Estimation of the Water Resource Capacity of Chinese Cities and Megalopolises in the Future Urbanization

(Estimation of the Water Resource Capacity of Chinese Cities and Megalopolises)

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1. Introduction

With 30 years' fast and stable development, China has become the second largest economy, meanwhile, the national water consumption has increased 1.37 times from 1980 to 2010 (Liang,1998; NBSC,2011), which undermines the sustainability of China's current and future development. As one of the primary influential factor, the accelerated urbanization has contributed much to the water consumption increase of China in the past 30 years (Liu,2012; Shen, Liu,2008; JIANG,2009). In 2011, the urbanization ratio of China has firstly reached 51.3%, however, predicted by the United Nations (2012), the accelerating phase of Chinese future urbanization will generally finish around 2035-2045, which means urbanization ratio reaches 70%(*Figure 1*). Consequently, in the future, the on-going urbanization process will continue to influence the structure and gross amount of water demand in Chinese urban area (Liu,2012; Shen, Liu,2008).

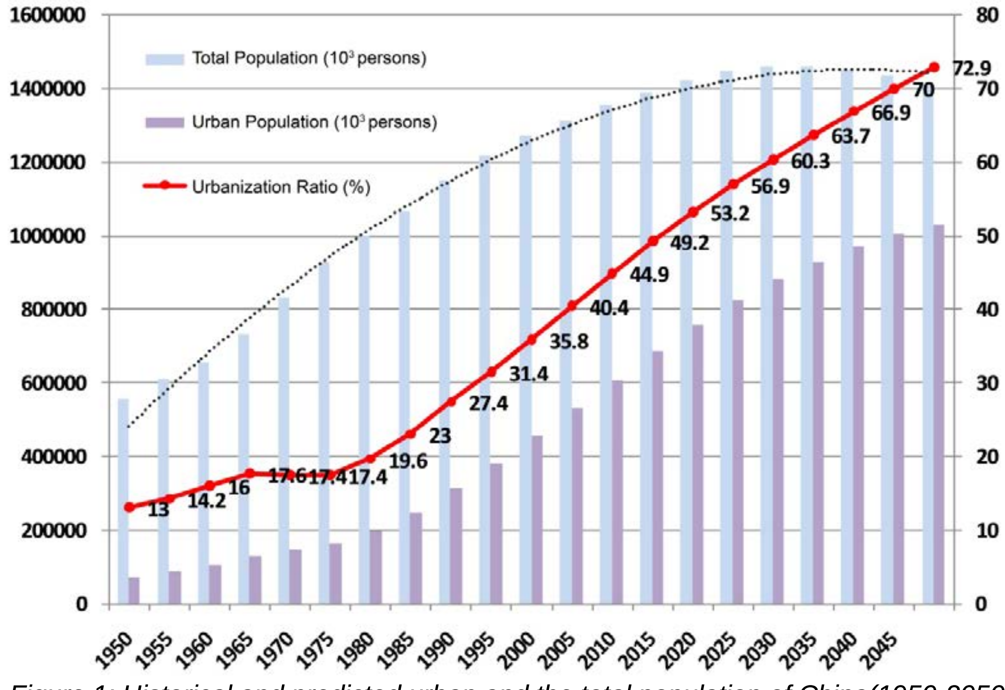

Figure 1: Historical and predicted urban and the total population of China(1950-2050)
(Drawing by the data of UN World Urbanization Prospects2007)

As water scarcity and regional maldistribution is always the dominant constraint for Chinese development (Jiang,2009; Shen,2008), facing the future trend in urbanization, Chinese current issues related to water resource will be much severer, such as the extra investment on water conservancy facilities, the contradiction among multiple megalopolises in water resource allocation, and the further over-exploitation of groundwater in some urban area etc. Accordingly, water resource is one of the central factors to consider for the urbanization and the accompanied population redistribution process in the future. Specifically, the 656 county-level(and above this level) cities will be the foremost locations to settle the emigrated rural population and transmigrated urban citizens(*Figure 2*).

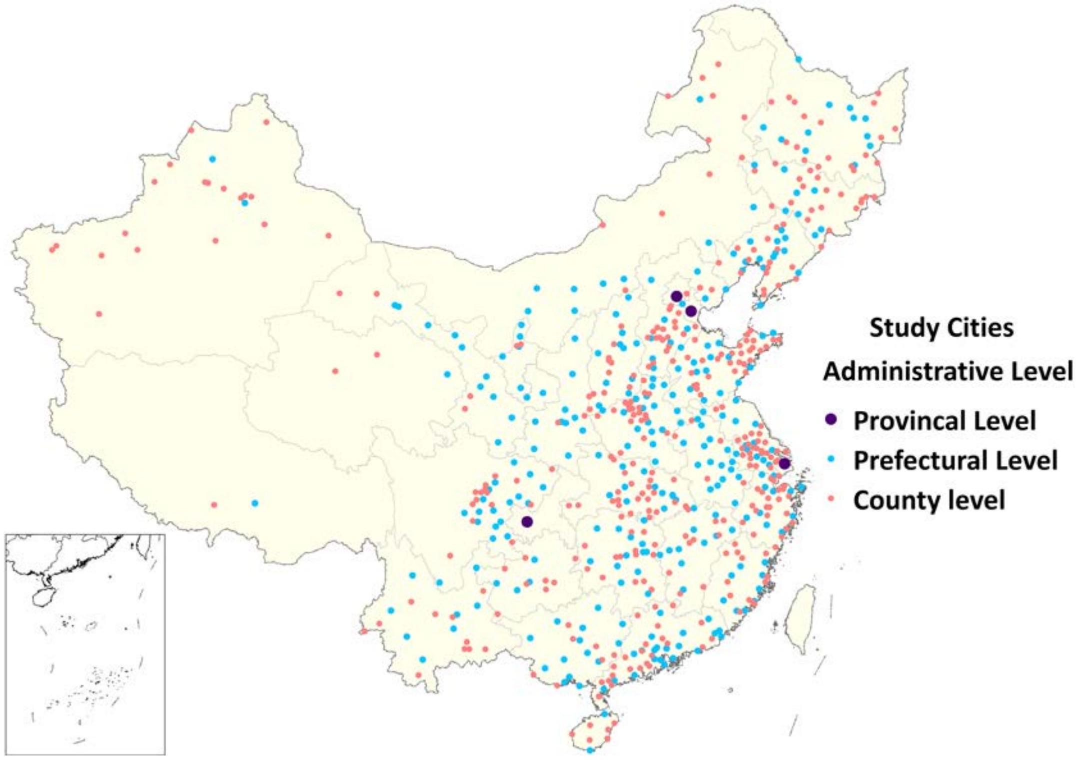

Figure 2: Spatial distribution of the 656 county-level (and above this level) cities of China

To facilitate the potential population migration process and to benefit its social and economic development in the long run, China has issued several national spatial strategic planning, including the "*National Urban System Planning(2006-2020)"*, and the "*Major Function Oriented Zoning*"(*Figure 3*), which are sponsored and implemented by the Ministry of the Housing and Urban-Rural Development(MOHURD) and National Development and Reform Commission(DNRC) of China respectively.

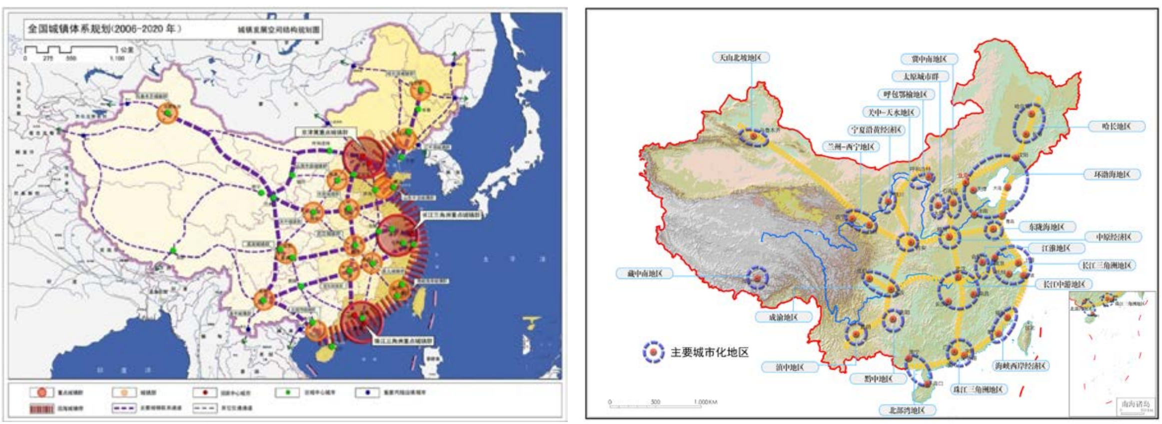

Figure 3:Important national spatial strategic plannings of China

In these national spatial strategic planning, there are 22 megalopolises or mega-regions that are proposed and encouraged to accommodate the newly emigrate rural population with both central governmental fiscal resources and supportive policies (Figure 4). The candidacy of these 22 megalopolises is generally based on their existing advantages and future potential in industrial accumulation and economic development, while the plausible environmental constrains or impacts, especially in water aspect, have not been cautiously discussed or fully emphasized.

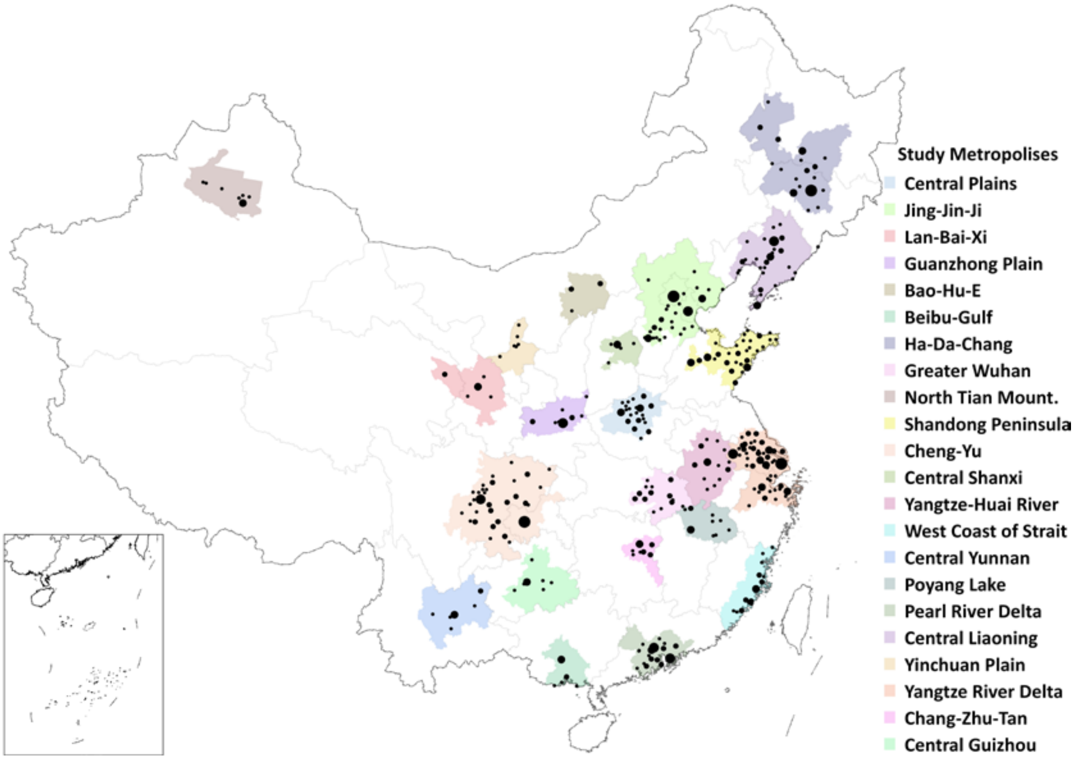

Figure 4: Spatial distribution of the 22 proposed megalopolises for Chinese future Urbanization

At present, there are two thirds of Chinese cities are suffering from water insufficiency, and about 100 cities are extremely lacking of water supply. During the future urbanization process, the enhancing demographic and economic density in some urban area will further boost the water consumption of Chinese urban area (Shen,2008), and this process will aggravate the shortage condition in water resource of most cities as well. Nevertheless, most existing studies have basically discussed related issues on the national or regional scale from the perspectives of the water resource sector, but little research has focused on the scale of urban level and the potential demand and influence of Chinese future urban development to water resource management.

Accordingly, This paper intends to estimate the water resource capacity of Chinese cities and to suggest the potential strategies for those cities in responding to the challenges during Chinese future urbanization. Based on the water-related statistical data from *China City Statistic Yearbook* and public statistical reports of the study cities, this paper intends to utilize the approaches of spatial analysis and spatial statistics to estimate the water resource capacity of the 656 Chinese county-level (and above this level) cities under the stress of future urbanization process, which will help to identify and indicate the potential and feasibility of Chinese cities to accommodate the newly emigrated population from the rural area and the suitability to further accumulate or develop related industries. In addition, this research will also estimate the water carrying capacity of the 22 megalopolises as a whole in the future population accumulation process.

The remainder of this paper is organized as follows. In the next chapter, we introduce the methodology. Respectively, Section 3 and 4 discuss water resource background and water consumption condition of the study cities. Section 5 calculates water resource potential or population overload ratio of the study cities, while Section 6 summarizes the water resource carrying capacity for population of the study megalopolises. The paper ends with a brief conclusion of our study and practical suggestions for decision makers.

2. Methodology

As mentioned above, the goal of this work is to analyze current water resource conditions of the study cities and offer suggestions for the population accumulation of these cities and the corresponding megalopolises in facing future urbanization. When referring to water resource condition, it is always related to water resource abundance, population density and water consumption structure and efficiency, which interactively determine the potential, equilibrium and dynamics of water resource endowment and water consumption. Thus, analysis and discussion about the dynamic of population density, structure and efficiency in water consumption of the study cities will be the prerequisite to raise the suggestions for the future development of the study cities and the 22 supported megalopolises. In consequence, issues about water resource background, water consumption conditions, water resource potential and overload ratio, carrying capacity etc. of the study cities will be analyzed through the steps below (Figure 5).

Firstly, the approaches of K-means cluster analysis will be employed to classify the study cities into different categories based on the representative factors elected in each analysis. Further, based on the data of water resource amount, current population, water consumption amount of the study cities, the Method of Comprehensive Water Use per Capita, Water Carrying Capacity Index(WCCI), and other indicators are utilized to evaluate the potential or the overload ratio of the study cities and to estimate the water carrying capacity for population of the study Megalopolises. Finally, suggestions will be concluded based on the above analysis.

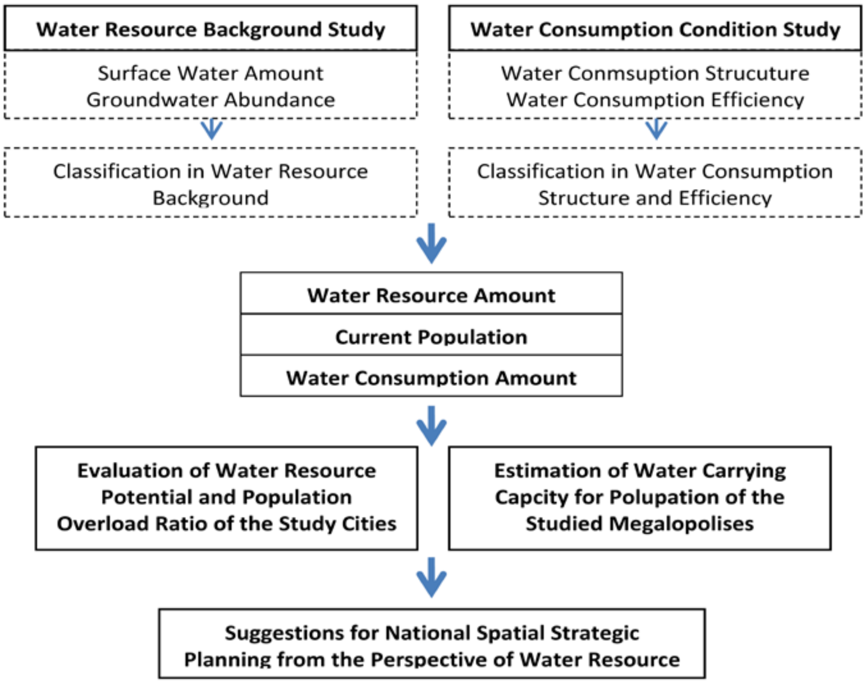

Figure 5: Framework and main procedures of this study

3. Water Resource Background Study of the Study Cities

As the broad land territory and diverse geographic characteristics of China, the natural endowments in water resource among the study cities are different. In this research, we intend to categorize the patterns of different cities in water resource richness through analyzing two factors, and that is the average annual precipitation and the abundance level in groundwater resource.

3.1 Average Annual Precipitation of the Study Cities

Precipitation is a sufficient factor to indicate the water resource background of a region. In this paper, annual average precipitation dataset in the national database of "*Data Sharing Network of Earth System Science, DSNESS*" is utilized to evaluate the surface water richness of the study cities. This dataset is processed and interpolated based on precipitation observational time-series data(1950-1996) and from almost 1915 rainfall stations distributed nationally, by the Institute of Agricultural Resources and Regional Planning, CAAS.

Based on the calculation with the spatial dataset referred above, the surface water conditions of the study cities can be summarized as follows. There are 33 cities with a rainfall depth below 200mm and 22 cities with the rainfall between 200-400mm, which are subordinated in water resource richness. Secondly, there are 242 cities are located in the region with a moderate rainfall condition between 400-800mm. Besides, there are 143 cities with a rainfall depth between 800-1200mm, and the precipitation of the left 216 cities are over 1200mm.

Through the above categorizing analysis, except for those cities located in the western arid region which has relatively worse surface water condition, most of the study cities are close or over 800mm. Accordingly, from the perspective of city location choosing, most of Chinese cities are settled in the regions with moderate or sufficient surface water potential(Figure 6).

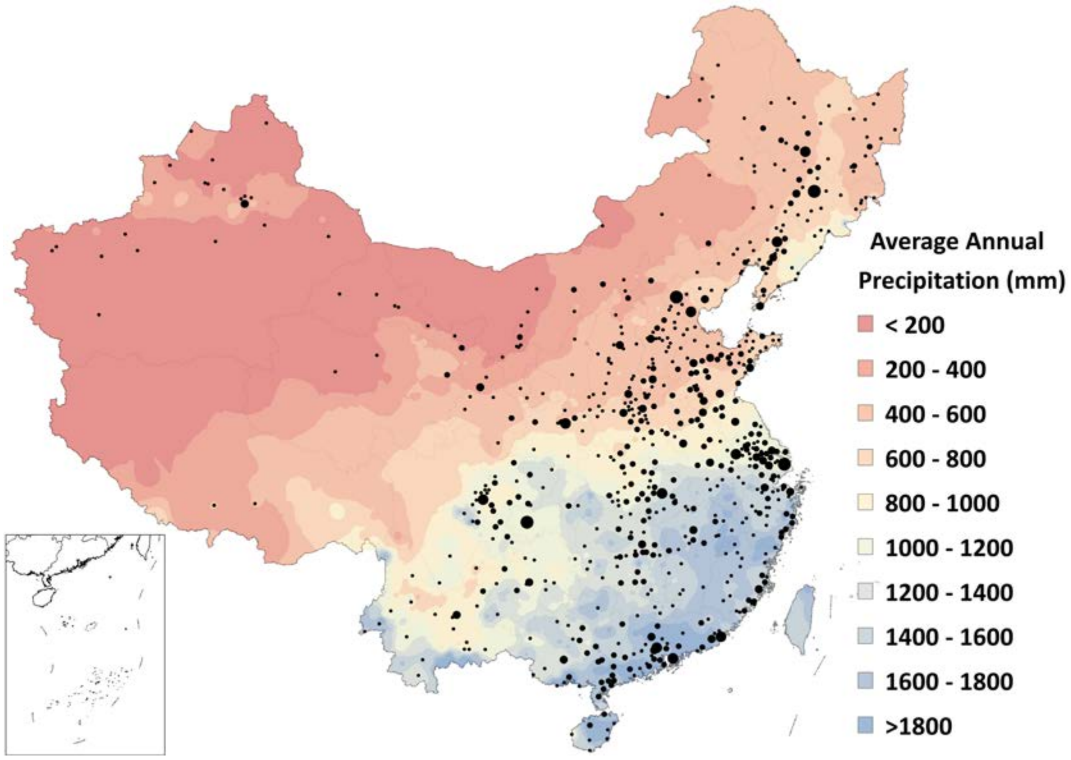

Figure 6: National average annual precipitation distribution and the location of the study cities

3.2 Groundwater Abundance of the Study Cities

According to incomplete survey, there are 400 cities that groundwater takes up more than 30% of their total water supply, and this demonstrates that the abundance of groundwater is also significant in determining the water utilization patterns of most Chinese cities. Consequently, this paper also identified the groundwater condition of the study cities through the "*Chinese Hydrogeological Information Spatial Dataset* issued by "*National Land-Resource Scientific Data Sharing Platform*". The study cities are classified into 3-level (high, medium, low) categories based on their groundwater abundance (Figure 7). According to the above classification, most of Chinese cities' groundwater resource is limited and the quality is about 420, while only around 150 cities have abundant groundwater resource comparatively.

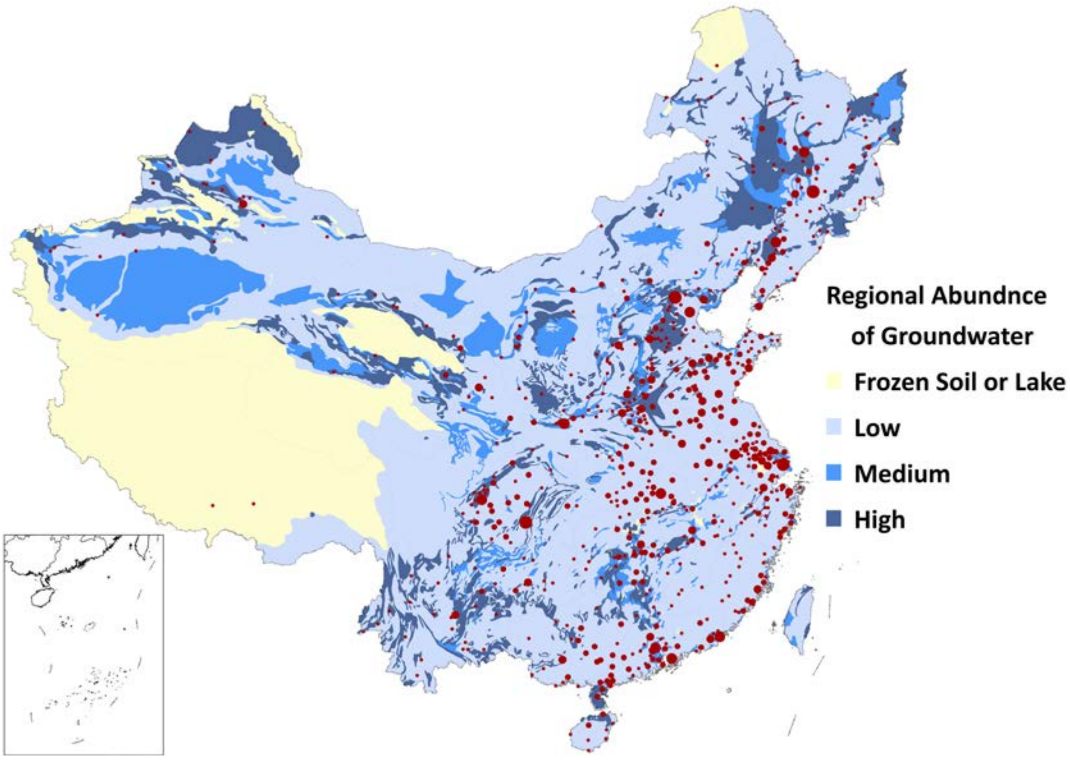

Figure 7: Groundwater-abundant-level spatial distribution of the study cities

3.3 Water Resource Background Classification of the Study Cities

When combined the two factors by K-means cluster analysis, the study cities can be classified into 9 categories that will represent the characteristics of their water resource background. The 9 categories include: High level in surface water and high level in groundwater, low level in surface water and low level in groundwater, medium level in surface water and medium in groundwater etc.(Figure 8).

From the spatial distribution pattern of the study cities, in terms of water resource background characteristics, it can be easily identified that there are two dominant types. The first type is high-level in surface water & low-level in groundwater, and these cities are mainly located in Anhui, Jiangsu, Fujian, Guangdong, Guangxi, and Hainan provinces, while the other type is medium-level in surface water & low-level in groundwater, which are mostly distributed in Jiangsu, Hubei, Sichuan, Guizhou, Anhui provinces. Comparatively, the cities in the other categories are relatively diffusively distributed.

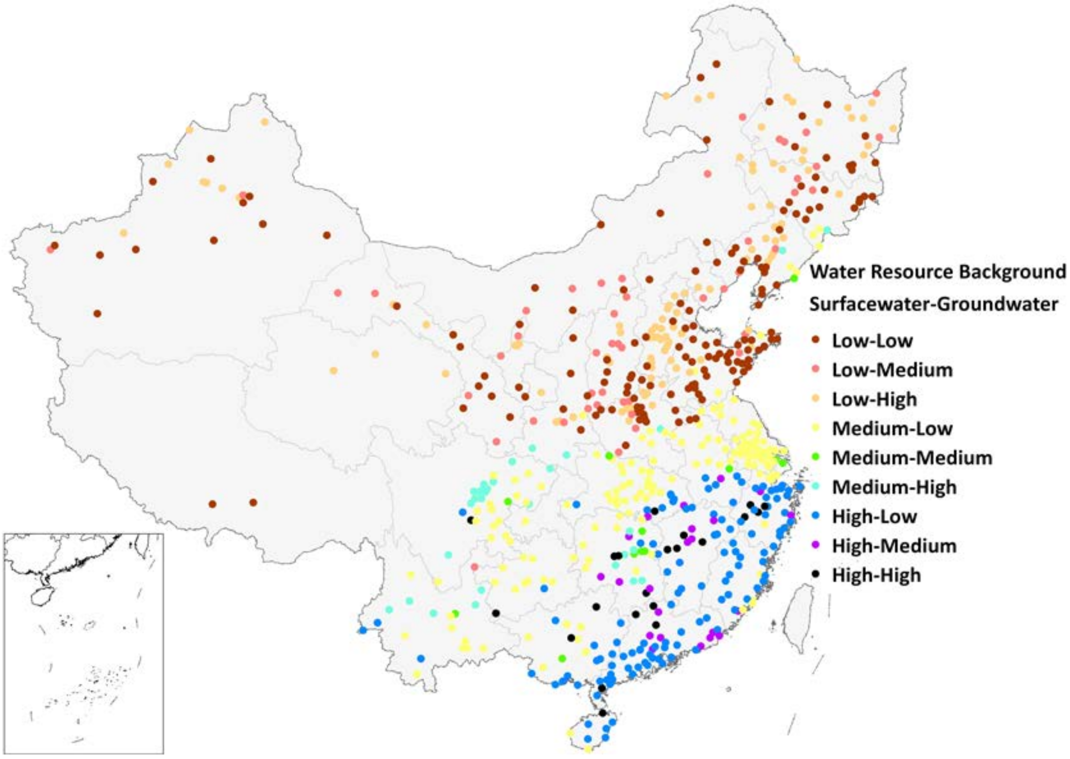

Figure 8: Water resource background classification of the study cities based on the factors of precipitation and groundwater abundance

4. Water Consumption Condition Study of the Study Cities

Water consumption structure and efficiency of the study cities contribute to the explanation about the current amount and future trend of water consumption, therefore the analysis towards these two aspects will help to understand the future dynamics of water demand of the study cities, and it is also the basis for providing suggestions in industry selection and population accumulation for the study cities and the related megalopolises.

4.1 Water Consumption Structure Classification of the Study Cities

Water consumption structure varies depending on different study objectives. From the urban perspective, water structure always includes the water consumption in industries, public service and household use. Hence, this research elected the above three influencing factors to identify the characteristics of the water consumption structure of the study cities through K-means cluster analysis in the statistical software *SPSS20.0*.

K-means Cluster analysis helps to classify the study samples by calculating the spatial distance, correlation coefficient or similarity coefficient of the samples in an N-dimensional variables' space. K-means cluster analysis is advanced in calculating speed and processing large amount of data, but its weak points are that the count of clusters should be predefined, and the final analyzing result highly relies on the features of the predefined cluster centers.

As mentioned above, the goal of this analysis is to identify the relative relationship of the study cities in industrial water consumption, public service water consumption and household water consumption, such as one use is dominant and the other two are subordinated, or the three water uses are nearly equal to one another. The identification of these relationships will be used to understand the mechanism of water demand dynamics of the study city and for raising specific suggestions.

Based on the above description, the analysis should firstly define the amount of clusters. With the general analysis towards the statistic frequency distribution of the study cities in the above 3 aspects, both industrial and household water consumption should be divided into 3 levels, while water consumption of public service should be divided into 2 levels (Figure 9). The pre-classification is based on the natural break classification method(Jenks), and the final cluster count is calculated as 13.

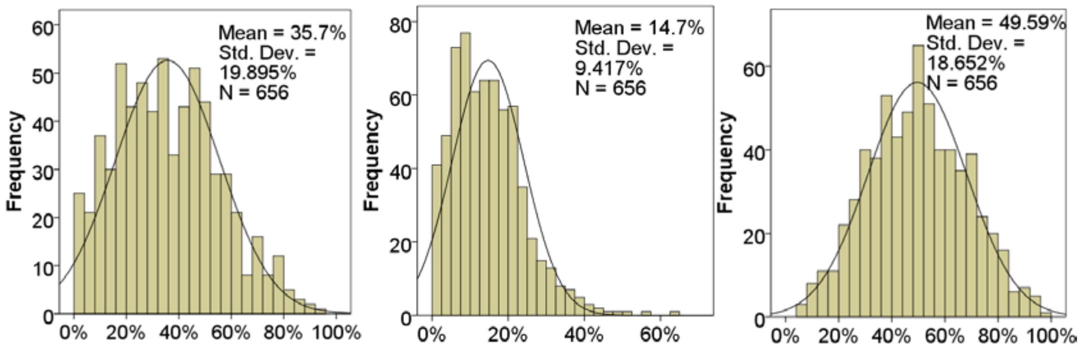

Figure 9: statistic frequency feature of water consumption in industry, public service and household

The result of K-means cluster analysis shows that there are 6-7 major categories that have a large number of cities, while the other categories have only around 20 cities.

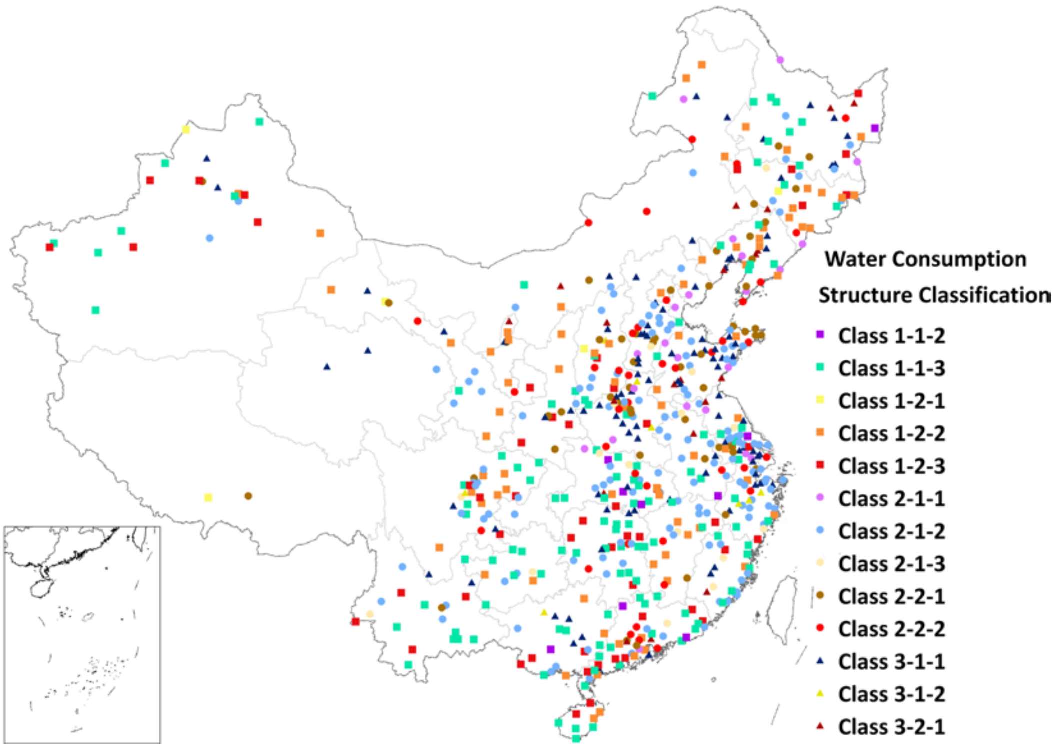

Figure 10: Water consumption structure classification of the study cities

The characteristics and final cluster center of specific categories of the study cities in water consumption structure could be referred in Table 1.

Table 1: Cluster centers and city amount in water consumption structure of the study cities

Name of the Categories	Final Cluster Centers of Water Consumption Structure			Count of Cities
	Industries	Public Service	Household	
2-1-2	42.6%	8.3%	49.1%	140
1-1-3	5.7%	8.1%	86.2%	119
3-1-1	80.5%	6.0%	13.5%	97
1-2-2	5.3%	45.6%	49.1%	78
2-2-1	39.7%	24.2%	36.1%	52
1-2-3	11.4%	20.8%	67.8%	51
2-2-2	29.9%	19.7%	50.3%	39
2-1-1	51.7%	10.1%	38.2%	22
3-2-1	55.4%	19.9%	24.7%	20
2-1-3	18.1%	7.9%	74.0%	16
1-1-2	29.5%	9.6%	60.9%	9
3-1-2	66.8%	6.1%	27.0%	8
1-2-1	20.3%	30.2%	49.5%	5

4.2 Water Consumption Efficiency Classification of the Study Cities

The improvement or falling behind in water consumption efficiency will influence the potential of the study cities in water carrying capacity. In this study, we choose 2 factors to assess their efficiency. That is water use per capita GDP which mostly reflect the efficiency in industrial water use, while the other is leaking ratio of water supply which can represent of efficiency in household use. Similarly, K-means cluster analysis method is also utilized for this analysis, and the two factors are both divided into 3 levels based on their quantity by the Jenks method before the K-means analysis. The cluster counts finally is calculated as 8, and the K-mean analysis result is shown in Figure 11.

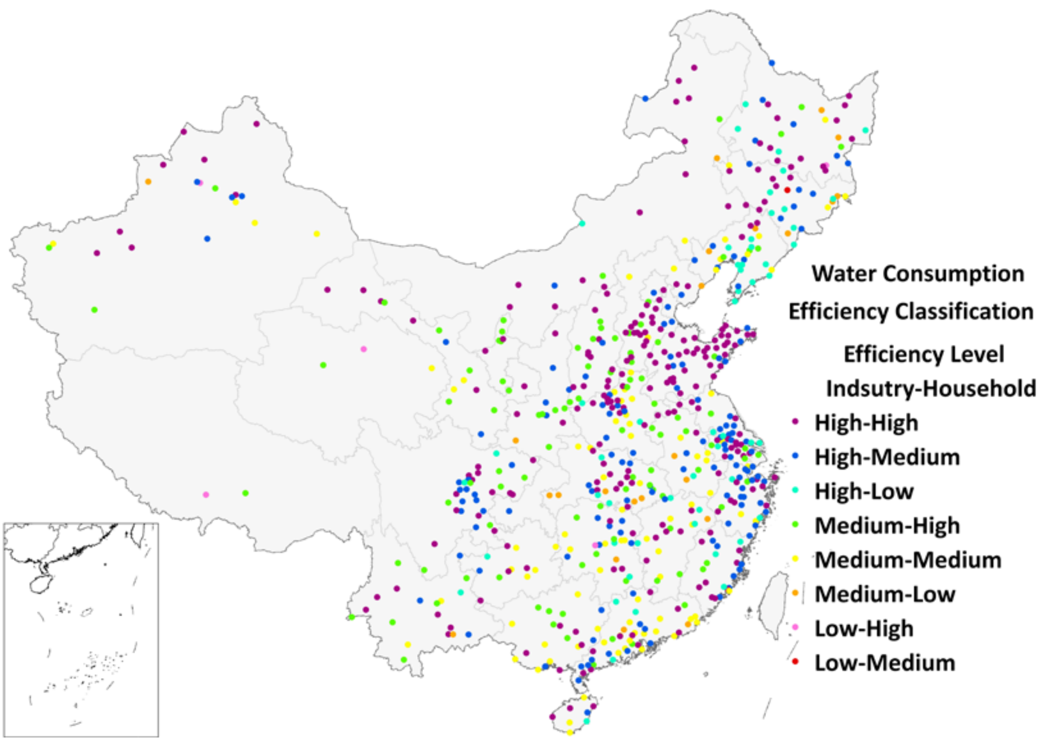

Figure 11: Water consumption efficiency classification of the study cities

Through the clustering analysis, there are 5 classes in the 8 ones are dominant classes, which are with relatively more cities. The rest classes has less cities included, and mostly is with around 20 cities. The analysis result tells us that most of the study cities are both highly efficient in industrial and household water consumption, and some others are classified into the types of high-medium or medium-high(Table 2). In consequence, from the perspective of water consumption efficiency, there is limited space left for most of the study cities to improve, unless revolutionary technical paradigms emerges and broadly utilized.

Table 2: Cluster centers and city amount in water consumption efficiency of the study cities

Name of the categories Efficiency in Industries-Efficiency in Household use	**Final Cluster Centers**		**Count of Cities**
	Water use per capita GDP (m^3/10000yuan)	**Leaking Ratio of water supply(%)**	
High-High	**6.68**	**9.3%**	**239**
High-Medium	**13.99**	**11.2%**	**141**
High-Low	**21.44**	**12.4%**	**53**
Medium-High	**42.26**	**9.5%**	**102**
Medium-Medium	**30.80**	**11.9%**	**92**
Medium-Low	**96.70**	**14.1%**	**23**
Low-High	**82.30**	**4.4%**	**5**
Low-Medium	**185.49**	**9.3%**	**1**

5. Water Resource Potential or Population Overload Ratio of the Study Cities

Water Carrying Capacity means that, under different social and technical conditions, the amount of population or economic development a city or watershed can sustained(Zhu, Xia et al., 2002). There many methods to evaluate the water carrying capacity, including multi-criteria analysis, tendency analysis, comprehensive water use per capita, system dynamics, fuzzy evaluation etc. (Duan, Chen et al., 2010; Sun, Zheng et al. 2006; Zhu, Xia et al., 2002).

In this study we apply the approach of comprehensive water use per capita referred by related scholars (NPFPC, 2009; Zhang, Feng et al. 2008). The key of this method is to analyze and determine the comprehensive water use on average for a single person, which mostly includes household, public service, industrial, and environmental use etc. Internationally, 500m^3/ capita is considered as the benchmark of severe water shortage, and this value is fixed as comprehensive water use in this analysis based on the consideration of Chinese actuality. Besides, the equations of this method are as follows.

$$WCC = W / Wpc \quad (1)$$
$$WCCI = P_a / WCC \quad (2)$$
$$R_p = (P_a - WCC) / WCC * 100\% = (WCCI - 1) * 100\% \quad (3)$$
$$R_w = (WCC - P_a) / WCC * 100\% = (1 - WCCI) * 100\% \quad (4)$$

In (1)， ***WCC*** is water carrying capacity of the city (the unit is persons)； ***W*** is the total available water resource of the city (m^3)； W_{pc} is the comprehensive water use on average(m^3/capita)

In (2), (3), (4), ***WCCI*** is water carry capacity index, which indicate the potential of future water supply or overload condition of population in terms of water resource； ***WCC*** is water carrying capacity of the city； ***Pa*** is the actual population of the city (person)； ***Rp*** is the population overload ratio of water resource of the city； ***Rw*** is water sufficiency ratio of the study city.

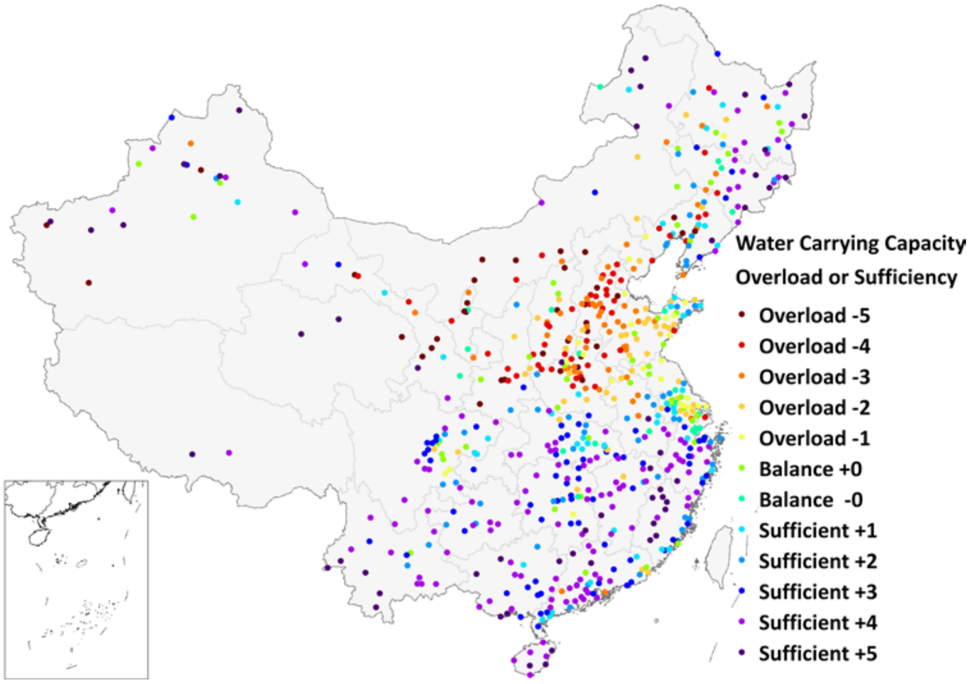

Figure 12: Water resource potential or population overload ratio of the study cities

In general, the analytical result shows that most Chinese cities are still relatively sufficient in in water resource (Figure 12, Table 3), while there are 265 overloaded cities, which takes up 40.4% of the total cities, and only 144 cities have been over one time of the calculated capacity and just less than 90 cities have surpassed twice of the capacity. Comparatively, the overloaded cities are also highly concentrated spatially, which mostly distributed in Hebei, Shanxi, Henan, and part of Shandong, Jiangsu provinces etc..

Table 3: Indicator calculation and classification in Water Carrying Capacity of the study cities

Categories	Carrying Capacity	Indicators of Water Carrying Capacity			Count of Cities
		Water Carrying Capacity Index（WCCI）	Population Overload Ratio (Rp)	Sufficient Ratio of Water Resource (Rw)	
Water resource Sufficiency	+5	<0.1		Rw>90%	53
	+4	0.1-0.3		70%<Rw<90%	131
	+3	0.3-0.5		50%<Rw<70%	81
	+2	0.5-0.7		30%<Rw<50%	60
	+1	0.7-0.9		0%<Rw<30%	44
Generally Balanced	+0	0.9-1.0		0%<Rw<10%	22
	-0	1.0-1.3	0%<Rp<30%		45
Water Resource Overload	-1	1.3-1.5	30%<Rp<50%		26
	-2	1.5-2.0	50%<Rp<100%		50
	-3	2.0-3.0	100%<Rp<200%		56
	-4	3.0-6.0	200%<Rp<500%		51
	-5	>6.0	Rp>500%		37

6. Water Resource Carrying Capacity for Population of the Study Megalopolises

Based on the above analysis of the study cities, we further make a summation to the 22 megalopolises that are supposed to be the centers for population and industry accumulation during Chinese future urbanization. In the 22 megalopolises, the highest potential ones to sustain future population, from the perspective of water capacity, are Ha-Da-Chang, Cheng-Yu, Pearl River Delta megalopolises, which can absorb 50 million more people in the future. The secondary level megalopolises in future water capacity are Beibu Gulf, West Coast of Strait, Poyang Lake, Greater Wuhan, Chang-Zhu-Tan, Central Guizhou, which can sustain 10-20 million more population if needed. Besides, even part of the cities in Central Yunan, Yangtze-Huai River, North Tian Mount megalopolises has appeared to be overloaded in capacity, there is still relatively great potential capacity for them to receive and accumulation more people if considering the city clusters as a whole(Table 4, Figure 13).

Table 4: Population overload condition or future potential in water capacity of the study megalopolises

Megalopolis Name	City Count	Count of overloaded cities	Overloaded population (10 thousand)	Count of sufficient cities	Further carrying potential (10 thousand)	Net population Capacity (10 thousand)
Ha-Da-Chang	17	6	559.1	11	-5438.4	-4879
Cheng-Yu	31	8	423.9	23	-5014.6	-4591
Pearl River Delta	17	1	620.9	16	-4894.0	-4273
Beibu Gulf	5	0	0.0	5	-2223.2	-2223
West Coast of Strait	14	2	93.3	12	-1919.6	-1826
Poyang Lake	9	1	98.8	8	-1707.4	-1609
Greater Wuhan	16	2	39.9	14	-1369.1	-1329
Central Guizhou	7	0	0.0	7	-1069.2	-1069
Chang-Zhu-Tan	7	2	112.8	5	-1094.3	-982
Central Yunnan	6	1	31.5	5	-683.8	-652
Yangtze-Huai River	13	4	371.0	9	-829.2	-458
North Tian Mount	8	4	106.5	4	-371.2	-265
Central Liaoning	28	13	1327.8	15	-1417.2	-89
Yangtze River Delta	50	22	2828.5	28	-2835.6	-7
Yinchuan Plain	6	5	199.4	1	-0.5	199
Bao-Hu-E	3	3	282.7	0	0.0	283
Lan-Bai-Xi	5	4	380.2	1	-13.6	367
Central Shanxi	5	4	379.7	1	-1.9	378
Guanzhong Plain	8	8	775.0	0	0.0	775
Shandong Peninsula	30	22	1273.4	8	-155.8	1118
Central Plains	23	21	1436.9	2	-7.6	1429
Jing-Jin-Ji	27	27	3294.0	0	0.0	3294

On the contrary, for the overloaded megalopolises, Jing-Jin-Ji has extremely surpassed the capacity of the region, and all the cities included in the megalopolis has crossed the baseline of water carrying capacity of the cities. The amount of overloaded population in Jing-Jin-Ji megalopolis is around 33million. Secondly, the megalopolises of Central Plains, Shandong Peninsula, Guanzhong Plain are also heavily overloaded, and the overloaded population are about 10 millions. Besides, the megalopolises of Central Shanxi, Lan-Bai-Xi, Bao-Hu-E, Yinchuan Plain are also experiencing, relatively lower, pressure from water capacity.

For Yangtze River Delta, Central Liaoning megalopolises, some of the cities are overloaded in water capacity, while some other cities still have huge potential to carry more population in the future.

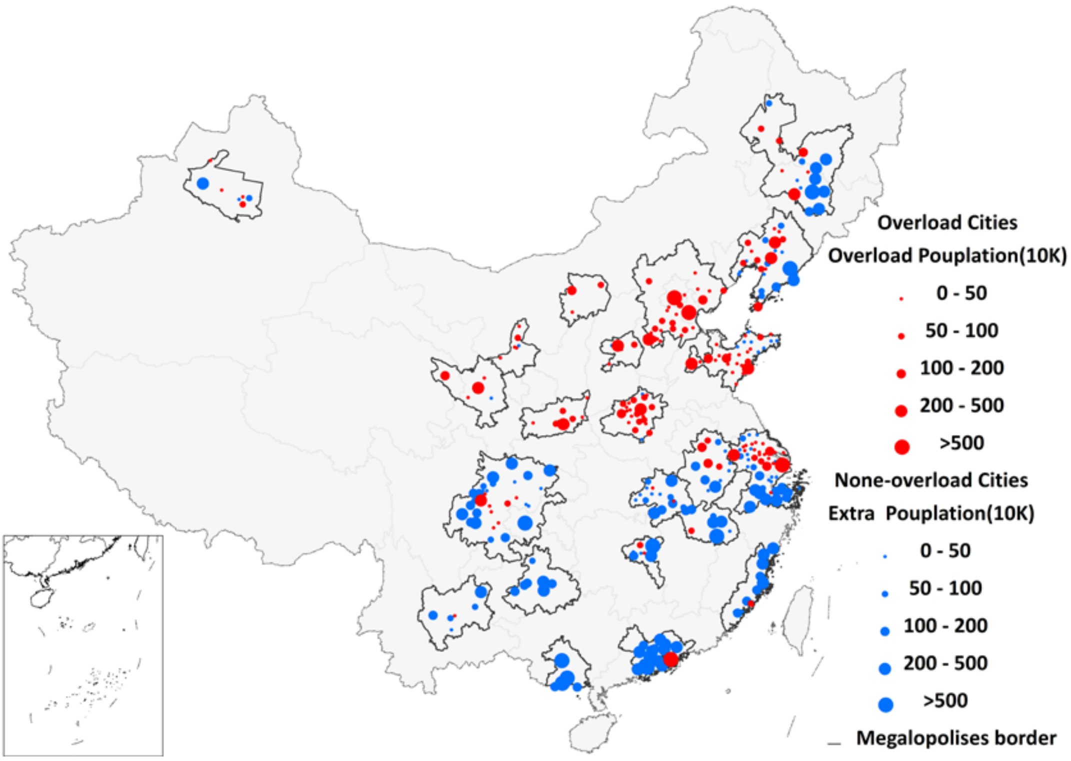

Figure 13: Population overload or future potential in water capacity of study cites and megalopolises

7. Conclusion and Policy Implication

Compared with the most existing studies, the prospect contribution of this paper is to study the water resource related issues, including water resource conditions, water consumption structure and efficiency, water consumption amount and water resource carrying capacity, in a much finer spatial scale(city level) and from the perspective of urban studies. By identifying the potential water resource capacity and constraint factors of different cities, suggestions about population potential and megalopolises' developing and water management policies are raised to lead Chinese urbanization process towards a more sustainable pattern.

Through the study result, we can initially conclude that, for the studied Chinese cities and especially the 22 focused megalopolises, the cities located inside Pearl River Delta and Cheng-Yu megalopolises should be the national central urbanization emphasize compared with the other two primary ones (Jing-Jin-Ji and Yangtze River Delta), from the perspective of future water carrying capacity. Combined with the consideration about social and economic development, Greater Wuhan, Western Coast of Strait, Chang-Zhu-Tan megalopolises should be more supported with encouraging policies and central governmental fiscal resources to spur the future accumulation in population and industries, as they are also advanced in water carrying capacity. Besides, Beibu Gulf, Poyang Lake, Central Yunnan, Central Guizhou megalopolises could also be relied on in receiving more newly emigrating population from rural area in the future, even the economic development of these megalopolises are relatively subordinated.

In the future studies, there are still many aspects to be improved. Firstly, more water carrying capacity analyzing methods could be utilized to reflect the condition of study cities and megalopolises from various perspectives. Secondly, classification analysis in water consumption structure and water consumption efficiency should be combined with the analysis in water carrying capacity, which will offer more practical conclusions and suggestions for the study cities and megalopolises. Furthermore, because most of Chinese policies are based on the cost-benefits in economics, it would be necessary to conduct cost-effective evaluation to the study cities and megalopolises based on the estimation of overall efficiency and benefits of the accumulated population and industries in specific cities or megalopolises when considering the potential pulling effect from water resource or other related environmental aspects.

Notes:

***** This research is supported by *Urban China Initiative* (a non-governmental organization)
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