water

MDPI

Article

Projection of Future Water Resources Carrying Capacity in the Huang-Huai-Hai River Basin under the Impacts of Climate Change and Human Activities

Mingming Xie [1,2,3], Chengfeng Zhang [1,2,3], Jianyun Zhang [2,3,4], Guoqing Wang [2,3,4], Junliang Jin [2,3,4], Cuishan Liu [3,4], Ruimin He [3,4] and Zhenxin Bao [2,3,4,*]

1 College of Hydrology and Water Resources, Hohai University, Nanjing 210098, China; mmxie@hhu.edu.cn (M.X.); cfzhang1230@163.com (C.Z.)
2 Yangtze Institute for Conservation and Development, Nanjing 210098, China; jyzhang@nhri.cn (J.Z.); gqwang@nhri.cn (G.W.); jljin@nhri.cn (J.J.)
3 Research Center for Climate Change, Ministry of Water Resources, Nanjing 210029, China; csliu@nhri.cn (C.L.); rmhe@nhri.cn (R.H.)
4 State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing 210029, China
* Correspondence: zxbao@nhri.cn

check for updates

Citation: Xie, M.; Zhang, C.; Zhang, J.; Wang, G.; Jin, J.; Liu, C.; He, R.; Bao, Z. Projection of Future Water Resources Carrying Capacity in the Huang-Huai-Hai River Basin under the Impacts of Climate Change and Human Activities. *Water* **2022**, *14*, 2006. https://doi.org/10.3390/w14132006

Academic Editor: Roko Andricevic

Received: 17 April 2022
Accepted: 15 June 2022
Published: 23 June 2022

Abstract: Water resources are essential for human beings. It is of significance to project future water resources carrying capacity for water resources planning and management. In this study, the Huang-Huai-Hai River Basin (HHHRB), where the contradiction between humans and water is prominent in China, is selected as the study area. The fuzzy comprehensive evaluation model of regional water resources carrying capacity is constructed, the variation characteristics of water resources affected by climate change are analyzed based on the Budyko-Fu model, and considering the influence of transit water resources and water diversion projects, the future water resources carrying capacity in HHHRB under four future climate scenarios in CMIP6 is projected. The results indicate that: (1) On the whole, the carrying capacity of water resources in HHHRB is weak, and the spatial difference is great. (2) Under the background of climate change in the future, precipitation, temperature, and water resources in HHHRB all show increasing trends with changes of 0.90–12.59%, 1.22–1.80 °C, and 13.12–34.29%. (3) Under the background of global change, the water resources carrying capacity of most prefecture-level cities in HHHRB will be greatly improved in the future, and the spatial distributions of change rates among different climate scenarios are relatively consistent. (4) The construction of water diversion projects such as the South-to-North Water Diversion Project has played an obvious role in improving the carrying capacity of water resources. The research results can provide important scientific and technological support for the rational allocation of water resources in the basin under the background of global change.

Keywords: climate change; water resources; carrying capacity evaluation; Huang-Huai-Hai River Basin; CMIP6

1. Introduction

Water resources are the necessary conditions for agricultural production, the core elements of ecological environment, and the material basis for human survival [1,2]. The carrying capacity of water resources refers to the maximum carrying capacity of population and social economic development through the rational allocation of water resources under certain conditions, satisfying the living standards and social development, and maintaining a good ecological circulation system as the premise [3,4]. The global change characterized by climate change and human activities has an important impact on regional water resources, and is the forefront and hot issue of current research [5]. Precipitation, temperature, and other climatic factors change the runoff production characteristics of the basin by participating in the hydrological cycle process, which directly affects the amount of water resources in the basin [6]. A series of human activities, such as reservoir construction and urbanization, indirectly affect the hydrological process of the basin by changing the underlying surface condition [7,8], so that the amount of water resources in the basin changes [9]. For a long time, the total amount of water resources in China has been insufficient and the temporal and spatial distribution is uneven, which restricts the high-quality development of economy and society [10,11]. What is more serious is that in recent decades, the amount of surface water resources in Hai River, Yellow River, Huai River, Liao River, and other major rivers in China has obviously decreased [12,13], and the contradiction between supply and demand of water resources in some areas has become more and more prominent [13]. Therefore, under the background of global change, the present situation evaluation and the future trend projection of water resources carrying capacity are of great significance to the sustainable utilization of water resources, ecological environment protection, and social development in the basin [14].

With the rapid development of social economy, the impact of human activities on water resources is becoming more and more significant, which has greatly changed the hydrological characteristics of the basin and the development and utilization of water resources [15]. The influence of human activities on water resources system is manifested in many aspects, and the change of underlying surface conditions is one of them [16]. A series of human activities, such as the change of land use mode, reservoir construction and so on, have changed the natural state of watershed water cycle and water resources volume [17]. At the same time, the construction of lots of water diversion projects has significantly increased the water resources supply capacity in water-scarce areas [18]. For example, inter-basin water diversion projects such as the South-to-North Water Diversion Project have increased the availability of water resources in Huang River Basin, Huai River Basin, and Hai River Basin in northern China. The planned construction of the South-to-North Water Diversion Project eastern-middle route phase II and western route project are designed with an annual water transfer capacity of 37.5 billion m^3, equivalent to 64.7% of the average annual river runoff of the Yellow River.

Changes in water resources systems are affected by the combination of climate change and human activities [19]. Climate change, characterized by global warming, changes the hydrological cycle by affecting the changes of hydrological factors such as rainfall, evaporation, runoff and so on, resulting in the spatiotemporal redistribution of regional water resources [20,21]. Hydrographers have carried out a lot of research work. For example, Wang et al. have simulated the monthly runoff of 21 different basins in China under different climatic conditions based on water balance models. It was found that the increase of 1 °C may lead to the decrease of runoff by 1.2–4.4%, and the decrease of precipitation by 10% would lead to the decrease of runoff by 9.4–17.4% [5]. Li et al. used the global climate models to drive the hydrological model to predict the future change of water resources in the Dongting Lake Basin of China, and forecasted the average reduction of water resources in 2016–2045 and 2046–2075 as 4.4% and 1.4%, respectively [22].

In order to rationally develop and utilize water resources and protect the ecological environment, in recent years, many scholars have used different scientific methods to evaluate the carrying capacity of regional water resources, such as system dynamics model (SD) [23,24], ecological footprint model [25], analytic hierarchy process (AHP) method [26], principal component analysis (PCA) method [27], and so on. For example, Fan et al. established an improved method based on the Mann–Kendall test and correlation analysis to evaluate the water resources carrying capacity in Hubei Province [28]. Ren et al. put forward the theory of regional water resources metabolism by analogy with the material exchange process between organisms and the environment, and improved the evaluation index system of water resources carrying capacity [29]. Yang et al. used a multi-standard evaluation system combined with analytic hierarchy process (AHP) and system dynamics (SD) models to comprehensively evaluate the carrying capacity of water resources in Xi'an [30].

In previous studies, the data of water resources selected in evaluating the carrying capacity of regional water resources mainly come from the water resources bulletins [30,31]. For example, He et al. evaluated the carrying capacity of agricultural water resources in Zhangjiakou by using the water resources data of "Zhangjiakou Water Resources Bulletin (2006–2016)" [32]; Wang et al. analyzed the water resources carrying capacity of Jilin Province by using the water resources data of "Jilin Province Water Resources Bulletin (2017)" [33]. Human beings live by water, and the main cities and villages are located near the rivers, using a large number of transit water resources. At the same time, the external water resources brought by the water diversion projects will significantly affect the amount of water resources in the region [34]. Due to the data of water resources in the water resources bulletins being the runoff produced by local precipitation, these do not include the amount of transit water resources and the external water resources, and cannot accurately reflect the actual amount of local available water resources, therefore, there is a systematic deviation in the carrying capacity of regional water resources. In addition, most of the previous studies have evaluated the current situation of regional water resources carrying capacity, with less mention of future estimates [24,29,30]. There will be further significant changes in the global climate in the future, and the sixth IPCC assessment reported that in the SSP2–4.5 emission scenario, the global warming range may exceed 2 °C in 2100. Therefore, based on the evaluation of the current situation of water resources carrying capacity, it is an important research direction to analyze the amount of water resources, and project the water resources carrying capacity under the background of global change in the future.

Considering that the previous research mainly focuses on the evaluation of the current situation of regional water resources carrying capacity and the improvement of evaluation methods, there is a lack of the analysis of the actual available water resources in the region and the projection of water resources carrying capacity in the future. This research takes the Huang-Huai-Hai River Basin as the study area, where the contradiction between Chinese people and water is prominent. The main research objectives are as follows: (1) considering the influence of transit water resources and inter-basin water diversion projects, to analyze the actual available water resources in the basin, establish the evaluation model of water resources carrying capacity, and scientifically evaluate the water resources carrying capacity; (2) to study the response of water resources system to climate change, analyze the variation characteristics of precipitation and temperature of HHHRB in the future, and project the future change of water resources; (3) based on the projection of relevant evaluation indexes, to project the water resources carrying capacity under the influence of climate change and human activities in the future. The rest of this paper is arranged as follows: the second part includes the research area, data sources, and main research methods; the third part introduces the research results; the fourth part discusses the significance of the results, and the fifth part gives the conclusion.

2. Data and Methods

2.1. Study Area

Huang-Huai-Hai River Basin is located at 95–122° E and 32–43° N, including the three major rivers in China—the Yellow River, Huai River, and Hai River (Figure 1). The basin is an important economic development area in China with rich resources and a long history of farming [35]. There is a serious shortage of water resources in HHHRB, and the per capita water resources account for about 7% of the national average. The whole basin belongs to the continental monsoon climate. The spatial distribution of precipitation is highly uneven with an annual average precipitation of 556 mm in the basin, from about 1000 mm in the southeast coastal area to less than 400 mm in the northwest region. On the whole, the temperature increases from west to east in HHHRB, and the average annual temperature has been in the range of −4~16 °C for many years. Due to the vast territory and complex terrain, the climatic conditions in HHHRB are complex and changeable, which have a severe impact on environmental change [36]. In recent decades, under the influence of climate change and human activities, as an important agricultural production area and population-intensive area in China, HHHRB has a growing demand for water resources. Therefore, it is of great significance to evaluate the carrying capacity of water resources under the background of climate change in HHHRB.

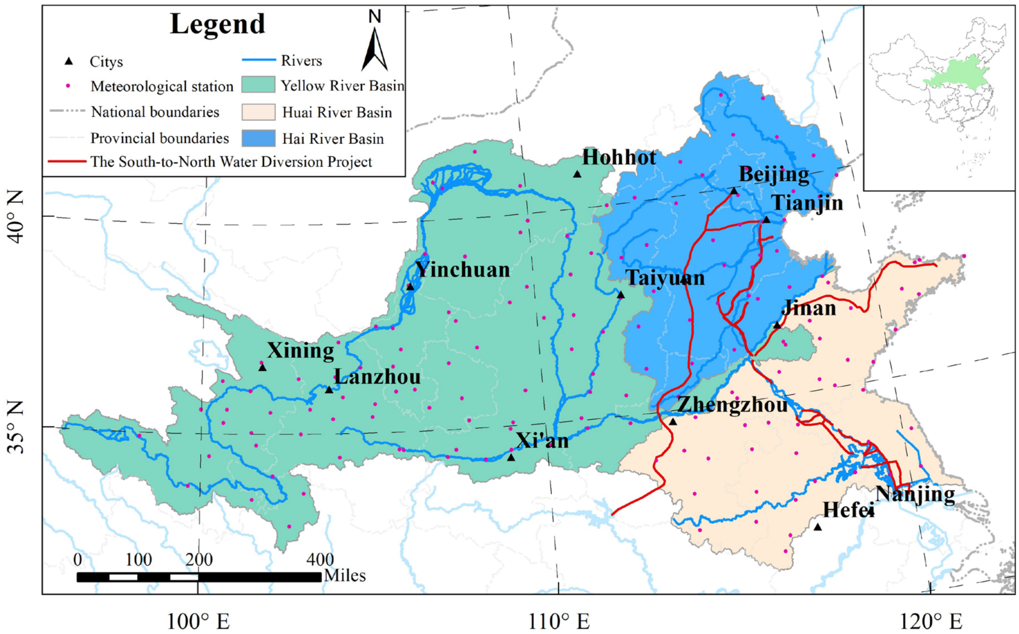

Figure 1. Overview of Huang-Huai-Hai River Basin.

In order to alleviate the problem of water shortage in northern China, especially in the HHHRB, the Chinese government decided to build the South-to-North Water Diversion Project. At present, the first phase of the middle route and the eastern route have been completed and put into use, while the western route is still in the planning stage. In addition, China implements the strictest water resource management system, with the total water consumption control index used to limit the amount of water withdrawn from various water sources by basins and regions. These human activities have a great impact on the spatiotemporal distribution of water resources in HHHRB.

2.2. Data Source

The related data involved in the construction of water resources carrying capacity evaluation system in the study area mainly come from the water resources bulletin and all kinds of statistical yearbooks, statistical annual reports, etc., and individual missing data are filled by the interpolation method in adjacent years.

In predicting the future water resources, the HHHRB was divided into 59 third-class watersheds. Runoff data were collected from watershed hydrologic stations and water resources bulletins for the period of 1982–2016. The meteorological data were downloaded from the official website of the data Information Center of the China Meteorological Administration (http://cdc.cma.gov.cn/home.do) (accessed on 24 April 2020) and the National Meteorological Information Center (http://data.cma.cn) (accessed on 26 April 2020). The former included precipitation, temperature, relative humidity, wind speed, sunshine, daily average, and maximum and minimum temperature of the 160 meteorological stations in the basin, with the time length of 1982–2016. The latter provided a monthly data set of 0.5° × 0.5° grid points for surface temperature and precipitation in China (V2.0) [37]. The actual evapotranspiration data came from the GLEAM-V3.3a product developed by the University of Amsterdam in The Netherlands [38,39], and the data set has a spatial resolution of 0.25° and a time length of 1980–2018. The normalized difference vegetation index (*NDVI*) remote sensing data set GIMMS AVHRR *NDVI* was downloaded from the Environmental and Ecological Science data Center (http://westdc.westgis.ac.cn) (accessed on 13 April 2020) in western China, and the data set has the spatial resolution of 8 km and the time resolution of 15 days, with the time length of 1982–2016. The downloaded *NDVI* data set was calculated and processed based on the maximum value synthesis method MVC (Maximum Value Composites), and the monthly *NDVI* data of 59 tertiary basins in HHHRB were obtained.

Global climate models (GCMs) are important tools to study the characteristics of climate change and predict the change of water resources in the future. They can provide data support for the study of regional water resources carrying capacity under the background of climate change. Among them, various GCMs in CMIPS are widely used in the study of climate change and extreme climate events [40,41]. The GCMs data selected are the precipitation and temperature grid data of eight GCMs of the Coupled Model Intercomparison Project Phase 6 (CMIP6), and four estimated future climate scenarios are also selected from the CMIP6 plan, which are SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5. The GCMs data and estimated future climate scenarios come from CMIP6 (https://esgf-node.llnl.gov/search/cmip6/) (accessed on 3 June 2020). The time period of model assessment is 1982–2014, and the period of future simulation is 2015–2100. Although GCMs have a strict theoretical basis, there is still some uncertainty in the calculation results. The historical data of temperature and precipitation in the above different GCMs are used to correct the errors with the delta-change method. To feed the lumped hydrological model, all of the data from different GCMs are interpolated to a common 0.5° × 0.5° grid, the grid is extracted within the boundary of HHHRB, and the catchment area average values are calculated by using arithmetic average method.

2.3. Methods

2.3.1. Overview

In this research, the evaluation indexes of water resources carrying capacity are selected, the weight of each evaluation index is determined by combined weighting method and each index is graded, the fuzzy comprehensive evaluation model is established, and the water resources obtained by three different statistical methods are used to evaluate the water resources carrying capacity of the study area. Considering the response characteristics of water resources system to climate change, the future precipitation and temperature changes as well as the changes of water resources caused by them are analyzed. On the basis of the projection of future water resources and socio-economic data, the regional water resources carrying capacity under the influence of climate change and human activities in the future is projected. Figure 2 shows a flow chart of the research methodology.

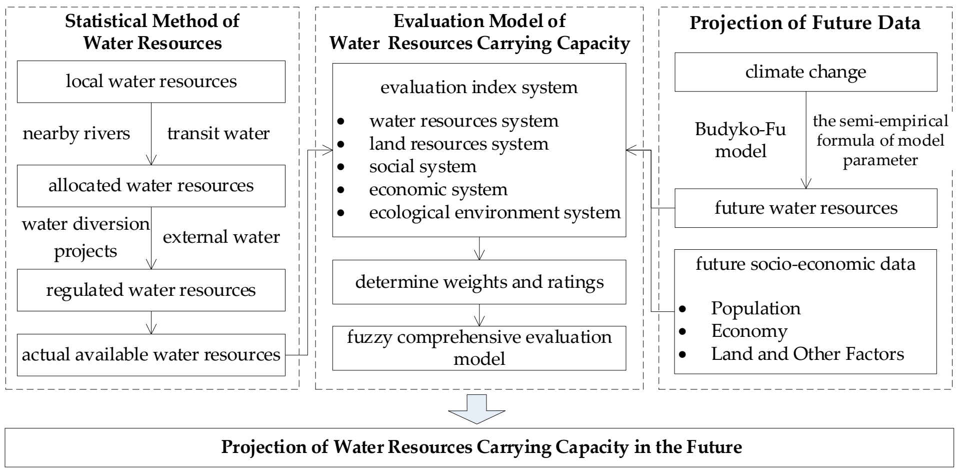

Figure 2. Flow chart of the research methodology.

2.3.2. Evaluation Model of Water Resources Carrying Capacity

Water resources carrying capacity is closely related to regional water resources system, land resources system, social system, economic system, and ecological environment system [42], and several systems influence and interact with each other. When counting the amount of water resources in the basin, three different statistical methods are adopted: the data of water resources in the water resources bulletins usually refer to the runoff generated by local rainfall (called "local water resources"), regardless of the use of transit water resources, which is different from the amount of actual available water resources in the region. Rivers bring transit water resources to cities along the route. In order to allocate these water resources to each prefecture-level city reasonably, the Chinese government has formulated policies for controlling the total amount of water consumption. The amount of water resources calculated according to these rules is accumulated with the runoff generated by local precipitation, which is called "allocated water resources". On this basis, considering the influence of the inter-basin water diversion projects, the external water resources of HHHRB are allocated according to the same rules, and the calculated amount of water resources is called the amount of "regulated water resources".

According to the selection principle of the water resources carrying capacity evaluation index [43], the index system framework is established: the first layer is the target layer, the second layer is the criterion layer, the third layer is the system layer, and the fourth layer is the index layer. In order to facilitate the calculation and comparative analysis of the selected evaluation indexes, the dimensionless normalization of the original data of the index is carried out by using the method of extreme difference standardization, so that the range of the processed data is between 0 and 1.

In order to improve the accuracy and science of regional water resources carrying capacity evaluation, it is necessary to give reasonable weight to the selected evaluation indexes after the construction of the evaluation index system. Entropy weight method and analytic hierarchy process (AHP) are the representative methods of objective weighting method and subjective weighting method, respectively. Entropy weight method calculates the weight by using specific formulas according to the discrete degree of each evaluation index; AHP decomposes the indexes to different levels and carries on qualitative and quantitative analysis [33,44]. Considering the different characteristics of these two methods, the combined weighting method based on entropy weight method and AHP is used. As there is no preference for these two methods, the average value of the calculated results obtained by the two methods is taken as the final weight of each index.

Based on the actual situation of each index in the evaluation index system of water resources carrying capacity in HHHRB, referring to official reports and the average standard of relevant indexes in China, the indexes are divided into three grades according to different critical values [45]. From V_1 to V_3, the carrying capacity of water resources decreases step by step. The level V_1 indicates that the regional water resources carrying capacity is strong, and the regional development demand for water resources can be effectively guaranteed; the level V_3 indicates that the regional water resources supply pressure is close to saturation, and the government must take corresponding measures to prevent the shortage of water resources; the level V_2 is between the two, indicating that the supply and utilization of regional water resources has already had a considerable scale, but still has certain development potential. In order to quantitatively evaluate the carrying capacity of water resources in different research areas, the grade of evaluation set was quantified by 1 score system: $\alpha_1 = 0.95$, $\alpha_2 = 0.5$, $\alpha_3 = 0.05$. This can quantify the influence of different grades on the carrying capacity of regional water resources, and the higher the value, the higher the carrying capacity of water resources [45].

According to the principle of the fuzzy comprehensive evaluation model [46], $C = \{C_1, C_2, \cdots, C_m\}$ is set up as a set of all evaluation indexes and $V = \{V_1, V_2, \cdots, V_n\}$ is set up as a set of all evaluation grades. The evaluation index $C_i(i = 1, 2, \cdots m)$ is evaluated by single index, the membership degree r_{ij} of the evaluation index C_i to the evaluation grade $V_i(i = 1, 2, \cdots n)$ is determined, and the single index evaluation set

$r_1 = (r_{i1},\ r_{i1},\ \cdots r_{im})$ of the i-th evaluation index C_i is obtained, so there is an evaluation set which has m evaluation indexes to construct the evaluation matrix R:

$$R = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} \tag{1}$$

In the formula, r_{ij} is the membership degree of the evaluation index C_i to the evaluation grade V_i.

The comprehensive evaluation of regional water resources carrying capacity is the following fuzzy transformation: $B = A \times R$, $A = (a_1,\ a_2,\ \cdots a_m)$ which represents the weight coefficient of each evaluation index to the importance of fuzzy comprehensive evaluation of water resources carrying capacity, and thus obtains the judgment result matrix $B = \left(b_1,\ b_2,\ \cdots b_j\right)$. The comprehensive evaluation adopts the value of quantitative evaluation set α_i and the membership degree b_j of each grade in the matrix B. According to the calculation formula $A = 0.95b_1 + 0.5b_2 + 0.05b_3$, the final comprehensive score A is obtained [45].

2.3.3. Response of Water Resources to Climate Change

In order to evaluate the carrying capacity of water resources in the future more scientifically, the projection of water resources under the background of future climate change is carried out. The elastic coefficient of runoff to precipitation, potential evapotranspiration, and model parameters are calculated by using Budyko-Fu model [47], the response relationship between potential evapotranspiration and temperature change is analyzed by using Penman–Monteith formula, and the direct runoff effects of precipitation and temperature change is studied. Based on the elastic coefficient of runoff to model parameters, the elastic coefficient of parameter ω to $NDVI$ is calculated by the semi-empirical formula of model parameter ω, and then, according to the elastic coefficients of $NDVI$ to precipitation and temperature, the indirect runoff effects caused by precipitation and temperature by changing vegetation conditions in the watershed are further analyzed by using the compound function chain derivation rule [48]. Combined with the direct runoff effects and indirect runoff effects of precipitation and temperature change, the comprehensive response of runoff to climate change is analyzed, which provides a method for predicting the amount of water resources under the background of climate change in the future. The expressions are as follows:

$$\varepsilon_{P,R} = \varepsilon^1_{P,R} + \varepsilon^2_{P,R} = \varepsilon^1_{P,R} + \varepsilon_{\omega,R} \times \varepsilon_{NDVI,\omega} \times \varepsilon_{P,NDVI} \tag{2}$$

$$\varepsilon_{T,R} = \varepsilon^1_{T,R} + \varepsilon^2_{T,R} = \varepsilon_{E_0,R} \times \varepsilon_{T,E_0} + \varepsilon_{\omega,R} \times \varepsilon_{NDVI,\omega} \times \varepsilon_{T,NDVI} \tag{3}$$

In the formula, $\varepsilon_{P,R}$, $\varepsilon_{T,R}$ are the comprehensive elastic coefficients of runoff to precipitation and temperature, $\varepsilon^1_{P,R}$, $\varepsilon^1_{T,R}$ are the direct elastic coefficients of runoff to precipitation and temperature, $\varepsilon^2_{P,R}$, $\varepsilon^2_{T,R}$ are the indirect elastic coefficients of runoff to precipitation and temperature, $\varepsilon_{\omega,R}$ is the elastic coefficient of runoff to model parameter, $\varepsilon_{NDVI,\omega}$ is the elastic coefficient of model parameter to $NDVI$, $\varepsilon_{P,NDVI}$, $\varepsilon_{T,NDVI}$ are the elastic coefficients of $NDVI$ to precipitation and temperature, $\varepsilon_{E_0,R}$ is the elastic coefficient of runoff to potential evapotranspiration, and ε_{T,E_0} is the elastic coefficient of potential evapotranspiration to temperature.

3. Results

3.1. Construction of Evaluation Model and Present Situation Evaluation of Water Resources Carrying Capacity in Huang-Huai-Hai River Basin

The evaluation of water resources carrying capacity can be based on the supply and demand of water resources. Precipitation, water supply modulus, and other indexes can reflect the regional available water resources. The demand of water resources is related to the water consumption of land resources system, social system, economic system, and ecological environment system. Due to the wide distribution range of HHHRB, 17 evaluation indexes which have the greatest influence on water resources in the study area are selected to construct the evaluation index system of water resources carrying capacity in HHHRB, the weight of evaluation indexes are calculated by combined weighting method, and each index is classified as shown in Table 1.

Based on different statistical methods, the amount of water resources in HHHRB is calculated, and the present situation of water resources carrying capacity is evaluated. (According to Section 2.3, "local water resources" means the runoff generated by local rainfall and comes from the water resources bulletin; on this basis, the water resources that consider the impact of transit water resources is called "allocated water resources", and water resources that further consider the impact of external water resources transferred by water diversion projects is called "regulated water resources".)

Figure 3 shows that the spatial difference of water resources carrying capacity based on local water resources in HHHRB is large. The water resources carrying capacity in the upper reaches of the Yellow River, the lower reaches of the Hai River, and the southern part of the Huai River is strong, while the carrying capacity of water resources in other areas is weak. The carrying capacity of water resources based on allocated water resources in most prefectural cities of the Yellow River Basin is weak, while the carrying capacity level of Hai River Basin and Huai River Basin is stronger. The spatial distribution of water resources carrying capacity based on regulated water resources is basically the same as that based on allocated water resources, and the carrying capacity of water-receiving cities in water diversion projects in the basin has been improved to varying degrees.

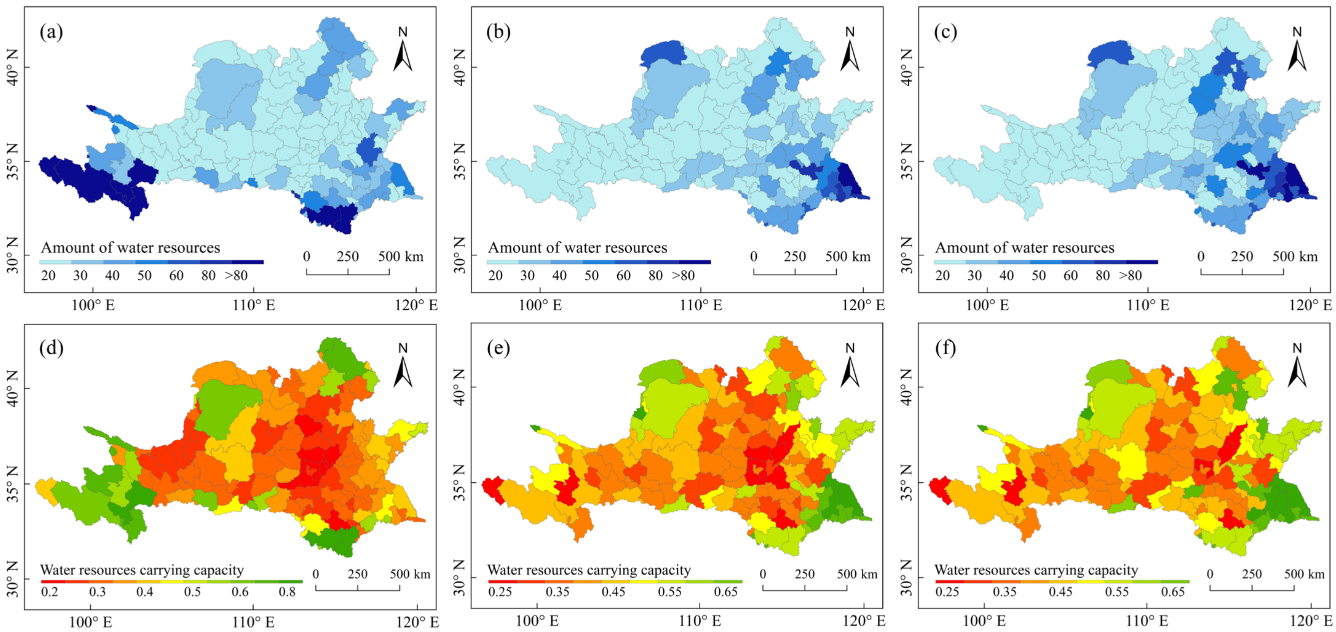

Figure 3. Spatial distributions of water resources and water resources carrying capacity in Huang-Huai-Hai River Basin ((**a**,**d**), (**b**,**e**), and (**c**,**f**) show the spatial distributions of local, allocated, and regulated water resources and corresponding spatial distributions of water resources carrying capacity).

Table 1. Evaluation index system of water resources carrying capacity in Huang-Huai-Hai River Basin.

Target Layer (A)	Criterion Layer (B)	System Layer (C)	Weight	Index Layer (D)	Weight	V_1	V_2	V_3
Water resources carrying capacity	Water supply	Water resources System	0.324	Precipitation/(mm)	0.272	>800	400–800	<400
				Water supply modulus/ (10^4 m^3/km^2)	0.224	<10	10–20	>20
				Per capita water resources/ (m^3/people)	0.366	>1000	500–1000	<500
				Per capita water consumption/(m^3/people)	0.139	<200	200–500	>500
	Water demand	Land resources system	0.311	Per capita cultivated land area/(mu/person)	0.336	>2	1–2	<1
				Irrigation rate of cultivated land/(%)	0.134	>70	50–70	<50
				Multiple cropping index/(%)	0.116	<100	100–150	>150
				Matching coefficient of water and land resources/ (ten thousand m^3/hm)	0.414	>1	0.5–1	<0.5
		Social system	0.106	Natural population growth rate/ (‰)	0.433	<2	2–4	>4
				Urbanization rate/(%)	0.281	>70	50–70	<50
				Resident population density/ (person/km^2)	0.287	<200	200–400	>400
		Economic system	0.11	Per capita GDP/ (yuan/person)	0.511	>70,000	40,000–70,000	<40,000
				Water consumption of per CNY 10,000 GDP /(m^3/CNY 10,000)	0.262	<30	30–80	>80
				Primary industry proportion/(%)	0.226	<5	5–15	>15
		Ecological environment system	0.149	Rehydration rate of ecological environment/(%)	0.221	>10	3–10	<3
				Vegetation coverage rate/ (%)	0.458	>40	20–40	<20
				Wet land rate/(%)	0.32	>10	5–10	<5

3.2. Future Water Resources

3.2.1. Response of Water Resources to Climate Change

Based on the historical data, Formulas (3) and (4) are used to calculate the comprehensive effects of precipitation and temperature changes on water resources, and the results are shown in Figure 4.

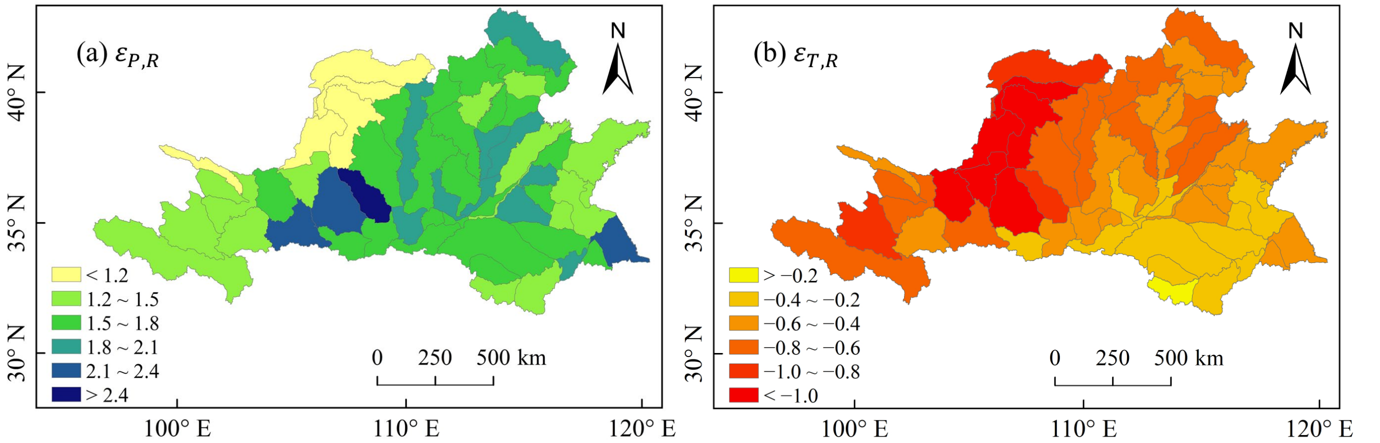

Figure 4. Spatial distributions of $\varepsilon_{P,R}$, $\varepsilon_{T,R}$. ((**a**) shows the spatial distribution of the comprehensive elastic coefficients of runoff to precipitation, (**b**) shows the spatial distribution of the comprehensive elastic coefficients of runoff to temperature).

From the calculation results, the comprehensive elastic coefficient of runoff to precipitation in 59 third-class basins in HHHRB is positive, and the average value of the whole basin is 1.62 which means that the runoff increases by 16.2% on average when the temperature increases by 10%. Additionally, the comprehensive elastic coefficient of runoff to precipitation in the middle reaches of the Yellow River is relatively large which indicates that the area is more sensitive to the change of precipitation. The comprehensive elastic coefficient of the basin to the temperature is negative and the average value of the whole basin is −0.59, which means that the runoff decreases by 5.9% on average when the temperature increases by 1 °C. Moreover, the comprehensive elastic coefficient of runoff to temperature in the basin has a certain spatial difference, showing "high in the east and low in the west, high in the south and low in the north", which indicates that the runoff in the western region and the northern region is more sensitive to the temperature change.

3.2.2. Future Climate Scenarios

According to the estimated future precipitation of each model after error correction, the changes of precipitation and temperature in the future reference period of HHHRB under four scenarios are calculated, including 2020–2050 in the future period and 1982–2014 in the base period. Figure 5 shows that most of the precipitation change rates of each climate model are positive under the four emission scenarios, and the rates of different GCMs are quite different. The temperature change values of these GCMs are positive, and with the increase of emissions from low to high in different future scenarios, the temperature change values of HHHRB under the corresponding model are also gradually increasing.

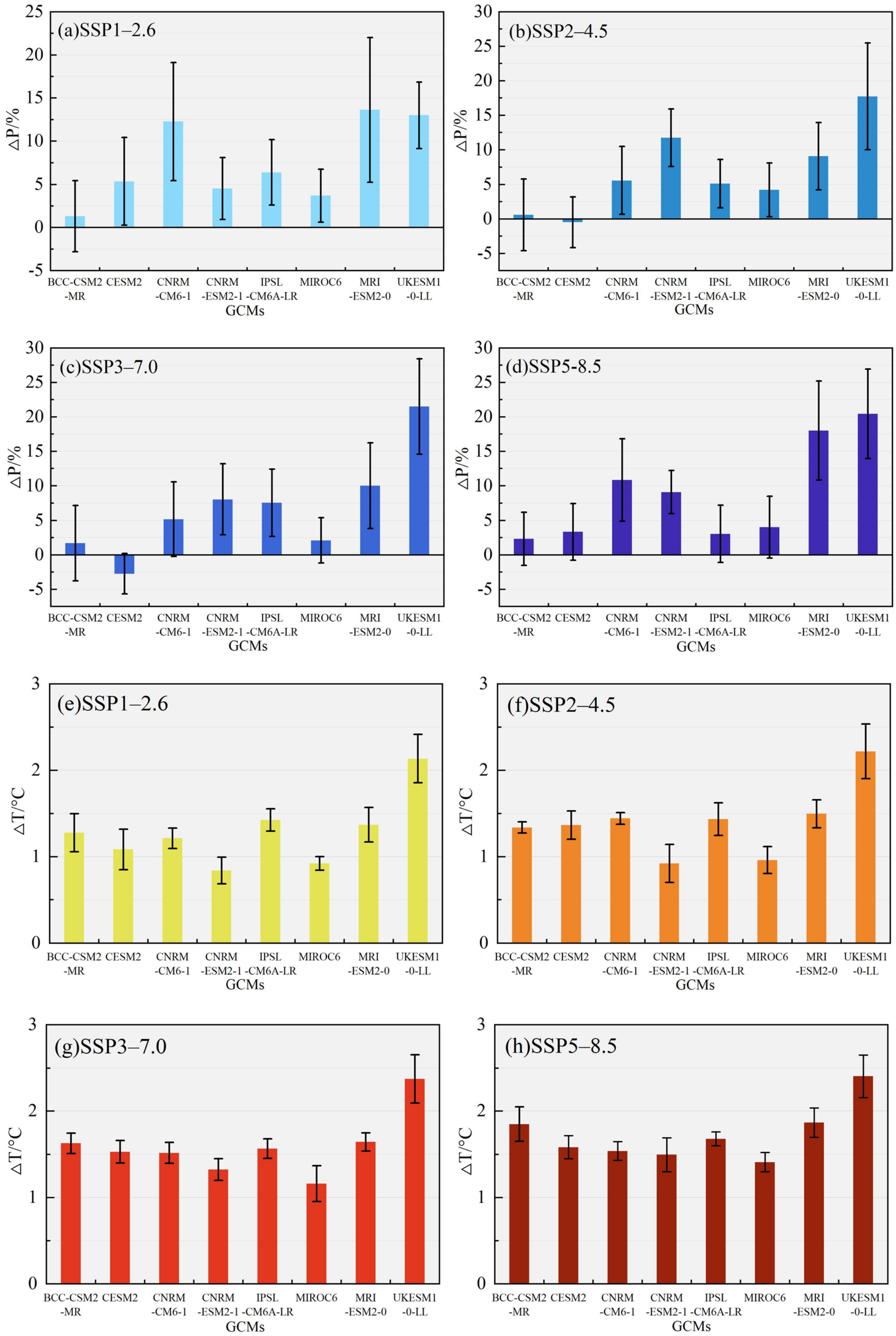

Figure 5. Changes of precipitation (**a**–**d**) and temperature (**e**–**h**) in the future, relative to the base period of each model under different climate scenarios.

3.2.3. Future Water Resources

Based on the climate scenario data from 2020 to 2050, the impact of future climate change on the amount of water resources in HHHRB is estimated. Figure 6 shows the spatial distributions of precipitation, temperature, and water resources in the future period of HHHRB (2020–2050) relative to the base period (1982–2014) under four SSP scenarios. From the figure, the precipitation change rates of HHHRB under different climate scenarios are more than 0, and the differences are great. The temperature change values are more than 1.2 °C and there are some spatial differences; with the increasing emissions of climate scenarios, the heating range of HHHRB is more obvious. The change rates of water resources have certain spatial differences, and the change trends of water resources in the Yellow River Basin and the Huai River Basin are not consistent under different climate scenarios.

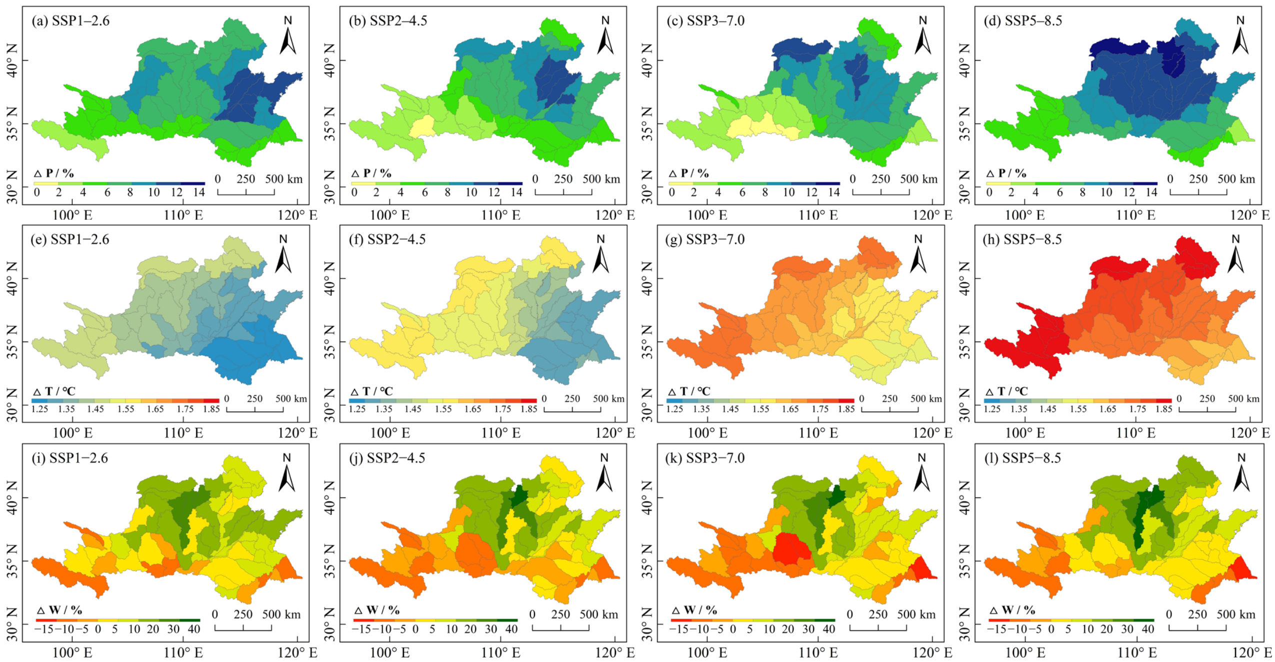

Figure 6. Spatial distributions of precipitation (**a**–**d**), temperature (**e**–**h**), and water resources (**i**–**l**) in the future, relative to the base period under different climate scenarios.

In addition, it is found that under different SSP scenarios, the increases of water resources in each sub-basin of HHHRB (shown in Figure 7) are not consistent in the future, which is 8.41–12.24% in Hai River Basin, 2.22–6.66% in Yellow River Basin, and 0.50–3.66% in Huai River Basin.

3.3. Projection of Water Resources Carrying Capacity under the Background of Future Global Change

3.3.1. Projection of Population, Economy, Land, and Other Factors in the Future

In order to evaluate the future carrying capacity of water resources, it is necessary to predict the future value of each index in the model. China is the most populous country in the world and has basically realized the transformation of population growth model from traditional to modern at present. According to the research team of the China Center for population and Development Research, the total population of China will reach its peak in 2027 and drop to 1.403 billion in 2035 [49].

The shortage of water resources and the prominent contradiction between supply and demand of water resources limit the high-quality development of China's social economy. Based on the analytical "supply constraint-economic scale-production level" ternary water consumption driving mechanism, the researchers of the China Institute of Water Conservancy and Hydropower Research put forward the water use adaptive increase curve (AIR curve), which is restricted by resources, and predicted the total amount of water consumption in China in the future scientifically. The results show that the total amount of water consumption in China in 2035 is 645.1 billion m^3, and the inflection point will appear in 2037, when the total water consumption in China will be 648 billion m^3 [50].

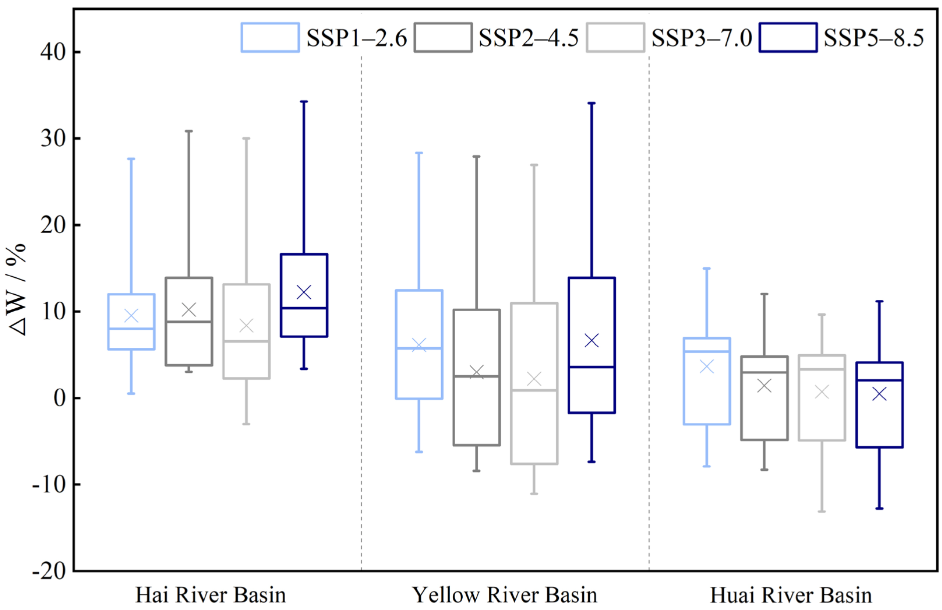

Figure 7. Change rates of water resources in the future relative to the base period of each sub-basin under different climate scenarios.

In order to reasonably predict the cultivated land area in China in the future period, based on the data of cultivated land area at the end of 2013–2017 in China, the average annual reduction of cultivated land area in 2014–2017 is calculated, and the cultivated land area in 2035 is predicted to be about 12,667 million km^2.

Assuming that the changing trends of different indexes of each prefecture-level city in HHHRB are consistent with the change of the whole country, the index values of each prefecture-level city in 2035 can be calculated.

3.3.2. Projection of Regulated Water Resources in the Future

Based on the change of water resources in HHHRB under the background of climate change in Section 3.2, considering the external water resources transferred by the water distribution projects that will be put into use in the future to HHHRB, according to the total water consumption control index and water quantity allocation schemes implemented by China, the total amount of water resources in HHHRB are distributed to each prefecture-level city according to the proportion of total water consumption control index. On this basis, the projection of the total amount of regulated water resources of each prefecture-level city in the future is carried out, as shown in Figure 8. Compared with the regulated water resources relative to the base period, the total amount of water resources in the future period of each prefecture-level city will increase to varying degrees. Among them, the amount of water resources in Hengshui, Tianjin, and other cities has increased significantly, with a change rate of more than 50%; the amount of water resources in prefecture-level cities in the upper reaches of the Yellow River has increased greatly, with a change rate of 30–40%, and in the lower reaches of the Huai River, the increase in the amount of water resources in prefectural cities is only about 10%.

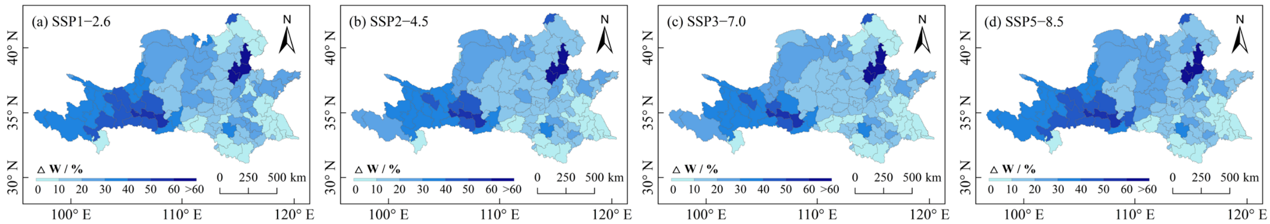

Figure 8. Spatial distributions of the change rates of regulated water resources in the future relative to the base period under different climate scenarios (%).

3.3.3. Projection of Water Resources Carrying Capacity in the Future

In order to analyze the change of water resources carrying capacity of each prefecture-level city under the background of global change in the future, the predicted values of the evaluation indexes are input into the fuzzy comprehensive evaluation model to calculate the change rates of the water resources carrying capacity in the future relative to the base period of each prefecture-level city (based on the regulated water resources). Figure 9 shows that the change rates of water resources carrying capacity are different in various scenarios. Under the scenarios of SSP1–2.6, SSP2–4.5 and SSP5–8.5, the carrying capacity of water resources in most prefectural cities in the basin is improved, and the change rates of water resources carrying capacity in some cities is 30% or more; while the carrying capacity in more prefectural cities in the basin decreases slightly under SSP3–7.0. The reason for this may be related to the relatively small increase in the amount of regulated water resources in the future under this scenario. Under the four scenarios, the spatial distributions of the change rates of water resources carrying capacity in the basin are almost the same, and the water resources carrying capacity of most prefectural cities has been greatly improved.

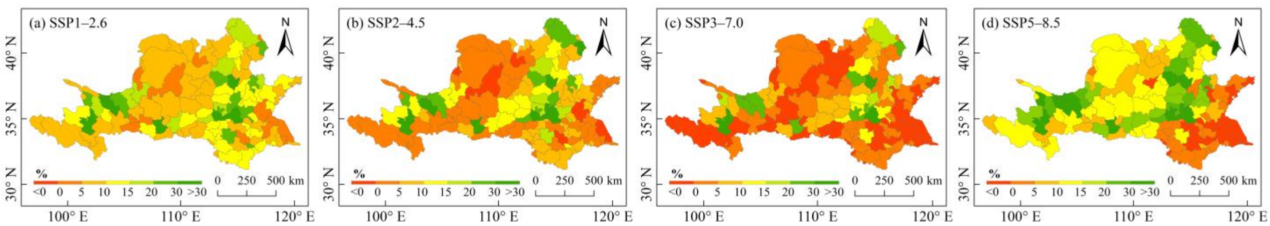

Figure 9. Spatial distributions of change rates of water resources carrying capacity in the future relative to the base period under different climate scenarios (%).

4. Discussion

4.1. Actual Available Water Resources in the Region

The study of water resources carrying capacity is not only a significant part of resources carrying capacity research, but also an important research content of sustainable utilization of water resources [51,52]. In the previous research of evaluating the carrying capacity of regional water resources, the data of water resources came from the local water resources bulletin [25,29–31]. The water resources counted in the water resources bulletin refer to the total amount of surface water and groundwater produced by local precipitation, which is calculated by the sum of surface water resources and groundwater resources, and then the repetition of the two is deducted. The water resources obtained by this statistical method do not include the transit water resources and cannot reflect the actual available water resources in the region. In addition, there are inter-basin water diversion projects such as the South-to-North Water Diversion Project in HHHRB. The construction of water diversion projects will change the water consumption of cities along the route [18,34], which should also be taken into account when counting the amount of water resources in the area. Since 2012, China has implemented the strictest water resources management system [53]. On the basis of considering the impact of transit water resources and external water resources, the total amount of water resources in the basin can be scientifically allocated to various sub-units according to the total water consumption control, and more accurate regional available water resources can be obtained.

In Section 3.1, the regional water resources based on three different statistical methods are used to evaluate the water resources carrying capacity, and the results are obtained. Figure 3 shows that the evaluation results based on the allocated water resources are quite different from those based on the local water resources. The main reasons are the analysis of transit water and the redistribution of water resources according to the policy, and that the carrying capacity based on the regulated water resources has been improved to varying degrees compared with the previous two, which is consistent with the fact that many cities in HHHRB are water-receiving cities of the South-to-North Water Diversion Project [34]. This statistical method, which considers the influence of transit water resources, water diversion projects, and the national total water consumption control policy, can effectively improve the accuracy of the evaluation results of water resources carrying capacity [54].

4.2. Contribution of Projected Results

In Section 3.2, based on the Budyko-Fu model and elastic coefficient method, the comprehensive impact of climate change on water resources is studied. The hydrological model has a certain physical basis and can simulate the change of runoff. Many scholars have studied the relationship among climate, vegetation, and water resources based on the hydrological model and elastic coefficient method [48,55,56]. Fully understanding the impacts of future changes in precipitation, temperature, and other factors on water resources in the basin can help the water resources departments to formulate corresponding strategies to better adapt to climate change.

In this study, the projected results of water resources carrying capacity in the future can provide reference for regional water resources management and allocation [57]. On the whole, due to the influence of climate change and water diversion projects, the future water resources carrying capacity of most prefectural-level cities in HHHRB has been improved, which means that the shortage of water resources in HHHRB may be alleviated in the future, and the water resources in these areas can be moderately developed and utilized. The carrying capacity of water resources in some cities may decline. The government needs to take corresponding measures to change the development and utilization methods of regional water resources into sustainable development, develop water-saving technology, and restrict the water consumption quota of industry, agriculture, and other industries [30].

4.3. Application and Limitation of Evaluation Method

HHHRB has a complex water system [36] and is the main water-receiving area of the South-to-North Water Diversion Project [34]. Therefore, it is necessary to consider both transit water resources and external water resources in evaluating the carrying capacity of water resources. In applying the evaluation method to other regions, it should be proceeded from the actual situation of the specific region: if there are no rivers near the region, there is no need to consider transit water resources; if there are no water diversion projects in the area, there is no need to consider external water resources; if both occur at the same time, only the runoff generated by local rainfall needs to be taken into account in evaluating the water resources carrying capacity in the region.

In addition, this study has some limitations: (1) in the evaluation index system of water resources carrying capacity, the data of each index comes from all kinds of yearbooks and bulletins rather than from the actual measurement, which causes the evaluation results to have certain errors; (2) when projecting the amount of future water resources, only 8 GCMs data are used, and if more GCMs are selected, the uncertainty of the projected results may be reduced; (3) the projection of population, economy, land, and other factors in the future is also a major difficulty [49,50], as these socio-economic factors may change greatly with the different governance policies of the future society, resulting in the uncertainty of the projected results of water resources carrying capacity.

5. Conclusions

In recent decades, climate change and human activities have had a great impact on the global water resources, and the water resources carrying capacity of HHHRB under this background is studied. The results show that the spatial difference of water resources carrying capacity in HHHRB is large, the carrying capacity of cities in Yellow River Basin is weak, while in Huai River Basin and Hai River Basin it is relatively strong, and this spatial difference will continue to exist in the future. Considering the influence of transit water resources and water diversion projects in the basin, and allocating the calculated actual available water resources to each prefecture-level city according to the total water consumption control policy, more accurate evaluation results of water resources carrying capacity can be obtained.

According to the characteristics of the four predicted future climate scenarios in CMIP6, the precipitation and temperature in HHHRB will increase and the change values of temperature will exceed 1.2 °C in the future. The increase of water resources in each sub-basin will not be consistent: 8.41–12.24% in Hai River Basin, 2.22–6.66% in Yellow River Basin, and 0.50–3.66% in Huai River Basin. At the same time, the planned South-to-North Water Diversion Project will also effectively alleviate the shortage of water resources in HHHRB as the amount of regulated water resources in most cities will increase by more than 10% relative to the base period, and the change rates in some cities will reach more than 50%.

The change rates of water resources carrying capacity in different future climate scenarios are different, but the spatial distributions are the same. On the whole, the water resources carrying capacity of most prefecture-level cities in the basin will be improved, and the change rates of some cities will reach more than 30%. There will be a slight decrease in the water resources carrying capacity in some cities and the decline range will be less than 10%, therefore, the government should take corresponding water resources management measures according to different results.

In addition, in the construction of an evaluation index system of water resources carrying capacity in HHHRB, 17 representative evaluation indexes were selected based on prefecture-level cities. In order to reflect the carrying capacity of regional water resources more accurately, several typical small watersheds can be selected in the future and the evaluation index system of water resources carrying capacity can be further improved.

Author Contributions: Conceptualization, J.Z. and Z.B.; methodology, G.W. and Z.B.; software, M.X. and C.Z.; formal analysis, M.X. and C.Z.; writing—original draft preparation, M.X.; writing—review and editing, J.Z., G.W., Z.B., J.J., C.L. and R.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Key R&D Program of China, grant numbers 2017YFA0605002, 2017YFA0605004, National Natural Science Foundation of China, grant numbers 41961124007, 52121006, 41830863, 51879164, and "Six top talents" in Jiangsu province, grant number RJFW-031.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author or the first author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hyandye, C.B.; Worqul, A.; Martz, L.W.; Muzuka, A.N.N. The impact of future climate and land use/cover change on water resources in the Ndembera watershed and their mitigation and adaptation strategies. *J. Syst. Res.* **2018**, *7*, 7. [CrossRef]
2. Kumar, N.; Tischbein, B.; Kusche, J.; Beg, M.K.; Bogardi, J.J. Impact of land-use change on the water resources of the Upper Kharun Catchment, Chhattisgarh, India. *Reg. Environ. Chang.* **2017**, *17*, 2373–2385. [CrossRef]
3. Ait-Aoudia, M.N.; Berezowska-Azzag, E. Water resources carrying capacity assessment: The case of Algeria's capital city. *Habitat Int.* **2016**, *58*, 51–58. [CrossRef]
4. Daily, G.C.; Ehrlich, P.R. Socioeconomic equity, sustainability, and Earth's carrying capacity. *Ecol. Appl.* **1996**, *6*, 991–1001. [CrossRef]
5. Wang, G.Q.; Zhang, J.Y.; He, R.M.; Liu, C.S.; Ma, T.; Bao, Z.X.; Liu, Y.L. Runoff sensitivity to climate change for hydro-climatically different catchments in China. *Stoch. Environ. Res. Risk Assess.* **2017**, *31*, 1011–1021. [CrossRef]
6. Mohor, G.S.; Mendiondo, E.M. Economic indicators of hydrologic drought insurance under water demand and climate change scenarios in a Brazilian context. *Ecol. Econ.* **2017**, *140*, 66–78. [CrossRef]
7. Pang, G.J.; Wang, X.J.; Yang, M.X. Using the *NDVI* to identify variations in, and responses of, vegetation to climate change on the Tibetan Plateau from 1982 to 2012. *Quat. Int.* **2017**, *444*, 87–96. [CrossRef]
8. Lamchin, M.; Lee, W.-K.; Jeon, S.W.; Wang, S.W.; Lim, C.H.; Song, C.; Sung, M. Long-term trend of and correlation between vegetation greenness and climate variables in Asia based on satellite data. *MethodsX* **2018**, *5*, 803–807. [CrossRef]
9. Fu, B.J.; Wang, S.; Liu, Y.; Liu, J.B.; Liang, W.; Miao, C.Y. Hydrogeomorphic Ecosystem Responses to Natural and Anthropogenic Changes in the Loess Plateau of China. *Annu. Rev. Earth Planet. Sci.* **2017**, *45*, 223–243. [CrossRef]
10. Li, P.Y.; Qian, H.; Wu, J.H. Conjunctive use of groundwater and surface water to reduce soil salinization in the Yinchuan Plain, North-West China. *Int. J. Water Resour. Dev.* **2018**, *34*, 337–353. [CrossRef]
11. Chou, L.C.; Dai, J.; Qian, X.Y.; Karimipour, A.; Zheng, X.P. Achieving sustainable soil and water protection: The perspective of agricultural water price regulation on environmental protection. *Agric. Water Manag.* **2021**, *245*, 106583. [CrossRef]
12. Wang, G.Q.; Zhang, J.Y.; Guan, X.X.; Bao, Z.X.; Liu, Y.L.; He, R.M.; Jin, J.L.; Liu, C.S.; Chen, X. Quantifying attribution of runoff change for major rivers in China. *Adv. Water Sci.* **2020**, *31*, 313–323.
13. Zhang, J.Y.; Wang, G.Q.; Jin, J.L.; He, R.M.; Liu, C.S. Evolution and variation characteristics of the recorded runoff for the major rivers in China during 1956—2018. *Adv. Water Sci.* **2020**, *31*, 153–161.
14. Sun, J.; Li, Y.P.; Suo, C.; Liu, Y.R. Impacts of irrigation efficiency on agricultural water-land nexus system management under multiple uncertainties—A case study in Amu Darya River basin, Central Asia. *Agric. Water Manag.* **2019**, *216*, 76–88. [CrossRef]
15. Hassanzadeh, E. Trade-Offs between Human and Environment: Challenges for Regional Water Management under Changing Conditions. *Water* **2019**, *11*, 1773. [CrossRef]
16. Li, Y.Y.; Chang, J.X.; Luo, L.F.; Wang, Y.M.; Guo, A.J.; Ma, F.; Fan, J.J. Spatiotemporal impacts of land use land cover changes on hydrology from the mechanism perspective using SWAT model with time-varying parameters. *Hydrol. Res.* **2019**, *50*, 244–261. [CrossRef]
17. Bryan, B.A.; Gao, L.; Ye, Y.Q.; Sun, X.F.; Connor, J.D.; Crossman, N.D.; Stafford-Smith, M.; Wu, J.G.; He, C.Y.; Yu, D.Y.; et al. China's response to a national land-system sustainability emergency. *Nature* **2018**, *559*, 193–204. [CrossRef]
18. Zhuang, W. Eco-environmental impact of inter-basin water transfer projects: A review. *Environ. Sci. Pollut. Res.* **2016**, *23*, 12867–12879. [CrossRef]
19. Lang, Y.Q.; Song, W.; Zhang, Y. Responses of the water-yield ecosystem service to climate and land use change in Sancha River Basin, China. *Phys. Chem. Earth* **2017**, *101*, 102–111. [CrossRef]
20. Kanakoudis, V.; Tsitsifli, S.; Papadopoulou, A.; Curk, B.C.; Karleusa, B. Water resources vulnerability assessment in the Adriatic Sea region: The case of Corfu Island. *Environ. Sci. Pollut. Res.* **2017**, *24*, 20173–20186. [CrossRef]
21. Schilling, J.; Hertig, E.; Tramblay, Y.; Scheffran, J. Climate change vulnerability, water resources and social implications in North Africa. *Reg. Environ. Chang.* **2020**, *20*, 15. [CrossRef]
22. Li, Z.; Zhou, H.; Zhang, L.; Mao, D. Water Resources Evolution in Dongting Lake Basin Based on Different Emission Scenarios. *J. China Hydrol.* **2018**, *38*, 29–36.
23. Sun, Y.H.; Liu, N.N.; Shang, J.X.; Zhang, J.Y. Sustainable utilization of water resources in China: A system dynamics model. *J. Clean. Prod.* **2017**, *142*, 613–625. [CrossRef]
24. Yang, J.F.; Lei, K.; Khu, S.; Meng, W. Assessment of Water Resources Carrying Capacity for Sustainable Development Based on a System Dynamics Model: A Case Study of Tieling City, China. *Water Resour. Manag.* **2015**, *29*, 885–899. [CrossRef]
25. Wang, H.; Huang, J.J.; Zhou, H.; Deng, C.B.; Fang, C.L. Analysis of sustainable utilization of water resources based on the improved water resources ecological footprint model: A case study of Hubei Province, China. *J. Environ. Manag.* **2020**, *262*, 110331. [CrossRef]
26. Wang, Y.M.; Zhou, X.D.; Engel, B. Water environment carrying capacity in Bosten Lake basin. *J. Clean. Prod.* **2018**, *199*, 574–583. [CrossRef]
27. Zhang, J.; Zhang, C.L.; Shi, W.L.; Fu, Y.C. Quantitative evaluation and optimized utilization of water resources-water environment carrying capacity based on nature-based solutions. *J. Hydrol.* **2019**, *568*, 96–107. [CrossRef]
28. Song, F.; Yang, X.H.; Wu, F.F. Catastrophe progression method based on M-K test and correlation analysis for assessing water resources carrying capacity in Hubei province. *J. Water Clim. Change* **2020**, *11*, 556–567. [CrossRef]

29. Ren, C.F.; Guo, P.; Li, M.; Li, R.H. An innovative method for water resources carrying capacity research—Metabolic theory of regional water resources. *J. Environ. Manag.* **2016**, *167*, 139–146. [CrossRef]
30. Yang, Z.Y.; Song, J.X.; Cheng, D.D.; Xia, J.; Li, Q.; Ahamad, M.I. Comprehensive evaluation and scenario simulation for the water resources carrying capacity in Xi'an city, China. *J. Environ. Manag.* **2019**, *230*, 221–233. [CrossRef]
31. Shi, K.; Diao, C.; Sun, X. Evaluation of soil-water resources carrying capacity based on entropy weight extension decision model in the Three Gorges Reservoir Region of Chongqing. *Acta Sci. Circumstantiae* **2013**, *33*, 609–616.
32. He, L.; Du, Y.; Wu, S.; Zhang, Z.L. Evaluation of the agricultural water resource carrying capacity and optimization of a planting-raising structure. *Agric. Water Manag.* **2021**, *243*, 106456. [CrossRef]
33. Wang, D.L.; Shi, Y.H.; Wan, K.D. Integrated evaluation of the carrying capacities of mineral resource-based cities considering synergy between subsystems. *Ecol. Indic.* **2020**, *108*, 105701. [CrossRef]
34. Zhang, Q.F. The South-to-North Water Transfer Project of China: Environmental Implications and Monitoring Strategy. *J. Am. Water Resour. Assoc.* **2009**, *45*, 1238–1247. [CrossRef]
35. Liu, Q.; Yan, C.R.; Ju, H.; Garre, S. Impact of climate change on potential evapotranspiration under a historical and future climate scenario in the Huang-Huai-Hai Plain, China. *Theor. Appl. Climatol.* **2018**, *132*, 387–401. [CrossRef]
36. Yan, D.H.; Xu, T.; Girma, A.; Yuan, Z.; Weng, B.S.; Qin, T.L.; Do, P.; Yuan, Y. Regional Correlation between Precipitation and Vegetation in the Huang-Huai-Hai River Basin, China. *Water* **2017**, *9*, 557. [CrossRef]
37. Guan, X.X.; Zhang, J.Y.; Yang, Q.L.; Wang, G.Q. Changing characteristics and attribution analysis of potential evapotranspiration in the Huang-Huai-Hai River Basin, China. *Meteorol. Atmos. Phys.* **2021**, *133*, 97–108. [CrossRef]
38. Miralles, D.G.; Holmes, T.; De, J.; Gash, J.H.; Meesters, A.; Dolman, A.J.J.H.; Discussions, E.S.S. Global land-surface evaporation estimated from satellite-based observations. *Hydrol. Earth Syst. Sci.* **2010**, *7*, 453–469. [CrossRef]
39. Martens, B.; Miralles, D.G.; Lievens, H.; van der Schalie, R.; de Jeu, R.A.M.; Fernandez-Prieto, D.; Beck, H.E.; Dorigo, W.A.; Verhoest, N.E.C. GLEAM v3: Satellite-based land evaporation and root-zone soil moisture. *Geosci. Model Dev.* **2017**, *10*, 1903–1925. [CrossRef]
40. Jiang, D.B.; Hu, D.; Tian, Z.P.; Lang, X.M. Differences between CMIP6 and CMIP5 Models in Simulating Climate over China and the East Asian Monsoon. *Adv. Atmos. Sci.* **2020**, *37*, 1102–1118. [CrossRef]
41. Yang, X.L.; Zhou, B.T.; Xu, Y.; Han, Z.Y. CMIP6 Evaluation and Projection of Temperature and Precipitation over China. *Adv. Atmos. Sci.* **2021**, *38*, 817–830. [CrossRef]
42. Lopez-Moreno, J.I.; Vicente-Serrano, S.M.; Moran-Tejeda, E.; Zabalza, J.; Lorenzo-Lacruz, J.; Garcia-Ruiz, J.M. Impact of climate evolution and land use changes on water yield in the ebro basin. *Hydrol. Earth Syst. Sci.* **2011**, *15*, 311–322. [CrossRef]
43. Liu, H.; Geng, L.H.; Chen, X.Y. Indicators for evaluating sustainable utilization of regional water resources. *Adv. Water Sci.* **2003**, *14*, 265–270.
44. Liu, T.; Yang, X.H.; Geng, L.H.; Sun, B.Y. A Three-Stage Hybrid Model for Space-Time Analysis of Water Resources Carrying Capacity: A Case Study of Jilin Province, China. *Water* **2020**, *12*, 426. [CrossRef]
45. Xi, D.; Xu, X.; Han, D.; Yang, Z. Evaluating water resources-carrying capacity in Beijing-Tianjin-Hebei region. *J. Beijing Norm. Univ. Nat. Sci.* **2017**, *53*, 575–581.
46. Tan, K.; Yan, Z.; Zhao, Z.; Pu, J.; Li, S.; Miao, P.; Zhao, X. Evaluation of Resource and Environmental Carrying Capacity of Wenshan City in Karst Area Based on Fuzzy Model. *Res. Soil Water Conserv.* **2021**, *28*, 218–227.
47. Bao, Z.X.; Zhang, J.Y.; Wang, G.Q.; Chen, Q.W.; Guan, T.S.; Yan, X.L.; Liu, C.S.; Liu, J.; Wang, J. The impact of climate variability and land use/cover change on the water balance in the Middle Yellow River Basin, China. *J. Hydrol.* **2019**, *577*, 123942. [CrossRef]
48. Zhang, J.Y.; Zhang, C.F.; Bao, Z.X.; Li, M.; Wang, G.Q.; Guan, X.X.; Liu, C.S. Analysis of the effects of vegetation changes on runoff in the Huang-Huai-Hai River basin under global change. *Adv. Water Sci.* **2021**, *32*, 813–823.
49. LI, Y.; Zhang, X.Y. Analysis of China's "14th Five-Year Plan" Period and Mid- and Long-Term Population Development Trend. *Popul. Health* **2020**, *8*, 41–47.
50. Zhao, Y.; Li, H.; Liu, H.; Wang, L.; He, G.; Wang, H. The law of growth: Prediction of peak water consumption in China. *J. Hydraul. Eng.* **2021**, *52*, 129–141.
51. Zhou, Z.; Huang, Y.; Huang, J. Regional Differences and Influencing Factors of Soil-Water Resources Carrying Capacity. *Bull. Soil Water Conserv.* **2015**, *35*, 344–349.
52. Chen, X.; Dai, Q. A study on water-soil capacity in north west arid area with systemic dynamics—A Case of HEXI Corridor, Gansu Province. *Arid Land Geogr.* **2002**, *25*, 377–382.
53. He, Y.H.; Chen, X.H.; Sheng, Z.P.; Lin, K.R.; Gui, F.L. Water allocation under the constraint of total water-use quota: A case from Dongjiang River Basin, South China. *Hydrol. Sci. J.-J. Sci. Hydrol.* **2018**, *63*, 154–167. [CrossRef]
54. Han, Y.; Zhang, S.; Lv, A. Research of effect on water resources carrying capacity in Beijing-Tianjin-Hebei region by water transfer. *Resour. Sci.* **2018**, *40*, 2236–2246.
55. Liu, M.X.; Xu, X.L.; Xu, C.H.; Sun, A.Y.; Wang, K.L.; Scanlon, B.R.; Zhang, L. A new drought index that considers the joint effects of climate and land surface change. *Water Resour. Res.* **2017**, *53*, 3262–3278. [CrossRef]
56. Zhang, D.; Liu, X.M.; Bai, P. Different Influences of Vegetation Greening on Regional Water-Energy Balance under Different Climatic Conditions. *Forests* **2018**, *9*, 412. [CrossRef]
57. Jia, Z.M.; Cai, Y.P.; Chen, Y.; Zeng, W.H. Regionalization of water environmental carrying capacity for supporting the sustainable water resources management and development in China. *Resour. Conserv. Recycl.* **2018**, *134*, 282–293. [CrossRef]