hanjiang River. Its relative comprehensive carrying capacity has changed from the overload in 2009 to the surplus in 2015, which was benefited from implementation of the local immigration policy and the ecological compensation in water source areas, as well as the establishment of tertiary industry such as the business, catering and transportation industries driven by the tourism industry led by the scenic spot of Danjiangkou Reservoir. Besides, Yunxi County is located in the northwest border of Hubei Province, which borders Shaanxi Province. Its carrying status has changed from surplus in 2009 to overload in 2015 which was related to the decrease of CCRNR caused by the reduction of cultivated land area due to the implementation of conversion of farm land into forest and grass land.

Table 2: Carrying capacity of resources in 2009.

District	C_{rl} (10^4 people)	C_{re} (10^4 people)	C_s (10^4 people)	Status (10^4 people)
Danjiangkou	88.32	10.24	49.28	0.39
Yunxi	103.99	3.59	53.79	-2.34
Yunyang	119.61	4.93	62.27	3.55
Zhangwan	15.67	7.55	11.61	20.39
Maojian	13.02	7.28	10.15	16.24
Xichuan	115.42	14.99	65.20	1.27
Xixia	99.03	17.45	58.24	-15.92
Study area	555.07	66.01	310.54	17.97

Table 3: Carrying capacity of resources in 2015.

District	C_{rl} (10^4 people)	C_{re} (10^4 people)	C_s (10^4 people)	Status (10^4 people)
Danjiangkou	76.25	21.22	48.74	-2.48
Yunxi	90.00	7.35	48.67	1.75
Yunyang	114.87	9.68	62.27	-4.27
Zhangwan	17.61	47.36	32.48	7.42
Maojian	14.71	30.69	22.70	12.53
Xichuan	105.16	22.74	63.95	4.05
Xixia	90.71	25.83	58.27	-11.31
Study area	477.96	191.24	334.60	10.17

CCRR in Yunyang District maintained the same in 2015 and 2009, but because 78.2 million of the population was decreased from 2009 to 2015, the carrying status of Yunyang District has become from overload to surplus. As of 2015, Zhangwan District and Maojian District had been carried 22% of the population with 5% of the land area of Shiyan City, which accounted for 51.5% of the regional GDP of Shiyan City. The headquarters of Dongfeng Commercial Vehicle Company locates in Zhangwan District, and the largest economy body in Shiyan City. Maojian District is closely followed, which is the political, economic, commercial, cultural and sports education center of Shiyan City, as well is the largest processing and sales base of auto parts. As new urban areas headed by automobile industry, the comprehensive carrying capacities of relative resources of Zhangwan District and Maojian District were still under overloaded status by 2015, due to their continuous consumption of large population size and resources. Compared with the year of 2009, its natural and economical carrying capacity have been evidently enhanced, benefited the insistence of the local government focusing on the ecological areas construction of the whole region, and accelerating the construction of ecological civilization and the transformation of industrial economy in accordance with the thoughts of building the entire region to be an ecological area, a water source area, and a scenic area.

Xichuan and Xixia are the subordinate counties of Nanyang City in Henan Province, which are the important pilot cities of ecological civilization for Nanyang. The ecological agriculture in Xixia County, including industry of kiwifruit and mushroom, together with the ecological industry cluster area construction of ecological industry and tea industry, etc. in Xichuan County, have played an significant role on supporting the construction of water source ecological economic zone across administrative units. In addition, CCRR in Xixia County was surplus in 2015, which was benefited from the development of eco-agriculture and eco-industry, as well as the continuous enhancement of the industrial restructuring and optimization. In spite of the preferable natural resources, CCRR of Xichuan County were overloaded, which were related to the low CCRER caused by the small total economic volume, unreasonable industrial structure, unbalanced development between urban and rural areas, and the low level of economic openness, not to mention the population of Xichuan County has already reached 680,000 in 2015, which are much more than the population of other regions in the study area.

5 CONCLUSIONS

This paper estimated and analyzed CCRR in Danjiangkou Reservoir in the Middle Route of SNWDP in 2009 and 2015 based on the data of national geographical situation census, basic surveying and mapping data and thematic data. The evolution patterns were outputted as follows.

Firstly, the overall CCRR of the study area was under the overload status in 2015, but compared with 2009, it has been significantly increased. Secondly, CCRNR in the study area is under surplus status, but in general a decline trend appeared. CCRNR contributes much more to the relative carrying capacity of comprehensive resources than to CCRER. The contribution to the comprehensive carrying capacity of relative resources from CCRNR was much more than it was from CCRER. Thirdly, CCRNR of the study area was under the overload status with an obvious rise. Moreover, the main reason of the rise of the carrying capacities was the continuous increasing of CCRER.

Based on the above, suggestions for development of the reservoir area were proposed as the followings: It was suggested to ensure the rational development and utilization of resources and to provide resources for the sustainable development of society and economy in Danjiangkou Reservoir area and its surrounding cities and counties of the Middle Route Project of SNWDP. Meanwhile the scope of national ecological compensation need to be continuously expanded and its scale need to be gradually enlarged. More Attention shall be paid to the construction of ecological engineering in water source areas, and more financial support should be provided to formulate improved and long-term governance planning and management measures of water source areas.

It was suggested to control the populations size reasonably while enhance the population quality continuously. In regard to Xixia County, its population size was under surplus status which illustrated a large space for the expanding of the carrying capacity of population size. To hold the opportunity of development, accelerate the social-economic development of Xixia County, and to solve the problem of the talent shortages, the actions shall be taken to bring in and cultivate various talents.

It was suggested to constantly promote the contribution to the comprehensive carrying capacity from the economical resource and to facilitate the progress of industrial restructuring. That is to optimize the structure of agricultural industry, develop organic ecological agriculture rapidly, adjust the industrial structure and build environmental protection industrial bases. Moreover, the tertiary industry such as trade logistics and service industry shall be positively developed, with a green tourism development plan to be formulated for Danjiangkou Reservoir area to promote the prosperity and development of the tourism industry.

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