Drivers of Water Resources Carrying Capacity and Changes due to Climate Change in China

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Abstract. With basic knowledge of global sustainable development, water resources carrying capacity (WRCC) relates closely to society, economy and environment. It has important affection on the knowledge and construction of water resources security system. Based on most updated international and national research outcomes on drivers of WRCC and future changes due to climate change, this paper collects and summarizes the theory and drivers of WRCC, as well as water resources and sustainable development, water sources-society-environment coupling system and trends of water cycle in a changing climate representing by the drivers of WRCC. With an overall understanding of water sources carrying capacity, this paper analyzes the evaluation methods of WRCC study, including the system dynamics theory, the decision model with multiple factors and so on. Finally, this paper concludes the current problems of water resources representing by WRCC.

Keywords: Water resources, water stress, carrying capacity analysis, climate change.

1. Introduction
Water resources is one of the fundamental natural resources. Importantly it is bound to human daily activities. The 2020 World Water Day was held on March 22nd. Since 1993, annual World Water Day is held focusing on the importance of water resources, especially freshwater resources. The theme of World Water Day this year was set to “water and climate change”. Meanwhile, the No. 22 China Water Week was held from March 22nd – 28th, 2020 and the theme this year is “save the water, protect the river”. Apparently, these would like to draw a great attention on water resource crisis. The increase in water stress and demand as well as the decrease in water quality have become three major problems which threaten the global natural water resources [1]. On the one hand, the scientific evidence is clear: climate is currently changing and will continue to change if human won’t take further actions for tackling climate change. This will affect societies and the environment including global water system. This happens to directly impact on water availability, water quality and extreme events and indirectly changes water demand, which can consequently have impacts on energy production, food security and the related economy, among others. On the other hand, increasing population growth, large city expansion, rapid economic development, changing consumption patterns and intensifying agricultural production are generating a substantial rise in water demand [2]. Therefore, humanity is facing an intensified water problem. The sustainable damage and use of water
resources is a global challenge. It is essential to identify the drivers of water resources carrying capacity. It is also important to track changes of these drivers and subsequently the potential trend of water resources carrying capacity.

1.1. Current water problems

China has 20% of world population, but only has 7% of world available water resource. The China per capita share of fresh water is only 2,200km$^3$, which is 25% of world averaging value with ranking at No.88 world widely. Overall, China is one of most thirteen countries with water scarcity. Baseline water stress measures the ratio of total water withdrawals to available renewable water supplies. Water withdrawals include domestic, industrial, irrigation and livestock consumptive and non-consumptive uses. Available renewable water supplies include surface and groundwater supplies and considers the impact of upstream consumptive water users and large dams on downstream water availability. The world baseline water stress is shown in Fig. 1. Higher values indicate more competition among users. Such changes are likely to exacerbate water stress, which is among the main problems to be faced by many societies and the World in the 21st century. Water use has been growing at more than twice the rate of population increases in the last century. Combined with a more erratic and uncertain supply, this will aggravate the situation of currently water-stressed regions, and generate water stress in regions with currently abundant water resources. Water stress already affects every continent (Fig. 1). Physical water scarcity is often a seasonal phenomenon, rather than a chronic one (Fig. 2). About four billion people live under conditions of severe physical water scarcity for at least one month per year [3]. Around 1.6 billion people, or almost a quarter of the world's population, face economic water. Obviously, regions in China are suffering medium to extremely high baseline water stress (Fig. 3). There is a clear spatial pattern within the land. Meanwhile, climate change is likely to cause shifts in seasonal water availability throughout the year in several places [4].

![Figure 1. Baseline water stress in 2019 (WRI, 2019).](image1)

![Figure 2. Seasonal variability (WRI, 2019). Seasonal variability measures the average within-year variability of available water supply, including both renewable surface and groundwater supplies. Higher values indicate wider variations of available supply within a year.](image2)
1.2. China water resources problem trend

In China, there has been significant depletion of water stores on the northern plains, the Tianshan region of Xinjiang and around the sources of the southwestern rivers. Decreases in the northwest and southwest are mainly due to climate change causing glaciers and permanent snow cover to melt, according to Professor Long. Water either evaporates directly or flows into the soil and evaporates from there. Glacial melt also flows into rivers, where it is used for irrigation or domestic use. These changes show that climate change is making our limited water resources even more precious. But these changes are not irreversible. Climate fluctuations can cause water stores to drop in one area but increase elsewhere. Water storage and transfer projects can be used to reallocate water and ensure it is used well. Of course, negative impacts on the environment must be minimized, and these projects must be used in the name of environmental restoration.

![Figure 3. Province water stress index and category in China. Note: Extremely high indicates that provinces have extremely high water stress. High indicates that provinces have high water stress. Medium-high indicates that the provinces have medium to high water stress. Low-medium indicates that provinces have low to medium water stress. Low indicates that provinces have low water stress.](image)

2. Development of environmental and water resources carrying capacity

Initially, capacity is an engineering definition. It represents the most ability of a foundation to hold and support a build above. Now it is popular to be used in the ecosystem. In 1921, Part and Burgess firstly proposed the definition of ecosystem capacity which shows at a certain ecological environment, the maximum numbers of individuals can be accommodated. As the population continues increasing, the society continues demanding, the unbalance links between environment and humanity becomes remarkable. More studies have been done to understand the drivers of capacities and project the future trends of capacities. Lots of researchers and scientists begun to work on the capacity problems, their more efforts laid into its research. The study and its outcomes will not only provide the basic overview of environment and individual components, will but also give insights of the temporal and spatial variations of them by tracking the changes of environment and related component capacities. Moreover, by constructing environmental capacity models with relevant social, economic, and other factors which have potentials to impact on capacities, scientists are able to examine the inner relationships among factors, monitor the changing trend of capacities, act in advance to balance human activities and natural environment, etc. Based on the definition, capacity has two components: carrying subject and carrying object. Carrying capacity is the most capacity of subject to its object. According to different applications, there are characteristic carrying capacities. There have been a series of capacities proposed, such as environment capacity, water resource carrying capacity, soil resource capacity, population capacity and city/region capacity in different the areas of ecosystem, environmental resources, economy,
society and so on. Basically, there are two major categories, one-factor capacity and multiple-factor capacity. One-factor capacity represents the subject will be only influenced by only one external factor, however multiple-factor capacity shows the complex and comprehensive dynamics among the capacity and relevant factors.

Water sustainable development is highly promoted these years. As the rapid development of human society and scientific technology, economy globalization and consequent environment problems become be concerned. The major missions of hydraulic sustainable development have shifted the gear to involve flood control, water supply, water drainage, irrigation, renewable energy generation, water transport, cultivation, water and soil protect and recreation and entertainment, etc. The theoretical research, engineering construction, management and policy and so on of water supply, water energy, water products and water service have enlarged research and application scales. Right now, the scale and depth of water problem research have been both amplified. There are three critical changes: 1) from hydraulic engineering to hydraulic sources and then to the sustainable development theories and dynamics of water resources, society and economy; 2) from the current status and deployment of water demand and supply to the sustainable deployment in the generations; 3) from national and regional water resources problem extended to global views on water resources problem. Correspondingly, the research content and methodology have stepped on a higher level as the historical development and increased human cognition. At the same time, the theories also tended to change from the quality analysis of hydraulic sustainable development, suitable deployment of water resources and water sustainable development to quality and quantity analysis combining society-economy system water, water security, water resource carrying capacity.

Water resources carrying capacity (WRCC) aims to present the contributions of water resources to society, environment and economy by applying water resources as one-dimensional resources. From a comprehensive point of view, WRCC will demonstrate the characteristics of its harmonious relationship with society, environment and economy in the development. Water resource carrying capacity is also a comprehensive indicator to present the internal features and interactions among the population, water resources, social economy and ecological environment. Water resource carrying capacity also fits with the basic knowledge of sustainable development. The inner-generational prejudice level of WRCC represents its supporting ability to the population, environment and economy at the current situation and static expression of the relations of these three factors. The intergenerational prejudice level of WRCC then represents the temporal supporting ability of water resources to the population, environment and economy and dynamic expression of the relations of these three factors. WRCC can be applied as the constrains of water resource supply and demand in the ongoing development of society, environment and economy coupling system.

### 3. Water resources carrying capacity and drivers in China

Several research studies have been conducted in China focusing on the water resources carrying capacity (WRCC) and analyzing its drivers. Sun et al. [5] applied major drivers of Anhui province WRCC, constructed one-factor carrying capacity analysis model and then a province-level water resource carrying capacity model using comprehensive indicators and finally evaluated the Anhui WRCC between 2006 to 2017. The major drivers or factors included resources, society and other ecological factors impacting on WRCC. By filtering the drivers, this study built a cluster model of water resources to predict future WRCC and provided theoretical basis for the warnings and adjustments of WRCC. The results showed from 2006 to 2017, the WRCC in Anhui have been increased generally which is mainly impacted by social factors. To further increase the WRCC in Anhui, the following efforts can be done: 1) to increase the WRCC especially in water scarcity regions of Anhui; 2) to enhance the water use efficiency by developing the water use scale, applying high technology and studying the water-saving tools; 3) to identify the redline of total water use amount.

Yu et al., [6] selected Beijing-Tianjin-Hebei region (BJH) as research target. Based on the knowledge of demand-supply balance of regional water resources, they applied the “carrying population” method to quantitatively analyze the WRCC to support the population and economic development module in
BJH during different year and development levels. Their results showed that in high precipitation year the supply and demand was balanced however in the normal precipitation year this balance could be destructed. As increasing population and society-economy development, this supply and demand conflict would be more outstanding. Benefited by South-North Water Diversion Project, the WRCC in BJH has been increased, however the consequences of increased population neutralized the enhanced social wealth which maintained at a tardy progress. Xu et al., [7] applied principal component analysis method and evaluate the temporal changes and spatial variations of WRCC in Jiangsu province. Their results show that the drivers of Jiangsu WRCC were divided into three factors: social development, population and natural factors of water resources. And the social development factors had most impacts on the local WRCC. The limited water supply was not able to satisfy the increasing water demand. The water saving project and hydraulic project should be promoted to increase WRCC. Also, an obvious spatial pattern was shown that Southern region of Jiangsu region had a higher development and utilization of water resources but also had significant water pollution problems. This would amplify the conflict of water supply and demand locally. Besides selecting a province and region as a region of interest (ROI), some studies have extended to a drainage basin. Chen et al., [8] constructed WRCC index from five systems in Heihe Basin: water resources, social indicators, economic factors, ecological environment components and coordination system, and applied entropy weight method to analyze the WRCC and evaluate its spatial and temporal variations. Their results presented that from 2010 to recent year (Year 2020 is the study year), the Gross Domestic Product (GDP) of most countries and regions have exceeded the carrying capacity. However, the population in Heihe Basin has been over the carrying capacity before 2010. Based on the systematic analysis of WRCC, the stress of WRCC has been released, but with a large fluctuation in the middle and lower Heihe Basin. Furthermore, the natural system restoring, decrease in water-demanding crops, plan on total water control and quota management will be local important measures to largely release water resources stress.

4. Conclusions
Under UN Sustainable Development Goals (SDGs) framework, water crisis is essential problem needed to be solved within 10 years. The pressure by human development and climate change urge the world to take immediate actions to protect global water resources. To understand and monitor the water resources, WRCC is a key indicator to provide more insights of the relations and progresses among water system, as one part of environment, society and economy. Overall, the major factors of WRCC can be quality and quantity of natural water resources, the degree of development and utilization of local water resources, productivity level, consumption level and structure, science and technology, population and labors, policy, regulation, market, religion, tradition and so on. A comprehensive indicator system and evaluation method based on WRCC will be able to make short-term and long-term plan of the supply-demand water resources to reach both internal and external balance for current and further generations. In China, localized research should be conducted each year, since the development speed and population growth rate has reached world top. Meanwhile, the changing climate in the future will definitely impact on the water nature system, social community and human behavior. These factors should be also taken into account in the evaluation of water resources carrying capacity to reflect the changing situation of water resources in a changing climate.

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