Evaluation of Water Resource Carrying Capacity of Small Towns in the Rapid Urbanization Period in China

Nailu Tian[1]

Abstract

With the acceleration of the urbanization process of the small town in China, the problem of shortage of the water resource has become evident, as a result, it is urgent to set up a system for monitoring and evaluation the water resource carrying capacity (WRCC) of these small towns and predicting the trends of the change of the WRCC in this rapid urbanization period according to the master plan of the town. By analysis the progress and problems of the previous research of the WRCC, this paper proposed a method: per-land water consumption method for monitoring the WRCC of the small town in the rapid urbanization period which can be cooperated with the 3S technology (RS, GIS, GPS) by surveying and calculating the average per land water consumption data of each water consumption unit in the small town. And based on the features of the water supply and consumption in the small town, this paper also proposed the index system and model for WRCC evaluation which is adaptable to the monitoring system. In the end, this paper takes Dongsheng town as a case for testing the reliability of the monitoring, evaluation and prediction system of the WRCC. And according to the result of the evaluation and prediction of the WRCC in Dongsheng town, the rationality of the master plan for 2020 has been tested and solutions are given to improve the WRCC in Dongsheng town.

1 Introduction

The WRCC of small town in the rapid urbanization period refers to the maximum support capacity of the reasonable optimized water resource for the local social and economic development, which is within the administrative region of small town, in the historical stage of rapid urbanization period, on the base of foreseeable technical, economic and social development, for the principle of sustainable development, and in order to maintain the virtuous circle of ecological environment.

Thus, the study of WRCC of small town in the rapid urbanization period is different from the normal study of WRCC. Firstly, it takes the small town as the study area. Since the water circle in the small town has dual characteristic, the WRCC is also impacted by the nature and social factors. So in the study of the WRCC of small town in the rapid urbanization period, the impact of the human activities on water resource and the constraints of water resource on human activities should also be considered. Secondly, the WRCC is corresponding to the background of rapid

[1] The University of Tokyo, Japan, sweetmouse2000@hotmail.com

urbanization. China now is facing the rapid urbanization process which is firstly reflected on the changes of land use: with the continuous expansion of urban construction land, a large number of rural lands have been eroded. Meanwhile, this process of land use change, with the rural- urban agglomeration and rural industry structure upgrading, has brought significant impact to the social and economy in the rural area. So the WRCC in this period will also change dynamically according to the huge changes in social and economy. It is the features of WRCC of small town in the rapid urbanization period that makes the evaluation and monitoring of the WRCC much more difficult.

Since the 1970s, scholars have done a lot of researches on the WRCC of small town. These researches have mainly been conducted on in nature resource and environment region, focusing on the improvement of algorithm and the application of evaluation model. Although none unified method of calculation for the WRCC has been confined now, algorithms for these various models have become mature. Meanwhile, there are two deficiencies in these previous studies.

First, in these studies, the data for the evaluation of the WRCC come from the local water resource statistics. However, these data still have some questions as follows: firstly, these data are based on annual statistics. The period of statistics is too long to reflect the dynamically change of the WRCC in the urbanization process. It is impossible to get the monthly even daily data, since it will bring huge amount of work to the statistics department. Secondly, the data of water resource which take small town as the statistic area can hardly be found out in China, because there is mostly no water resource bulletin in the town level. Though we can find out the annual water consumption data from the statistical yearbook of the small town, these data are too general to reflect the water consumption situation. That means these data are not detail enough for the evaluation of the WRCC. Finally, these statistical data may be processed by the local department, so the reliability of the data is not very high.

Second, these studies are tent to focus on the relationship between the town scale and the WRCC. They often reflect the scarcity of the water resource by evaluation of WRCC, like Guo xuan's study on the WRCC in Yiwu [9], or predict the change of WRCC by Scenario analysis, like Teng Zhaoxia's study in Jinan [10]. These studies always consider the needs of water resource first and then find out some method to divert and save water in order to satisfy the needs. However, none of these studies proposed to make constrains to the population or the scale of the towns according to the result of the WRCC. From this point of view, these studies can do little things with the planning for the small town.

2 Evaluation based on per-land water consumption method

In order to evaluate the WRCC which will change dynamically with the urbanization process of the small town in the quickly urbanization period, it is urgent to get the water consumption amount which will change in pace with the change of land use.

Thus, the concept of per land water consumption has been proposed in this paper, which means the average water consumption in 1 m^2 and 1 day for different land use area in the certain level of social- economic development.

The water consumption per land value can reflect the level of water consumption in different land use units. And through the water consumption per land value, it is easy to achieve the conversion between the land use data which can be obtained from remote science technology (RS) and the water consumption data for the dynamic monitoring of the WRCC.

The method for survey of the water consumption per land value is as follows：Firstly, set up the GIS database and put the data of land use and height of the building from RS into the database to form the map of land use and building height separately. Secondly, overlap the maps together to form the map of water use units. These water use units which have different land use and intensity of development are considered to have different value of water consumption per land, and they become the base units for the survey of water consumption per land. Also, according to the features of different water use units, they can be divided into 4 types which have different ways for the survey of water consumption. Then, the total water consumption in small town will be calculated by the water consumption in every water use units. Finally, the total water consumption value will be tested by comparing to the water consumption in annual statistics. If the result is reasonable, the water consumption per land value can be used in the prediction and evaluation of WRCC.

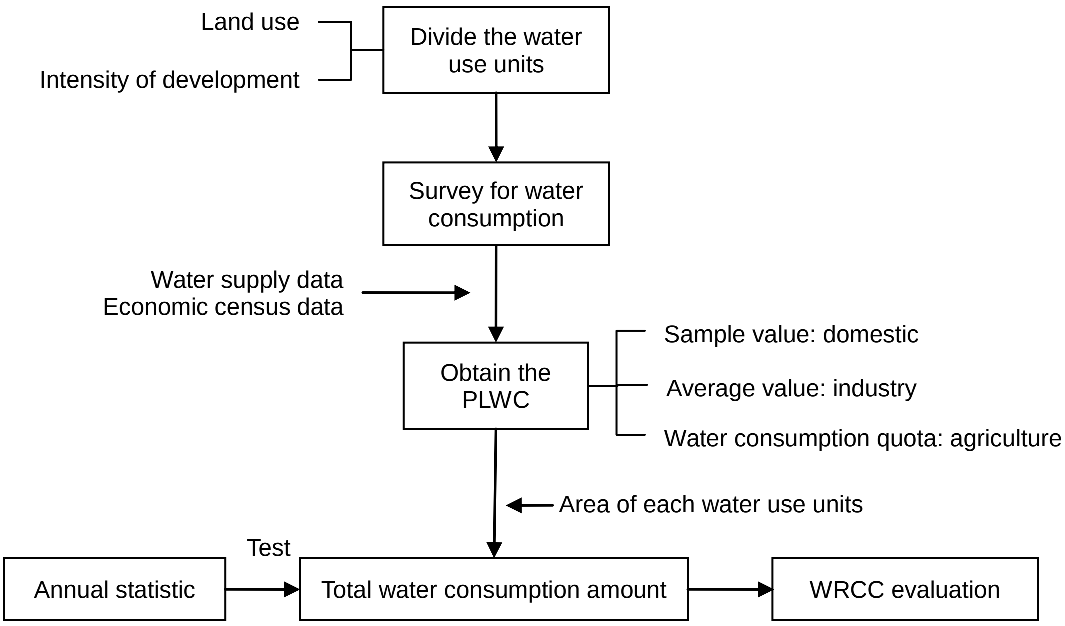

Figure 2.1: Structure of per-land water consumption method

Based on the water consumption per-land, the current system for WRCC evaluation would have to be improved, which means new index system will be set up, and the data for the new index system will be obtained by calculation with the water consumption per land value and the land use data from RS or mast plan of the town. Also, current evaluation model has to be improved to adapt to the new index system. This new evaluation system for the WRCC can solve the problems in the current evaluation system which is too static to monitor the changeable WRCC in urbanization period. And the new evaluation system can apply better in urban planning. For example, in the process for making the master plan for small town, this new system can evaluate the WRCC in the future according to the population and land use data which has been decided in the master plan. And the result of the evaluation can also be one of the test tools for the rationality of the master plan.

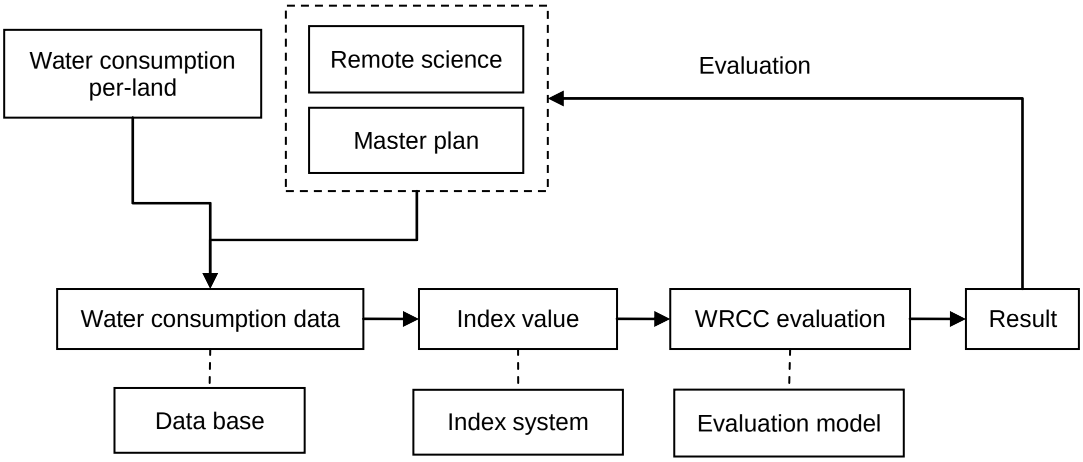

Figure 2.2: Evaluation of WRCC based on per-land water consumption

2.1 Divide the water consumption unit

Since the per-land water consumption is affected by the land use change greatly, the dividing of the water consumption unit is the key for surveying of the per-land water consumption. As the per-land water consumption is mostly affected by the land use and development intensity, these two elements are considered as the basis for dividing water consumption unit. The first thing to do is surveying for the land use and the height of buildings of the town and draw maps of them. The land use is divided into 12 types according to the "land use classification criterion" (GB/T 21010-2007). The heights of buildings are divided into 3 types: high rise buildings which have more than 10 floors, multi-storey buildings which have 4-6 floors and low-rise buildings which have less than 3 floors. Then, the two maps are imported into GIS to set up the spatial data set and overlaid to make the numbers of land units. These land units which have different land use and height information are confined as water consumption units. And these units are also the basic unit for the sample survey of the per-land water consumption.

2.2 Survey for per-land water consumption

On the basis of water consumption unit map, surveys are conducted in each unit. The data of water consumption are got from the water company, according to the different use of the water, the water consumption units can be divided into following 4 conditions.

1. Domestic water consumption: related with residential and business area, including the water consumption of public service facilities and in daily life. As the water is supplied by the water company, the water supply data of different user can be got from the water company and the water consumption data in different water consumption units can be counted. Sample survey will be conducted for the per-land water consumption data in this condition.

2. Industry water consumption: related with industry area and also supplied by the water company. As there are many kinds of industries in one town, the difference in industry have significant impacts on water consumption. In this study, typical industry area which including almost all the industries in this town will be chosen as the research area, all the industries in the research area will be surveyed and the water consumption data will be got from "the second nation economic census". As a result, the value of per-land water consumption of various industry enterprises can be got.

3. Agriculture water consumption: related with the agriculture area, the water directly comes from rain water and river. The per-land water consumption in this condition has already be studied and confined as water consumption quota for agriculture. So the water quota will also be used in this research as the per-land water consumption for agriculture.

4. Sanitation water consumption: related with road, green area and squares and the water mainly comes from rain water and river. As the water consumption in this condition is very low and relatively stable, annual data are used for this part of water consumption.

3 Establishment of evaluation system for WRCC

3.1 Index screening

The classification method and itemized method which are commonly used currently for screening of indexes are being combined together: the classification method is used first to list numbers of index exhaustively, and then itemized method is used to filter the index in order to get a small amount of itemized index for evaluation.

First, all of the index in current WRCC evaluation system were summarized and classified. And these indexes were sort by the frequency of occurrence. As a result, 50 indexes were listed. Since the number of indexes is too much for getting the data and determining the weight, these indexes need to be filter, and these indexes which have good representation and specification and easy to obtain are chosen for the index system. According to the data and standard value availability, initial screening has been done. Then, refer to the features of the WRCC in the rapid urbanization period of small town and on the basis of expert consultation, finally, 12 indexes were chosen for the index system (Table3.1).

Moreover, the weight of the indicators is determined by AHP, Scores from 0 to 1 are given to these indicators according to their importance by 20 experts.

Table 3.1: Index system of WRCC evaluation in small towns

Target layer	Standard layers	Index layers	Units	Weight	Explanation	Function
WRCC in small town (A)	Water resource quantity (B1)	Water resource availability rate per capita (C1)	M^3	0.24505	Water resource available quantity/Total population	Water resource availability per capita
		Crossing water utilization rate (C_2)	%	0.076069	Crossing water consumption/ Total water consumption	Utilization of crossing water
		Ground water exploitation rate (C_3)	%	0.076069	Ground water exploitation yield/Total ground water quantity	Exploitation of ground water
		Water resource utilization rate (C_4)	%	0.141773	Water supply quantity/ Water resource available quantity	Development of water resource
	Supply and demand of water resource (B_2)	Leakage percentage (C_5)	%	0.019514		Water resource management efficiency
		Domestic water consumption per capita (C_6)	Liter	0.056341	Domestic water consumption/Total population*days	Domestic water consumption
		Water modulus (C_7)	Million m^3/km^2	0.108719	Water demand/ Land area	Water demand
		Agricultural water consumption per acre (C_8)	M^3	0.056341	Agriculture water consumption/ Farmland area	Agriculture water consumption
		Industrial output water consumption per million Yuan (C_9)	Million m^3	0.056341	Industrial water consumption/ Industrial output	Industrial water consumption
	Water resource quality (B_3)	Ecological and environmental water rate (C_{10})	%	0.088271	Ecological and environment water demand/ Gross amount of water resource	Ecological water and environment demand
		Urban sewage treatment rate (C_{11})	%	0.026824	Sewage treatment amount/ Total sewage amount	Sewage treatment efficiency
		Surface water level (C_{12})	Class (Ⅰ-Ⅴ)	0.048685		Surface water pollution

3.2 Evaluation model

Currently, the most common models for WRCC evaluation are System dynamics method, multi-objective decision-making method, the conventional trend, fuzzy comprehensive evaluation method. Due to the aim for WRCC evaluation in this research which in order to grading the WRCC into 3 levels for early warning of the lack of water resource on the basis of several indexes, the most suitable model is fuzzy comprehensive evaluation method. This method can not only use the mathematical definition of matrix multiplication to rationally combine the impact of various indicators on WRCC, but also through the fuzzy processing of each indicator to eliminate the jump between the various evaluation levels, thus making the function transit smoothly between the levels. As this algorithm is more accuracy, in this paper fuzzy comprehensive evaluation method are chosen for setting up evaluation model.

3.3 Index grading

The standard value of the 12 indexes which were determined as the factors for WRCC evaluation have 3 sources: the first one is the relevant standards in the national evaluation and supply and demand analysis system; and the second is the existed evaluation system for WRCC; and the last one is the average values instead when standard value can be hardly found.

Table 3.2: Grades of comprehensive evaluation

Index	Unit	v_1	v_2	v_3
Per capita water availability	M^3	>600	600-400	<400
cross-border water	%	<5	5-50	>50
Groundwater extraction rate	%	<30	30-70	>70
Water resource utilization rate	%	<30	30-80	>80
Pipeline leakage rate	%	<7	7-12	>12
Per capita daily water consumption	Liter	<70	70-220	>220
Water modulus	Million m^3	<1.5	1.5-3.9	>3.9
Agricultural per mu water consumption	M^3	<400	400-800	>800
Industrial per million yuan output water consumption	Million m^3	<0.08	0.08-0.2	>0.2
Ecological and environmental water rate	%	>5	5-2	<2
Urban sewage treatment rate	%	>70	70-45	<45
Surface water level	(Ⅰ-Ⅴ)	Ⅰ、Ⅱ	Ⅲ、Ⅳ	Ⅴ

According to the standard value of the index, the effect of these indexes which taken into the WRCC are divided into 3 grades. The grade v_3 indicates that the situation of WRCC is comparatively worse, the WRCC is close to saturation, will not carry in the near future, the potential of the further development of water resource in very small, water resource shortage is likely to occur and the development of economic will be restricted by water resource. So in this situation, an early warning should be given and measures should be taken to improve the water demand and supply condition. The grade v_l indicates that the situation of WRCC is good, the water resource still has carrying potential. So in this situation, water supply is guaranteed. The WRCC condition in grade v_2 is between grade v_1 and $v_{3,}$ which indicates that the development and use of water resource has reached a certain scale, however, the potential of further development of water resource is still high and the water resource can support the economic development in the near future.

3.4 Evaluation matrix *R*

How to choose the evaluation matrix *R* plays a significant role in the fuzzy comprehensive evaluation. Since the value of evaluation grade is discrete, the final point of evaluation is discontinuous with respect to the value of some evaluation factor if we just assign some grade v_i to evaluation factors according to their values. In order to eliminate this kind of discontinuation, in this article we adopt some reasonable weight functions of evaluation grades *V*. These weight functions are characterized by piecewise linear and continuous with respect to the value of some evaluation factor.

4 Case study

In order to test the practicality and accuracy of the WRCC evaluation system which is proposed in this paper, Dongsheng town are chosen as the region for case study.

4.1 Test of the estimated value

Based on the survey methodology introduced before, surveys are conducted in different water consumption units and the per-land water consumption value of each water consumption unit has been obtained. Then, the total water consumption value of each unit is estimated according to the per-land value. Comparing the estimated value with the statistic value in statistical year book of 2008, it is easy to find out that in the first condition, the statistic value is 80% of the estimated value, while in the second and third condition the statistic value and estimated value are almost the same. The estimated annual water consumption of Dongsheng town is 62,250,000m^3, while the statistic value is 59,290,000 m^3, the error is 5%. This proves that the per-land water consumption method for predict the water consumption is relatively feasible.

4.2 Forecasting of water consumption

With the WRCC evaluation model and the estimated water consumption value by per-land water consumption method, not only the WRCC now but the WRCC in the future can also be evaluated. The land use, land scale and the development intensive data are obtained from the master plan, and the evaluation result itself will also become evaluation tools for the reasonability of the master plan.

Figure 4.1: Types of water consumption in different areas

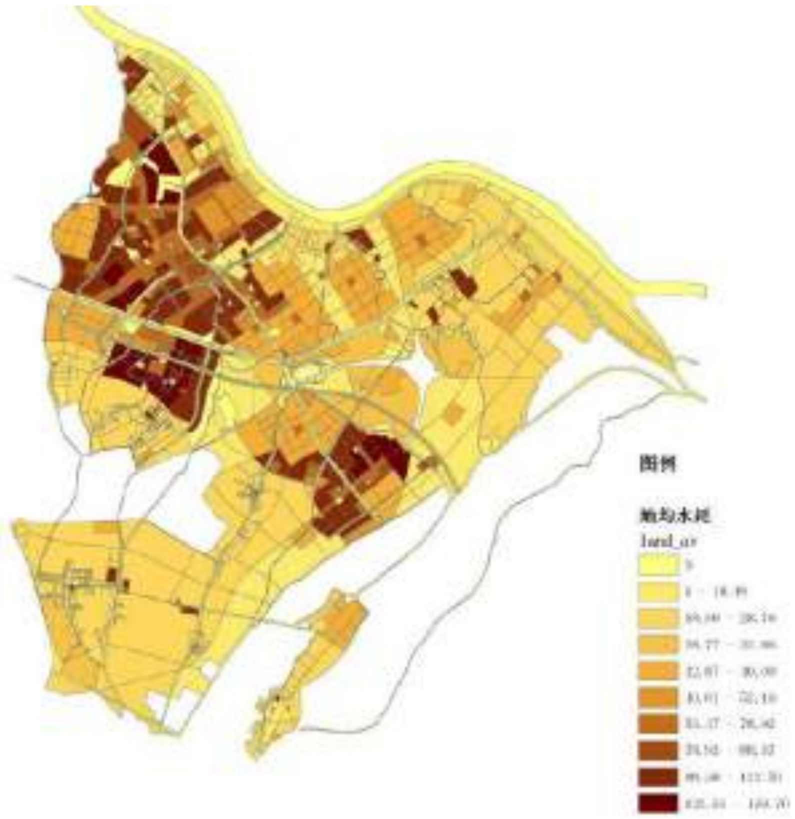

Figure 4.2: Average water consumption in different areas according to the master plan

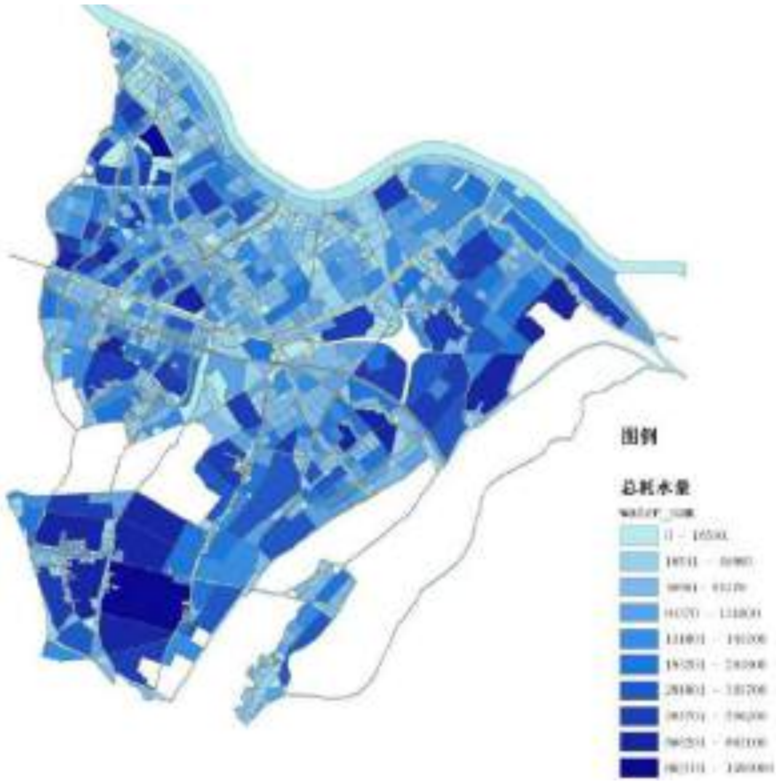

Figure 4.3: Water consumption in different areas according to the master plan

In this paper, the land use and height data are obtained from the master plan of Dongsheng town (2010-2020). 22 water consumption units are set up by overlaying the land use and the height data (Figure 4.1). Based on the per-land water consumption value which surveyed before (Figure 4.2), the water consumption of each unit can be calculated and maps are made (Figure 4.3). From these maps, it can be find out that the planned new town has relatively high per-land water consumption, due to the planning of high density of business and residential area.

Table 4.1 Predictive value of some indexes in Dongsheng, 2020

Index	Value
Per capita daily water consumption	196.91 Liter/person*day
Water modulus	20.22 Million m^3/km^2
Agricultural per mu water consumption	$590m^3$/acre
Industrial per million Yuan output water consumption	0.0027 Million m^3/million Yuan
Urban sewage treatment rate	100%

Based on the prediction of the water consumption data, the value of each index can also be predicted. It can be found out from the historical data that the amount of water resource stays stably in spite of the urbanization process. As a result, hypothesis can be proposed that the water resource amount in Dongsheng town will still stay stable in the future 20 years. According to the economic and population data planned in the master plan in 2020, the value of all the index can be calculated (Table 4.1).

4.3 Evaluation of WRCC

Also, the evaluation of WRCC of Dongsheng town in 2020 can be conducted. According to the result of evaluation, in 2020 the critical point of WRCC in the grade v_1 is 0.1916, the critical point of WRCC in the grade v_2 is 0.6162, the critical point of WRCC in the grade v_3 is 0.1922, and the integrated score of the WRCC is 0.4997. It is evidently that according to the master plan of 2020, the WRCC of Dongsheng in 2020 is still belong to grade v_2, which means the exploitation of water resource has already reached a quite big scale, however, there is still some potentiality left for exploitation. As a result, the water resource condition can still support the scale of land and population planned in the master plan in 2020. It also means that the master plan of 2020 is within the carrying capacity of WRCC and it is reasonable from the aspect of water resource. However, the integrated grade of WRCC in 2020 dropped 0.02 comparing to the WRCC in 2008 which is 0.512. So it is also shows that in the process of rapid urbanization, WRCC is being threatened by expanding of land scale and rising of population, and should be pay special attention on.

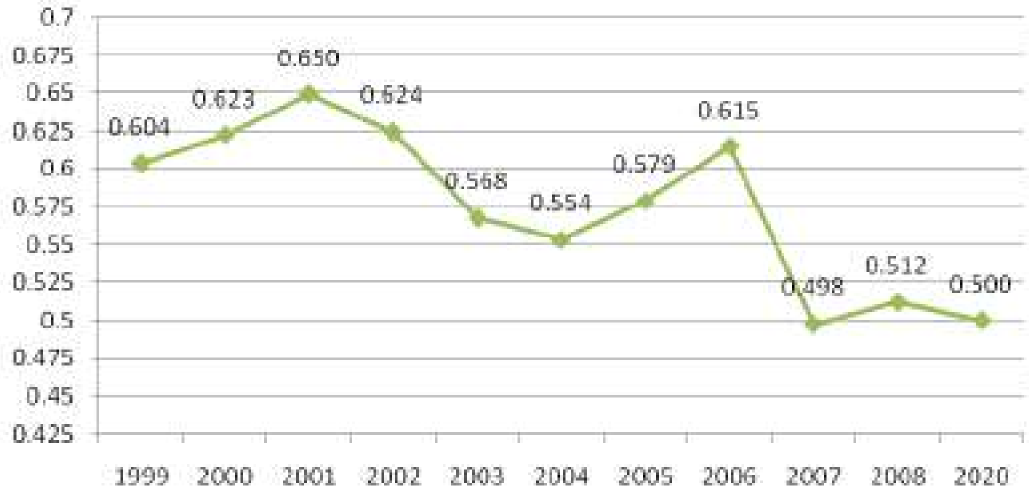

Figure 4.4: Annual integrate score of WRCC in Dongsheng

From the critical points, it is easy to find out that the critical points of 2 indexes: Daily per capita water consumption and water demand modulus in grade v_3 is rising constantly, especially the critical point of water demand modulus in grade v_3 which is 0.53 has exceeded the critical point in grade v_2, which is 0.47, that means this index is now in the warning state. It is the rise of the two indexes that induces the decline of the integrated score in 2020. In order to avoid the damage to the water resource caused by urbanization process, it is very urgent to take measures to improve the WRCC from the two aspects.

Table 4.2: Weights of index in the year 2020

Index	ri1	ri2	ri3
Per capita water availability	0	0.9345	0.0655
Cross-border water	0.5909	0.4091	0
Groundwater extraction rate	0.8	0.2	0
Water resource utilization rate	0.1420	0.8580	0
Pipeline leakage rate	0	0.93	0.07
Per capita daily water consumption	0	0.6539	0.3461
Water modulus	0	0.4739	0.5261
Agricultural per mu water consumption	0.025	0.975	0
Industrial per million Yuan output water consumption	0.7345	0.2655	0
Ecological and environmental water rate	0	0.3024	0.6976
Urban sewage treatment rate	0.8529	0.1471	0
Surface water level	0	0.25	0.75

5 Conclusion and outlook

The method for evaluation of WRCC of small town in the rapid urbanization period being proposed in this paper can be easily cooperated with 3S technology. By the land use and height data obtained by Remote Science (RS), with the spatial data base and calculation by GIS, the water consumption can be monitored dynamically. This method solves the problems in the current WRCC evaluation system which is static and difficult to obtain data, and can monitor and evaluate the WRCC in the rapid urbanization process conveniently. According to the application in the case Dongsheng, this method proved to be feasible, and the result of evaluation are turned out to be reasonable by experience judgment.

Since China has vast territory, and the climatic condition and economic development level are quite different from one region to another, as a result, the water resource condition and consumption amount are also have much difference. The per-land use water consumption value surveyed in this paper can only be representative of water consumption in economically developed small town in South China. In order to built a WRCC evaluation system which can be used in all the region in China, next it is urgent to divide China into several regions according to the climate condition and the habit of water use, and survey the per-land water consumption in all the regions, and set up the per-land water consumption system for the whole China.

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