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To cite this article: Wei Deng et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 237 032090

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A Study on Water Resources Carrying Capacity Based on Water Usage Intensity in Hainan Province

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Abstract. Since the establishment of Hainan Province 30 years ago, the population and the economy have been developed rapidly. At the same time, the contradiction between water resources and the economic and social development has also gradually emerged. How to realize the balance of the two is one of the problems that need to be solved urgently. To find out the carrying capacity of water resources to the social economy is a prerequisite for solving this problem. Based on the current water usage intensity, this paper makes a preliminary calculation of the carrying capacity of water resources in Hainan Province, and analyzes the current carrying capacity of Hainan Province. The results show that, under the existing development status and multi-year average condition, 75% assurance rate and 90% assurance rate, the population that can be carried is 24.0464 million, 17.1512 million and 12.773 million, respectively. In general, the carrying capacity of water resources is relatively strong. Regionally speaking, under the condition of multi-year average condition and 75% assurance rate, there is no overloaded county or city, and some of the counties and cities under the condition of 90% assurance rate are in overloaded condition, which are Haikou, Lingao, Dongfang and Sanya, and Danzhou is in the critical overload state. Cities and counties under the overload or critical overload state are mainly distributed in the western coastal region, and cities and counties under the surplus state are mainly distributed in the central mountainous areas and the eastern coastal areas.

1. Introduction
At present, there is no unified understanding of the definition of water resources carrying capacity at home and abroad. The concept of water resources carrying capacity can be roughly divided into two categories[1]: one is the water resources development capacity theory or the water resources supporting capacity theory[2-6], and the other is the maximum supporting scale of water resources[7-10]. The main evaluation result or index of the former theory is still based on the supporting water quantity, which is relatively intuitive in concept, while lacking in linkage with the social economy. Or it can be said that it is difficult to socially or economically scale the water resources in a specified ecologically constrained condition. The concept of “maximum support scale” is relatively complete, but also more complex, including the concepts of many aspects such as ecology, environment, society and economy. It is the game result of many factors. The maximum scale is relatively difficult in definition generally and the “support capacity” obtained from the previous concept is often the basis for conducting a “maximum support scale” evaluation of the latter concept. In this study, the latter concept is adopted to study the carrying capacity of water resources in Hainan Province. The definition of water resources carrying capacity is as follows: at this stage and in a certain period of time in the unforeseeable, on the premise of sustainable development under a certain economic and social and technological development level, the largest number of people in the region that can be supported by water resources.

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2. Methods and Materials

2.1. Method
The carrying capacity of water resources is determined based on the water usage intensity of the present situation, and the requirements of production, domestic usage and ecological water are considered respectively. The calculation steps, divided into seven steps, are shown in Fig 1:

1. Utilizable water \( W \) under different inflow conditions is calculated.
2. To determine the different carrying levels, this paper is calculated based on the current level.
3. The water use efficiency under different carrying levels is determined. This paper determines the GDP proportion of each industry, the water quota per unit added value and water utilization coefficient of each industry under different carrying levels. At the same time, the consumption quota of the per capita living water corresponding to different levels is predicted. This paper conducts analysis on the basis of the current level.
4. The comprehensive water consumption \( UC \) of unit GDP is calculated. The total GDP of different industries under different carrying levels is calculated according to the results of Step (3). Then, according to the net water consumption quota \( E_i \) and the water utilization factor \( \mu_i \) of each industry, the production water consumption \( C_u \) under different carrying levels is calculated. The total water consumption of unit GDP is obtained by dividing the total production water consumption by the total GDP.
5. The available amount of water resources that can be used for production is calculated. The available amount of water resources for production should be determined by deducting the amount of water available for living and out-of-channel ecology from the total amount of water available to be used. The population can be used to estimate the available amount distribution coefficient of water resources for production. The product of the total available amount of water resources and the coefficient is the estimated available amount of water resources for production.
6. The number of population that can be carried is determined. According to the available amount of domestic water resources, the number of people to be carried can be determined and the available amount of water resources for production can be used to determine the population that can be carried.
7. The number of population that can be carried is tested. By comparing the number of population that can be carried which is obtained from (6) with the estimated number of population, and if the former is greater than the latter, it means that the number of population calculated for domestic water use if relatively small; on the contrary, the calculation shall be carried out after deducting the estimated number of population, and the resulting number of the calculated population shall be equal to or close to the estimated population.
Fig 1 The method of the water resource carrying capacity calculation

The water resources carrying capacity is evaluated by the carrying index of water resources. Among them, the water resources carrying index equals the present population number/the carrying capacity of water resources. At the same time, according to the carrying capacity of water resources, it is divided into six grades, which are rich, surplus, balance, critical overload, overload and severe overload. The specific evaluation criteria are shown in Table 1.

Table 1 The classification of water resource carrying index

| Grade          | rich | surplus | balance | critical overload | overload | severe overload |
|----------------|------|---------|---------|-------------------|----------|-----------------|
| carrying index | <0.5 | 0.5-0.75| 0.75-1  | 1-1.25           | 1.25-1.5 | >1.5            |

2.2. Regional overview

Hainan Province is located at the southernmost end of China. The whole province covers the islands of Hainan Island and reefs and sea areas of Xisha Islands, Zhongsha Islands and Nansha Islands. The total area of Hainan Island is 34,000 km², which is the second largest island next only to Taiwan Island. Affected by the topography of raised middle part and flat surroundings, the terrain is high in the center and low in the perimeter. Therefore, the rivers are divided into the sea from the central mountain area or the hilly areas to form a radial island water system, of which the larger rivers are originated in the central mountains and smaller rivers are originated from the hills or platforms in front of the mountains, with a radial flow to the sea, belonging to the water system of the South China Sea. According to the water resources division, it is divided into the three main basins of the Nandujiang, Changghua River and Wanquan River and coastal small river systems.

There are many rivers in Hainan, with a large amount of water resources. However, the rivers are short in length and steep in slopes and in extreme rises and falls due to concentrated rainstorms. The rainfalls are unevenly distributed annually and regionally. The runoff in the flood season accounts for more than 3/4 of the total amount of rainfalls. Therefore, it is difficult to regulate and reserve water, and the seasonal and engineering water shortage problems are serious. At the same time, it is difficult for the construction of water conservancy project due to the special dome topography. For the plain area of
the outer ring terrace without topographic conditions for the construction of reservoirs, with small flat areas between the low mountains in the middle ring and the hills, small and medium-sized water storage works can be built. Large-scale water storage projects can only be built in the inner-ring mountainous areas, resulting in uneven distribution of water conservancy projects. Only when supplemented by long-distance water diversion and conveyance projects, can the water reach the surrounding plains with concentrated life and production. In some coastal cities and counties in eastern Hainan Province, such as Haikou, Sanya and other cities, the large number of migratory birds has further aggravated the water supply pressure in urban areas, causing the seasonal water supply shortage in some areas.

Fig 2  Regional overview

2.3. Data overview
As can be seen from the foregoing method, the data required for carrying out the calculation of the water resources carrying capacity of Hainan Province mainly includes:

(1) Water resource quantity data: the available amount of water resources in various counties and cities of Hainan Province under different inflow conditions (mainly considering a multi-year average, 75% assurance rate condition and 90% assurance rate condition) is derived from the Comprehensive Planning of Water Resources in Hainan Province.

(2) Water usage intensity data: the current status of water efficiency of each county in Hainan (taking 2015 as an example) for different industries (including agriculture, industry, ecology, life), from the Water Resources Bulletin of Hainan Province, 2015.

(3) Social economic data: the current situation of Hainan Province (taking 2015 as an example) population, GDP, industrial added value and other data from the Statistical Yearbook of Hainan Province in 2015.

3. Results and Discussion

3.1. Analysis on the carrying capacity of water resources in Hainan Province
The water resources carrying capacity of each county under different inflow conditions is calculated according to the above method (Fig 4). The results show that, according to the existing development level and water usage intensity, the available amounts of water resources of Hainan Province are 12.079 billion m³, 8.584 billion m³ and 6.364 billion m³, respectively for three inflow conditions such as the multi-year average, relatively dry year (75% assurance rate) and severely dry year (90% assurance rate). The number of the population which can be carried is 24.0464 million, 17.1512 million and 12.773 million, respectively, and the number of persons to be accommodated in each square kilometre is 705, 503 and 374 respectively (Fig 3). Compared with the current population status, the overall population
space in Hainan is relatively large, especially in the central and eastern cities, including Wuzhishan, Wenchang, Qionghai, Wanning, Tunchang, Qiongzhong and Baisha.

![Map showing the carrying capacity of Hainan province](image)

**Fig 3** Carrying capacity of Hainan province in different assurance rate (a: 90%; b: 75%; c: multi-year average)

![Graph showing the capacity of Hainan province in different assurance rate](image)

**Fig 4** capacity of Hainan province in different assurance rate

From results of analysis and calculation, firstly, due to the relatively abundant rainfall in the central and eastern regions, for example, the rainfall in the central mountainous area is more than 2500mm, which is a typical high-amount rainfall area, the natural condition of water resources in that area is better than that in the western region. Secondly, the population in the central area is relatively scarce, less than 200,000 in 2015, especially Wuzhishan, Baisha, Baoting, Qiongzhong and other central mountainous counties and counties. Last but not least, the current situation of the central region is relatively less
developed compared to the coastal areas, and the water usage intensity is relatively low, so that the population that can be carried in that area is more under the same water resource conditions.

3.2. Analysis of the carrying state of Hainan Province

According to the permanent population of Hainan of 91.082 million in 2015, the carrying capacity index for three inflow conditions is 0.38, 0.53 and 0.71, respectively, such as the multi-year average, relatively dry year (75% assurance rate) and severely dry year (90% assurance rate). According to the grading standard of the water resource carrying capacity, the carrying conditions of the Hainan Province are rich, surplus and surplus under the three different water conditions. In general, the capacity of the water resources is more in surplus.

From different cities and counties (Fig 5), under the multi-year average condition and 75% assurance rate, all the counties and cities are not overloaded and under the condition of multi-year average, there is no county or city in the critical overload state, and in the 75% assurance rate condition, only Haikou, and Sanya are in the critical overload state; and in the 90% assurance rate condition, some counties and cities are in the overload condition, namely Haikou, Lingao, Dongfang and Sanya, and Danzhou are in the critical overload condition. In general, there is much more urban water resources pressure in Haikou and Sanya, and there is also certain water resources pressure in the coastal areas in the west such as Lingao, Dongfang and Danzhou, and there is no water resource pressure in the central and eastern coastal areas.

The following several cases of water resources overload exist in cities and counties in Hainan Province. First, cities and counties are abundant in water resources with high regional economic development level, high population concentration, high population intensity and insufficient per capita water resources. For example, Haikou, according to the population statistics in 2015, the per capita average water resource under multi-year average conditions is only 874 m³, less than half of the national average amount. Second, the rainfall is relatively low, Dongfang and Lingao, which are located in the
relatively low rainfall amount areas in Hainan Province, especially Dongfang with the lowest average rainfall for many years. Third, there is a lack of engineering measures, and the rainfall cannot be converted into effective amount of water resources. The rivers are short in length and steep in slopes and extreme rises and falls due to concentrated rainstorms. Therefore, it is difficult to regulate and reserve water, and the engineering water shortage in various cities and counties in the coastal areas is a common problem especially Haikou, Sanya and Wenchang City, which are the cities of the most prominent problems, and the agricultural production in some areas can only be relied on natural precipitation or groundwater exploitation. Fourth, the migratory population and the tourist population flock in, which greatly increases the urban water supply pressure. For example, in Haikou and Sanya, the non-flood season (November-April) and the peak period of migratory population influx coincide with each other, posing a stricter test to the water conservancy projects and conveyance projects.

4. Conclusion
Hainan Province is rich in water resources and available amount of water resources in three inflow conditions including multi-year average, 75% assurance rate and 90% assurance rate are 12.079 billion m$^3$, 8.584 billion m$^3$ and 6.364 billion m$^3$, respectively. Under the current development level, the population can be carried out is 24.0464 million, 17.1512 million and 12.773 million, respectively. According to the grading standard of water resource carrying capacity, the carrying conditions of Hainan are rich, surplus and surplus under three different conditions. In general, the carrying capacity of water resources is large in space. For different regions, under the multi-year average condition and 75% assurance rate, all the counties and cities are not overloaded; and in the 90% assurance rate condition, some counties and cities are in the overload condition, namely Haikou, Lingao, Dongfang and Sanya, and Danzhou is in the critical overload condition. Generally speaking, the overload or critical overload cities and counties are mainly distributed in the western coastal region, and the surplus cities and counties are mainly distributed in the central mountainous area and the eastern coastal area. In the future, Hainan should accelerate the construction of the “water network”, accelerate the implementation of the connection project of the river, reservoirs and lake water system of the island, construct the key water source and the water system connection projects according to local conditions, and form a reasonable allocation and efficient utilization system of water resources communicated with each other, to solve the problems of engineering and seasonal water shortage.

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