Evaluation of water resources carrying capacity in Changzhi City Based on Analytic Hierarchy Process

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Abstract. With Changzhi City being established as the provincial sub central city, the demand for water resources in the whole city has changed greatly, and the contradiction between supply and demand of water resources still appears in some areas. In order to have a comprehensive and in-depth understanding of the local water resources carrying capacity, the index system was established by selected 14 indices from four subsystems, and the analytic hierarchy process and index evaluation method were used to establish the evaluation model to evaluate and analyze the whole city and each county. The results show that the water resources utilization degree was the largest. The whole city is in a strong level with great potential. Among the counties and districts, only Luzhou district and Shangdang district water resources carrying capacity was medium and other counties were high or highest. The conclusion reflects the current situation of water resources and has guiding significance for future planning and allocation.

1. Introduction
With the development of human society, the demand and development for water resources was becoming more and more. At the same time, it has brought many problems, the contradiction between people and water resources was becoming more and more prominent. 'Insufficient water conservancy facilities, water shortage deficit and water pollution' have become three urgent problems in the development of Chinese cities [1]

Shelby[2] et al, first put forward the idea of carrying capacity in 1961. In 1979, Slesser M[3], first put forward the quantitative model of water resources carrying capacity (Enhancement of Carrying Capacity Options) and applied it to practical research. In 1985, Research Team of Water Resource in Xinjiang [4] applied the idea of carrying capacity in the study of northwest China, which is the first step of Chinese researchers in this field. On the one hand, evaluation of the region based on the balance method. On the other hand focuses on the establishment of evaluation system to study. These two ideas were the main means of today's research [8].

This concept has been applied in Changzhi City. In 2007, Qiaolian Wang [9] successfully took Changzhi City as an example to study, and the system still has guiding significance. In 2019, Jiale Qiao et al [10] selected 14 evaluation indexes from four subsystems, and applied them to Zhangwei River system with the index evaluation method, which involved the evaluation of Changzhi City.

There are some shortcomings in current research. In view of the shortcomings of the objective, this paper selects 14 indices from four subsystems under the premise of considering the total control to comprehensively evaluate the water resources carrying capacity of 4 districts and 8 counties in Changzhi
city. This study will help reveal the current situation of water resources carrying capacity in counties of Changzhi City, and play a guiding role in future development.

2. Study Area
Changzhi City (111°58′～113°44′E,35°49′～37°02′) is located in the southeast of Shanxi Province. The east is bordered with Hebei and Henan, and the rest is bordered with other cities in Shanxi province. Its land area was 13896 km². The territory belongs to the yellow river basin and haihe river basin, haihe River Basin in the majority. The city's annual average total water resources 1907 million m³, including surface water resources 1192 million m³, underground water resources 925 million m³. There were 4 districts and 8 counties in Changzhi City, with a total population of 3455,000 in 2017.

Figure 1. Map of the Changzhi region

3. Materials and methods

3.1. Research framework and methods
Based on the water resources, economic, social and ecological environment situation of Changzhi City, this study established a model by analytic hierarchy process (AHP) and index evaluation method to evaluate the carrying capacity of water resources in 4 districts and 8 counties of Changzhi City. The research framework was shown in Figure2.
3.1.1. Determination of evaluation index. Based on the actual situation of Changzhi city, we build a
evaluation system with four subsystems of the water resources, social, economic and ecological
environment. It can be helped to understand each subsystems relationship on the carrying capacity of
water resources in the region. Each subsystems and its’ indices were shown shown in table 1.

| Water resource carrying capacity | Subsystem | Index code | Primary indexes | Index code | Calculation method | Unit |
|---------------------------------|-----------|------------|-----------------|------------|--------------------|------|
| Water resources                 | B1        | C1         | precipitation   |            |                     | mm   |
|                                 |           | C2         | water production modulus | total water resources/region area | % |
|                                 |           | C3         | Water resources utilization degree | total water consumption/total water resources control | 10^3 m^3/km^2 |
| Social                          | B2        | C4         | population density | total population/region area | person/km^2 |
|                                 |           | C5         | urbanization rate | urban populations/total population | % |
|                                 |           | C6         | urban domestic water quota | Urban Domestic Water Consumption/urban populations×365d | L/P-d |
|                                 |           | C7         | rural domestic water quota | rural domestic water consumption/total population | L/P-d |
| Economic                        | B3        | C8         | per capital GDP rate of irrigation | total gdp/total population | 10^3 yuan/person |
|                                 |           | C9         | land irrigation ratio | agricultural irrigation water/the practical irrigation area | m^3/hm^2 |
|                                 |           | C10        | water consumption of ten thousand yuan industrial added value | effective irrigation area/land area | % |
|                                 |           | C11        | environmental water use rate | gross industrial water consumption/industrial added value | m^3/10^3 yuan |
| Ecological environment          | B4        | C12        | Utilization rate of waste water | Waste water utilization/Waste water treatment | % |
|                                 |           | C13        | water quality of water function zone | Number of water function areas reaching the standard/total number of water function areas | % |
|                                 |           | C14        | environment water use rate | ecological water consumption/total water resources | % |

3.1.2. Analytic hierarchy process (AHP). Analytic hierarchy process (AHP) AHP, was a layer of
complex problems that can be easily investigated by researchers. Through this method, the complex
division of water resources carrying capacity was divided into four subsystems: water resources, society,
economy and ecological environment. Each subsystem was decomposed layer by layer. As mentioned
earlier, the four subsystems were broken down into 14 indices. By expert evaluation mark, the judgment matrix between the four subsystems and the indices in each subsystem were established. The result were shown as table 2 and table 3.

| Table 2. Evaluation mark of subsystem |
|--------------------------------------|
|   | A | B₁ | B₂ | B₃ | B₄ |
|---|---|----|----|----|----|
| B₁ | 1 | 3  | 3  | 2  |
| B₂ | 1/3 | 1 | 1 | 1/3 |
| B₃ | 1/3 | 1 | 1 | 1/3 |
| B₄ | 1/2 | 3 | 3 | 1 |

| Table 3. Evaluation mark of index |
|-----------------------------------|
|   | C₁ | C₂ | C₃ | C₄ | C₅ | C₆ | C₇ |
|---|----|----|----|----|----|----|----|
| C₁ | 1  | 1  | 1/4 | C₄ | 1  | 2  | 3  | 3  |
| C₂ | 1  | 1  | 1/4 | C₅ | 1/2 | 1  | 3  | 4  |
| C₃ | 4  | 4  | 1  | C₆ | 1/3 | 1/3 | 1  | 3  |
|    |    |    |    | C₇ | 1/3 | 1/4 | 1/3 | 1  |
| C₈ | 1  | 4  | 5  | 4  | C₁₂ | 1  | 1  | 1  |
| C₉ | 1/4 | 1  | 2  | 2  | C₁₃ | 1  | 1  | 1  |
| C₁₀| 1/5 | 1/2 | 1  | 3  | C₁₄ | 1  | 1  | 1  |
| C₁₁| 1/4 | 1/2 | 1/3 | 1  |

3.1.3. Index evaluation method. The index evaluation method uses the idea of grading assignment to divide the evaluated behavior into several grades, and then assigns a certain scale value to each grade. The corresponding scale value was determined by the difference of the evaluation behavior falling in the grade. This evaluation method often divides the scale value by percent or one full score. The results were as follows.

| Table 4. Classification criteria of water resource carrying capacity |
|---------------------------------------------------------------|
| Classification | Statement                                      | Eigenvalue |
| V₁             | Water resources carrying capacity is highest   | 1          |
| V₂             | Water resources carrying capacity is high      | 0.8        |
| V₃             | Water resources carrying capacity is medium    | 0.6        |
| V₄             | Water resources carrying capacity is low       | 0.4        |
| V₅             | Water resources carrying capacity is lowest    | 0.2        |

According to the level of 14 indices in Changzhi city and its surrounding areas, the index evaluation standard system was established. The results were as follows.
### Table 5. Index level

| Subsystem | indices | Subsystem indices | evaluation criterion |
|-----------|---------|------------------|----------------------|
| B₁        | C₁      | V₁               | [700,800]            | [600,700) | (500,600) | <500       |
|           | C₂      | V₂               | [9,12]               | [6,9)     | [3,6]     | <3         |
|           | C₃      | V₃               | <80                  | [80,85)   | [85,90)   | [90,95]    | >95        |
| B₂        | C₄      | V₄               | >80                  | [80,220)  | [220,360) | [360,500] | >500       |
|           | C₅      | V₅               | <40                  | [40,50)   | [50,60]   | [60,70]    | >70        |
|           | C₆      | V₆               | <90                  | [90,110)  | [110,130) | [130,150] | >150       |
|           | C₇      | V₇               | <50                  | [50,60)   | [60,70)   | [70,80]    | >80        |
| B₃        | C₈      | V₈               | <3                   | [3,4)     | [4,5)     | [5,6]     | >6         |
|           | C₉      | V₉               | <150                 | [150,250) | [250,350) | [350,450] | >450       |
|           | C₁₀     | V₁₀              | >60                  | [50,60)   | [40,50)   | [30,40)    | <30        |
|           | C₁₁     | V₁₁              | <30                  | [30,35)   | [35,40)   | [40,45)    | >45        |
| B₄        | C₁₂     | V₁₂              | >40                  | [30,40)   | [20,30]   | [10,20]    | <10        |
|           | C₁₃     | V₁₃              | >80                  | [60,80)   | [40,60]   | [20,40]    | <20        |
|           | C₁₄     | V₁₄              | >5                   | [4,5]     | [3,4)     | [2,3)      | <2         |

**Scale value**

|             | 1 | 0.8 | 0.6 | 0.4 | 0.2 |

#### 3.1.4. Carrying capacity result calculation.

Firstly, the weight value of each index is obtained by AHP. Secondly, using the index evaluation method to mark each index and get scale value. Finally, product of the index weight and scale value was the evaluation result of water resources carrying capacity. The calculation formula is as follows:

\[
Q = \sum_{i=1}^{n} q_i = \sum_{i=1}^{n} w_i \times a_i
\]  

where Q is evaluation result, \( n \) is the number of evaluation indices, \( q_i \) is index evaluation results, \( w_i \) is the weight of the \( i \)-th index; \( a_i \) is the scale value of the \( i \)-th index.

#### 3.2. Processing the results of the calculated index

#### 3.2.1. Weight calculation results of analytic hierarchy process.

Judgment matrix, which were response the importance between subsystems and response the importance between indices, were established by consider the actual situation of Changzhi city and expert evaluation. Using yaahp software to calculate the weight of each index to water resources carrying capacity. The results was shown as table 6.
Table 6. Weight result of subsystem and index

| Subsystem         | weight | index                          | weight |
|-------------------|--------|-------------------------------|--------|
| water resources   | 0.4435 | precipitation                  | 0.0739 |
|                   |        | water production modulus      | 0.0739 |
|                   |        | Water resources utilization degree | 0.2956 |
| social            | 0.1222 | population density            | 0.0527 |
|                   |        | urbanization rate             | 0.0395 |
|                   |        | urban domestic water quota    | 0.0194 |
|                   |        | rural domestic water quota    | 0.0106 |
| economic          | 0.1222 | per capital GDP               | 0.07   |
|                   |        | rate of irrigation            | 0.0233 |
|                   |        | land irrigation ratio         | 0.018  |
| ecological        | 0.3122 | Utilization rate of waste water | 0.1041 |
|                   |        | water quality of water function zone | 0.1041 |
|                   |        | environment water use rate    | 0.1041 |

3.2.2. Standard determination of index evaluation method. According to the level of water resources, society, economy and ecological environment in Changzhi city and its surrounding areas, the index evaluation standard system was established.

3.3. Data collection
This study used 2017 Changzhi water resources bulletin, 2017 Changzhi water statistics analysis report and 2017 Changzhi statistical bulletin of national economic and social development to analyze water resources carrying capacity in Changzhi city.

Table 7. Actual data of Changzhi city in 2017

| Inde   | Luzho | Shangdan | Xiangyu | Tunli | Pinghsu | Lichen | Hugua | Zhangzi | Wuxian | Qin | Qinyuan | Luchen | Changzi |
|--------|-------|----------|---------|-------|---------|--------|-------|---------|--------|-----|---------|--------|---------|
|        | x     | u        | g       | n     | n       | n      | g     | n       | g      |     | n       | g      |         |
| C₁     | 557.2 | 549.8    | 626.3   | 654.9 | 513.4   | 607.4  | 554.2 | 591.3   | 630.5  | 674.8| 702.3   | 555.2  | 617.9   |
| C₂     | 12.59 | 8.97     | 6.33    | 14.48 | 11.12   | 43.32  | 7.59  | 12.48   | 12.79  | 9.86 | 8.85    | 9.7    | 13.1    |
| C₃     | 90    | 91       | 87      | 75    | 70      | 82     | 74    | 89      | 82     | 84   | 98      | 86     | 84      |
| C₄     | 2417  | 734      | 237     | 262   | 98      | 139    | 302   | 344     | 118    | 137  | 63      | 374    | 248.6   |
| C₅     | 89    | 41       | 50      | 42    | 33      | 44     | 34    | 35      | 37     | 43   | 46      | 59     | 53      |
| C₆     | 120.12| 70.43    | 94.88   | 50.58 | 48.77   | 73.11  | 66.28 | 63.61   | 73.72  | 50.1 | 65.41   | 72.62  | 88.71   |
| C₇     | 77.14 | 54.67    | 70.17   | 77.57 | 60.18   | 67.75  | 45.86 | 43.66   | 60.73  | 554.9| 49.57   | 57.08  | 58.12   |
| C₈     | 4.84  | 5.19     | 5.63    | 5.31  | 3.12    | 1.7    | 1.84  | 3.01    | 3.69   | 2.27 | 4.73    | 6.07   | 4.3     |
| C₉     | 172.38| 91.13    | 232.21  | 107.61| 337.36  | 263.71 | 243.81| 161.92  | 98.54  | 98.4 | 332.77  | 169.23 | 161.6   |
| C₁₀    | 74    | 42       | 24      | 40    | 12      | 64     | 4     | 44      | 20     | 30   | 18      | 29     | 40.4    |
| C₁₁    | 19.11 | 8.7      | 9.81    | 6.45  | 10.5    | 35.44  | 14.04 | 6.02    | 8.25   | 37.5 | 6.5     | 8.52   | 41.19   |
| C₁₂    | 8     | 0        | 0       | 0     | 0       | 0      | 45    | 0       | 65     | 0    | 73      | 60     | 60      |
| C₁₃    | 100   | 33.3     | 100     | 100   | 100     | 66.7   | 100   | 100     | 100    | 100  | 100     | 100    | 100     |
| C₁₄    | 11    | 3        | 5       | 1     | 0       | 0      | 0     | 1       | 5      | 3    | 1       | 1      | 1.3     |
4. Results and Discussion

4.1. The weight of subsystem and indices
Through yaahp software analysis, the weights between subsystems and indices were as table 6. The results show that among the subsystems, the water resources subsystem has the greatest impact on water resources carrying capacity, and among the indicators, the water resources utilization degree has the greatest impact on water resources carrying capacity. In addition, the impact of ecological environment on water resources carrying capacity was also very important. Economic and social impact on water resources carrying capacity was the weakest. In other words, increasing the management and protection of water resources, and gradually improving the ecological environment, can ensure the sustainable development of society.

4.2. Results of carrying capacity of whole city and counties
Through calculation, the water resources carrying capacity of each county in the city as follows.

| Region  | Result |
|---------|--------|
| Luzhou  | 0.57   |
| Shangdang | 0.46   |
| Tunliu  | 0.72   |
| Lucheng | 0.69   |
| Changzh | 0.75   |

Table 8. Result of water resources carrying capacity in Changzhi city and each county

![Figure 3. Calculation results of the water resource carrying capacity of Changzhi city]
The results show that the overall carrying capacity of water resources in the city was at a high level, and the carrying capacity of water resources in some regions was medium.

Luzhou district and Shangdang district as the city's densely populated and economically developed areas, local water resources have made great contributions to social development. At present, there were potential contradictions between supply and demand of water resources in those region. In order to ensure local sustainable development, new water diversion projects should be built, industrial structure should be optimized, waste water utilization should be improved and ecological environment should be improved. In this way, water resources carrying capacity could be enhanced and potential contradictions could be saved.

Wuxiang county and Huguan county were high water resources carrying capacity. These areas could provide impetus for future socio-economic development.

There was development potential in Tunliu district and other areas, which were high water resources carrying capacity area.

5. Conclusions
(1) In this paper, 14 indexes were selected from four subsystems of water resources, society, economy and ecological environment to evaluate the carrying capacity of water resources in Changzhi City and counties by means of AHP and index evaluation. The evaluation process was comprehensive, the index system and standard accord close to the reality, and the results preferable reflect the carrying capacity of water resources in Changzhi city and counties.

(2) The city’s evaluation value was 0.75, the overall carrying capacity is strong. In each county, the maximum evaluation value is 0.85 in Wuxiang County, and the minimum is 0.46 in Shangdang District. Most counties have strong carrying capacity, and there was a local contradiction between supply and demand in Luzhou District and Shangdang District.

(3) In each county, the evaluation value of Shangdang District, Xiangyuan County and Zhangzi County is close to the lower limit, and the evaluation value of Luzhou District is close to the upper limit. The carrying capacity of water resources in these counties and districts may change and should be paid attention to it.

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