Current Research Status and Perspective of Water Resources Carrying Capacity in the Arid and Semi-arid Regions of Northwest China

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Abstract. The imbalance between supply and demand of water resources in the arid and semi-arid regions of northwest China is growing increasingly severe. Consequently, it is essential to study the water resources carrying capacity in the key areas timely. The research on water resources carrying capacity in these areas was summed through three aspects—city, district and valley, which is from focusing on local domain to doing systematic research on man-land relationship. Then, the research methods of water resources carrying capacity were summarized and analyzed, including simple routine method, fuzzy evaluation, principal component analysis, ecological footprint method, multiple objective decision making method and systematic dynamics method. Moreover, the relative merits and application condition were also provided. Finally, it is presented that the research on water resources carrying capacity in future would still refer the concept, theory and research methods. Ecological environment will be put more focus on and the growing number of methods and technique will be used.

Introduction

It is acknowledged that China is shortage of water resources. The contradiction between supply and demand of water resource, in China, have been increasingly intensified on account of seasonal and spatial distribution of water resources, water environmental pollution and unreasonable utilization of water resources. The arid and semi-arid regions of northwest China, especially, is located in Inner Eurasia. Consequently, it is poor in precipitation and available water resources. In addition of the fragile ecological environment, water resources shortage and ecological environment damage caused by unreasonable utilization of water resources has become the obstacle of sustainable development. Therefore, it has important theoretical and practical significance to study the water resources carrying capacity in the arid and semi-arid area of Northwest China, which can promote the science and rational development and utilization of water resources, economic development, environmental protection, ecological balance and the harmonious relationship between human and land.

Concept of Water Resources Carrying Capacity

The word "Carrying Capacity" is derived from the mechanics, which is the maximum load that the object can bear without changing the original shape and being damaged. Later, the ecology quoted it as “The limiting value of the number of species that can survive in a particular ecological environment”\cite{1}. As a part of the carrying capacity of resources, the concept of water resources carrying capacity is put forward lately.

Most developed countries have abundant water resources relatively, hence the research on water resources carrying capacity is less. The corresponding concept is few as well, which just be involved in the study of sustainable development usually. For instance, the North American Lake
Association had carried on the discussion and the research to the lake's carrying capacity and put forward the definition of the lake's carrying capacity.[2]

The research of water resources carrying capacity in China began in 1980s—the first time in our country—the soft science research group of water resources in Sinkiang proposed the concept of water resources carrying capacity[3]. Thereafter Y. F. Shi[4], Y. P. Xu[5], Y. H. Hui[6], C. W. Wang[7], J. Y. Tian[8] and X. Liu[9] also put forward the concept of water resources carrying capacity. All in all, the author reckon that water resources carrying capacity means that the capability being undertaken by utilizable water resources of one region in the population, ecological environment, industrial and agricultural development and urbanization level largely, which is within the national laws and regulations permit, the context of the current scientific and technological level and under the premise of sustainable development.

Research Progress of Water Resources Carrying Capacity in Arid and Semi-arid Regions of Northwest China

It is one of the important research topics in the field of water science that promoting the evaluation system of water resources carrying capacity in typical regions, especially in the arid and semi-arid regions of Northwest China around the connotation of water resources carrying capacity.

Study on the Carrying Capacity of Urban Water Resources

Carrying the development of industry, ecological environment, economy and population pressure, cities have a serious problem of water resources.

H. S. Mou[10] discussed the setting of urban strategic layout and different types of urban water resource standard. Then put forward the theory and method of urban water resources evaluation and prediction. In addition, estimation of water environmental capacity of urban area was also proposed. Y. Z. Zhu[11] established multiple objective decision making method to study the water resources carrying capacity in Zhangye, Gansu. The results show that the water resources carrying capacity had a greater potential to improve, which should be within the corresponding ecological environment protection standards. Based on principal component analysis, Y. Y. Xiao[12] analyzed the water resources carrying capacity in Yulin, Shaanxi. The research shows that the water resources carrying capacity of each district is obvious, and the water resources planning should be made immediately. X. G. Xing[13] also used principal component analysis to study the carrying capacity of groundwater resources in Xi'an city. The results show that the groundwater resources in Xi'an city have a certain bearing capacity, and some areas are over. The co-ordinate planning should be made promptly. Through the establishment of research index system, T. Wang[14] used principal component analysis method to analyze the water resources carrying capacity of Urumqi City. The research found that the degree of water resources utilization in Urumqi city is rather high, and the carrying capacity of water resources is declining.

Study on Regional Water Resources Carrying Capacity

The scope of study on regional water resources carrying capacity is larger. For instance, a province, urban agglomeration or a region are also included. Therefore, unified planning should be put forward.

The water resources carrying capacity evaluation model of the water shortage region is studied by R. Jia[15]. The model system of regional water resources carrying capacity was established and then it was used in Guanzhong Plain. Y. Zhu[16] used fuzzy model to analyze and predict the water resources carrying capacity of the current year and 10a, 20a, 50a in future in the arid and semi-arid regions of Northwest China. Y. Zheng[17] used multi-objective decision analysis method to study the water resources bearing capacity of Yanqi basin. The multi-objective decision model about regional water resources carrying capacity was established and then was used to forecast water resources carrying capacity. Basing on GIS, water resources carrying capacity on county scale in Shaanxi Province were analyzed by L.X. Wang[18]. F.F. Luan[19] investigated the condition of water
resources’ use about the current years in Sinkiang. The carrying capacity of Sinkiang prefectures in the future was analyzed by ecological footprint method and the law of supply and demand balance. The results showed that there are no carrying advantages in southern, northern and Eastern. Besides, the status of water resources carrying capacity should be paid more attention.

Study on Carrying Capacity of Water Resources in River Basin

The scope of water resources carrying capacity in River Basin is the largest. The inland river basin in arid and semi-arid areas are the main object of study. What’s more, sometimes, it is combined with urbanization to be studied.

Through the simple routine method, Y. G. Qu[20] forecast the water resources carrying capacity in Heihe river. According to the characteristics of water resources in different utilization stage and the special social and economic requirements of water in different regions, water resources should be reasonably allocated. Using the fuzzy evaluation model, the present situation of Yili River Basin in Sinkiang and the water resources carrying capacity of different level in Yili River Basin were evaluated by J. M. Li[21]. The results show that the water resources development potential of river basin is huge. With the economic development, but, water resources carrying capacity has gradually weakened. F. Jiang[22] selected the water resources carrying capacity evaluation model of National population development functional areas of technical guidelines. Water and soil resources carrying capacity in Yanhe River were studied. The results show the water resources carrying capacity in different counties are overload. R. F. Wei[23] set up a fuzzy evaluation model and studied the water resources carrying capacity of the Kaidu-Kongquehe river basin. The research found that the overall water resources carrying capacity of the river basin is rather poor and the regional differences are obvious. In addition, the carrying capacity of the whole water resources is declining and the development potential is not great.

To sum up the study progress, the research on water resources carrying capacity makes that people pay more attention to regional water resources problems. Under the background of the current economic and social development, the research on water resources carrying capacity of different scales is particularly important and urgent.

The Research Methods of Water Resources Carrying Capacity in the Arid and Semi-arid Regions of Northwest China.

There are many techniques in water resources carrying capacity, the techniques developed gradually from qualitative research and there are also diverse technical means to select. Currently, the main methods of water resources carrying capacity in the arid and semi-arid regions of northwest of China are as follows: simple routine method, fuzzy evaluation, principal component analysis, ecological footprint method, multiple routine method and systematic dynamics method, etc. The comparisons of each method’s advantage and disadvantage and applicability are in Table 1. The overview of each method is as follows:

Simple Routine Method

This method mainly predicts the development trend of the social and economic departments, the water demand standard and water demand in different levels of the research area. And it also analyzes and calculates how much populations, industries, farming and ecotope the water resources can carry. This method is easy and visualized. The soft science research group of water resources in Sinkiang[23] was the earliest to use the simple routine method to study the water resources carrying capacity in Sinkiang autonomous region. Y. F. Shi[4] also took this method to analysis the water resources carrying capacity of Urumqi River basin. But almost of indexes used by this method refer to social factors and it only analyzes the developing trend of single index. The mutual influence of each factor, in fact, is complex and the calculation results are difficult to reflect the actual situation of water resources carrying capacity in the study area accurately.
Fuzzy Evaluation

Y. P. Xu\textsuperscript{[5]} was the first to adopt fuzzy evaluation method of water resources carrying capacity in Hetian basin of Sinkiang. Y. Z. Zhu\textsuperscript{[16]} also used this method to study water resource carrying capacity in 5 provinces of Northwest (Sinkiang, Gansu, Qinghai, Shaanxi, Ningxia). This method usually selects the factors which influence the water resources carrying capacity of the study area and then each factor was assigned to weight on the basis of single factor analysis. Finally, it takes the comprehensive judgement matrix to make a multi factor comprehensive evaluation on the water resources carrying capacity in the research area. This method can reflect the status of water resources carrying capacity in the study area comprehensively. However, the fuzzy evaluation method in the selection of evaluation factors is selective and targeted and it needs to choose the factors that be more affective. This progress is rather subjective. In addition, during the process of the evaluation matrix calculation, the procedure of giving weight of each factor is subjective and the evaluation results inevitably have a deviation with the actual situation.

Principal Component Analysis

This method is a multivariate statistical method which divides several indexes into a few comprehensive indexes. Under the premise that the information loss of the variable indexes is minimal, it reduces the dimension of the high dimensional variables which affect the water resources carrying capacity. Finally, many indexes are replaced by a few comprehensive indexes. According to the relative date, X. Fu\textsuperscript{[24]} took principal component analysis to make a comprehensive analysis and research of regional water resources carrying capacity in Pingba basin of Hanzhong Shaanxi. T. Wang\textsuperscript{[14]} also have used this method to carry on the research of water resources carrying capacity in Urumqi city. However, a few comprehensive indexes should be given weight, which still have a problem in accuracy. In addition, it is also difficult to avoid the loss of information.

Ecological Footprint Method

This method means that it constructs the secondary account of water resources in the study area and then introduces the ecological productive land to analyze the carrying capacity of water resources quantitatively. In the end, it measures and evaluates the sustainable utilization of water resources by using ecological deficit and ecological surplus. Because it can make up for the lack of other method in the calculation of water resources carrying capacity and it can realize the research of dynamic changes about water resources carrying capacity at the same time. Therefore, this method is widely applicable. But in the calculation of water resources carrying capacity, the ecological footprint method uses the biological production capacity of water resources to calculate and measure indirectly. Hence, there is deviation between the calculation results and the actual situation deviation. J. Zhang\textsuperscript{[25]} used the ecological footprint method to study water resources carrying capacity and ecological deficit of Shule river basin. And H. Ma\textsuperscript{[26]} also used this method to analyze and study the water resources carrying capacity and water usual efficiency of autonomous region in Sinkiang.

Multiple Objective Decision Making Method

This method mainly selects the economy, society, population, ecological environment and other constraints which affect the water resources carrying capacity. According to the principle of sustainable development, it optimize the multi-objectives integrally. This method can combine the water resources system and the economic and social system to form a whole and then analyze it. Consequently, this progress is integral obviously. Utilizing this method, Z. M. Xu\textsuperscript{[27]} established the water resources carrying capacity analysis model of Heihe river basin and evaluated the water resources carrying capacity. This method, however, also has a problem that the procedure of giving weight to the impact factor is still subjective and one-sided.
**Systematic Dynamics Method**

This method is a system analysis technology that studies the system which is high order, nonlinear, multiple feedback and complex time-varying quantitatively, which is based on the theory of feedback control and computer simulation technology. Basing on the SD model, J. H. Wang used the system dynamics method to analyze and predict the water resources carrying capacity of Urumqi during 1993 to 2020. T. S. Li and F. Zhu also took this method to evaluate the water resources carrying capacity of Guanzhong region of the Weihe River Basin and Suzhou District of Jiuquan, Gansu Province. This method can grasp the response relationship between the various elements of the system well. But it also has a problem that the selection of the system’s parameters is difficult to control. The calculation results, accordingly, will still have deviation.

<table>
<thead>
<tr>
<th>Research Method</th>
<th>Merits and Drawbacks</th>
<th>Applicability</th>
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<tbody>
<tr>
<td>Simple routine method</td>
<td>Merit: simple, intuitive</td>
<td>Trend and potential analysis for single carrying factor</td>
</tr>
<tr>
<td></td>
<td>Drawback: There is no account and analysis of the interaction between the various factors</td>
<td></td>
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<tr>
<td>Fuzzy evaluation</td>
<td>Merit: comprehensive, relatively accurate</td>
<td>Apply to calculating the carrying factor accurately</td>
</tr>
<tr>
<td></td>
<td>Drawback: The selection of carrying factors is subjective and there is the deviation in the weight of the carrying factor</td>
<td></td>
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<tr>
<td>Principal component analysis</td>
<td>Merit: simplify complex calculations, relatively accurate</td>
<td>For water resources carrying capacity of horizontal comparison</td>
</tr>
<tr>
<td></td>
<td>Drawback: Reducing dimension lead to the loss of information and the weight of the composite index has the deviation</td>
<td></td>
</tr>
<tr>
<td>Ecological footprint method</td>
<td>Merit: Wide application Realize dynamic change trend study. The water resources ecological function is considered</td>
<td>Apply to research on dynamic change of water resources carrying capacity</td>
</tr>
<tr>
<td></td>
<td>Drawback: It is indirect calculation and be not comprehensive</td>
<td></td>
</tr>
<tr>
<td>Multiple objective decision making method</td>
<td>Merit: Under the principle of sustainable development, it considers the whole system of the relationship between people and land and the globality is fine. Drawback: There is deviation in the weight of the load factor.</td>
<td>Apply to vertical analysis of water resources carrying capacity and the overall optimization of the complex system of water resources, economy, population, and environment</td>
</tr>
<tr>
<td>Systematic dynamics method</td>
<td>Merit: The mutual influences of the carrying factors is accurate</td>
<td>Apply to analysis and study the open system of water resources, social development, population and environment which is highly complex and multi-level</td>
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</table>
Although there are many methods for water resource carrying capacity research, each method has its own disadvantages. It needs for further study to sum up and find a objective and unified method to meet the actual carrying capacity, and it is easy to calculate and easy to operate. At present, many domestic scholars are studying the evaluation index, method and application of water resources carrying capacity. They are trying to establish a unified method and evaluation system for carrying capacity of water resources to promote the application.

The Research Prospects of Water Resources Carrying Capacity in Arid and Semi-arid Regions of Northwest China

Related Concepts, Theories and Methods of Evaluation Will Continue to Be Carried Out

The development and research of any subject needs the support of theory. But the theory, concept and subject background of water resources carrying capacity are not unified. On the one hand, because of the cross of discipline and undefined concepts, the research direction may be expanded. But on the other hand, the lack of discipline background and foundation makes that the study of water resources carrying capacity is difficult to be promoted further. Moreover, there are large numbers of methods on studying water resources carrying capacity. The research on innovative and modified evaluation methodology will continue to be carried out, which makes the results close to actual. Therefore, the relevant concepts, theories and methods of water resources carrying capacity will also be the basic issues that the scholars continue to explore and study.

Research Will Be More Involved in the Ecological Environment

The study of water resources carrying capacity is usually involved in populational, industrial and agricultural water demand, which is often combined with the urbanization. The water resources, social economy, population and ecological environment constitute a system together. The interaction between the ecological environment and water resources is complex. However, research on the ecological environment problems caused by the lack of water and water resources carrying capacity should be pay more attention. The ecological environment is quite important for the survival of human beings and other organisms, but the special nature of the ecological environment in the arid and semi-arid area of Northwest China. Consequently, the response relationship between the ecological environment and water resources carrying capacity is a major study direction in the future.

Research Methods Tend to Diversification and Multi-Technology Combination

With the rapid development of science and technology, the research methods of water resources carrying capacity are also diversified. What's more, the basic data we get will be more accurate. Mathematical statistics method and dynamic simulation of mathematical model can add the time series to the study well, which make the results be closer to the actual. The study of water resources carrying capacity is a system problem. Because the conditions are complex, then the selection of different methods for different conditions can make the calculation results be more accurate. At the same time, the GIS technology has powerful spatial analysis and data processing capacity. It can provide a wider way for the study of water resources carrying capacity.

Conclusion

According to the background of physical geographical conditions and China Western Development in the arid and semi-arid area of Northwest China, the water resources carrying capacity is rather prominent. Only balance the water resources, ecological environment, social economy and population as well as the scientific and rational allocation and utilization of water resources, can we improve water resources carrying capacity and realize the sustainable development of the region and the harmony of human land relationship. Therefore, the research on water resources carrying capacity of arid and semi-arid regions of Northwest China has considerable scientific and practical significance.
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