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Evaluation of the sustainable development and water-related eco-environmental carrying capacity (EECC) inChina: A case study

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Abstract

For regions with significant concerns of water shortage, quantitative assessment of development sustainability may present a challenge to regional management and planning. In many parts of the world, surface-water decrease and excessive groundwater pumping have hampered economic growth and led to major environmental issues. In this research, a methodology for quantitatively assessing the sustainability of development was developed, with the water-related EECC serving as the main indicator. The created method was used as a case study using data from the Haihe River Basin, China, from 2008 to 2017. According to the calculation, the total sustainable development degree (SDD) is 0.39, indicating that this rate of development is not sustainable. The outcomes of the scenario study showed that the Basin's EECC has an overshoot, or resource over-exploitation, of roughly 20% for both population and economy. Based on the circumstances in the study region in 2017, the EECC could support a population of 108 million people and a gross domestic product (GDP) of 2.72 trillion CNY in order to achieve sustainable development, i.e., SDD>0.70 in this study. It is hoped that the newly created method for estimating eco-environmental carrying capacity will make it easier to manage resources for sustainable development in places with a lack of water.

Keywords: Eco-environmental carrying capacity, Sustainable development degree (SDD), Economic development level (EDL)

1. INTRODUCTION

In The Limits to Expansion, a book written in 1972 (Meadows 1972), it was predicted that unless the trajectory of population and industrial growth was changed, the world will surpass its human carrying capacity, resulting in an abrupt and uncontrollable collapse in population and industrial capacity. The follow-up article Limits to Growth: The 30-Year Update, published in 2014, came to the conclusion that the world has already reached a state of unsafe overloading based on thirty years' worth of additional data and improvements in computer modelling (Meadows et al. 2014).

Carrying capacity is a term that comes from the study of ecology (Park and Burgess 1921). It is typically described as the largest population of a certain species that a region can accommodate without adversely affecting its capacity to support that same species in the future. It is frequently described as the maximum "load" that humans may consistently and safely put on the environment (calculated as the product of population and per capita effect) (Food and Agricultural Organization of the United Nations 1985). The notion of sustainable development, which links ecological integrity to socioeconomic development in conditions of resource scarcity and rising environmental pollution, is fundamentally based on carrying capacity. The Brundtland Commission defines sustainable development as "development that satisfies present demands without compromising the ability of future generations to meet their own needs" (Rees and Smith 1987; UN 1987). A pattern of resource usage called sustainable development strives to satisfy human needs while protecting the environment. Both the carrying capacity of natural systems and the socioeconomic concerns facing humanity are taken into account.

Since Thomas Malthus' population theory introduced the idea of carrying capacity into the realm of human ecology, numerous researchers have examined its various facets (Seidl and Tisdell 2009). For instance, Wetzel & Wetzel (1995) talked about the planet's overall economic carrying capacity. At both the global and regional levels, Harris and Kennedy (2009) examined the carrying capacity of agriculture. A population-resource equation was developed by Pimentel et al. (1994, 2008) to determine the ideal population given the available natural resources. A physically based model of soil water holding capacity for vegetation was created by Xia and Shao in 2008. The majority of these research, however, did not take into account the connections and interactions between the input factors.

The capacity of the macro eco-environment system, comprising water resources and water quality that act as indicators for a regulatory services, has been represented by the water-related eco-environmental carrying capacity (EECC) (Zhu et al. 2015). EECC is typically stated at the demographic and economic scales, the latter of which is typically represented by the gross domestic product (GDP). The socio-economic scale and development rate of a certain region are assessed by EECC. EECC is defined in our earlier work (Zhu et al. 2010) as the maximum population and GDP that can be supported in a specific region depending on the amount of water and other resources available.

In this study, the regional water balance was used as the basis for the EECC computation, which included quantitative assessments for social, economic, and eco-environmental changes. The resulting EECC demonstrated how water availability is essential for sustainable development, particularly in regions with severe water shortages like China's Haihe River Basin (HRB). The study's particular goals were to: (1) create an index system for assessing development sustainability; (2) provide a framework and method for quantitative analysis of EECC; and (3) run a scenario analysis to identify sustainable population and economic scales based on the current situation. The established methodologies were used in the HRB between 2008 and 2017 to evaluate the accompanying EECC and regional development. The United Nations Conference on the Human Environment in Stockholm, 1972, is where the idea of sustainable development first took hold. The way the idea is typically portrayed is as the nexus of society, economy, and environment. The three characteristics must be quantified jointly even though each component can be examined and evaluated separately. When a place is still growing, governments frequently prioritise the economy, and the environment is frequently seen as separate from people. But there are connections between the three: society, the economy, and the environment. The presented results in this study can provide information for policy makers to fully understand that the integration of these aspects leading to sustainable development.

2. MATERIALS AND METHODS

The degree of development and EECC

Based on the definition of this study, the EECC could be determined under sustainable conditions. In the previous studies (Xia and Zuo 2011; Zhu *et al.* 2010), we evaluated the development sustainability based on economic development and eco-environmental quality. In this study, a separate indicator of social development (SDL) is introduced, and the degree of sustainable development at time T, SDD(T), (calculated at yearly time interval) is quantitatively estimated as,

$$SDD(T) = SDL(T)^{\beta_1} EDL(T)^{\beta_2} EQ(T)^{\beta_3} \qquad (1)$$

Where *SDL* is an indicator of social development level, *EDL* is an indicator of economic development level, *EQ* is an indicator of eco-environmental quality (Table 1), and β's are the weights of corresponding variables. The return-to- unit weights (β's) reflect the relative importance of social, economic, and eco-environment development in a given study area and period. Eq. (1) is designed by following the format of the Cobb-Douglas function, and the exponent for any input term represents the productivity elasticity of the input. In this study, we first determine the weights by an analytical hierarchy process (AHP). This approach is a structured technique for organizing and analyzing complex decisions (Saaty 2008), and has been widely used for eco-environmental quality evaluation (Stahl *et al.* 2012; Li *et al.* 2017b; Ying *et al.* 2017; Akhgari *et al.* 2011). Expert opinions from local professionals were incorporated in the AHP.

Table 1: **Data required in the quantification of eco-environmental carrying capacity**

Indicator	**Variable**	**Data needed**
Social development level (SDL)	Per capita GDP	Population; GDP
	Per capita water-use	Population; domestic water use
	Quality class of drinking water	Drinking water quality
Economic development level (EDL)	Water-use per unit GDP	Productive water use; GDP
	Irrigation water per unit farmland	Agricultural water use; cultivated area
	Wastewater discharge per unit GDP	Wastewater discharge; GDP
Eco-environmental quality (EQ)	Groundwater exploitation modulus	Groundwater consumption and recharge
	Water outflow	Total water resource; water use
	Quality class of surface water	Surface water quality

The values of the three indicators in eq. (1) are in the range of [0, 1], and the approaches for calculating them are described in the next section. The SDD, also within [0, 1], could be considered as a synthetic index to measure the degree of development in a given year. For the descriptive classification of SDD, a threshold value (SDD*) is required for a specific region of study. If SDD SDD*, we conclude that the evaluated system is sustainable. The relationship between the EECC and SDD can be expressed as,

$$EECC = \max(\text{popolution}, \text{GDP}),\ \text{given SDD} \geqslant \text{SDD}^{*} \quad (2)$$

Water balance and the indicators SDL, EDL, and EQ calculation

In this study, the elements of society, economy, and eco-environment were combined into a single system that was connected by water. On the basis of water supply and demand, the water balance is initially examined. The final water balance calculation specifically follows the stages listed below.

(1) Analysis of raw data on water amounts used by industry, agriculture, residents, and eco-environmental protection, and total use;
(2) Estimation of total water supply based on local water resources and water diversion from outside of the watershed;
(3) Calculation of overall water balance based on total water supply and demand.

The SDL, EDL, and EQ development assessment indicators are chosen based on statistical findings from fundamental datasets such as population, GDP, water resources, and water quality measurements. Indicators of life quality and per capita resources, such as per capita GDP, per capita water resources, and environmental conditions, were used to assess the social system's development. Numerous indicators are utilised to quantify social progress based on research reviews. The operable and quantitative criteria that define the study areas should be the foundation for the associated index system. The same is true for metrics used to assess the growth of an economic system, such as GDP per unit of water used, emissions per unit GDP, and the percentage of tertiary industry, which should represent economic structure and product efficiency. The quality of the eco-environmental system was determined by a few parameters that reflect ecological and environmental quality, such as the amount of forest cover, the amount of wetlands, the amount of water that is discharged into the ocean, and the quality of the water in streams. For the purpose of normalising the input variables into values between 0 and 1, a set of category criteria was created. These indices were created using the relation analysis method that we used in our earlier work (Xia 1996; Xia and Wang 2011).

The quantification of EECC is an iterative process involving adjusting population and GDP for simultaneously satisfying the requirements of water balance and sustainable development (i.e., SDD>SDD*). In this work, the EECC was estimated utilising a "trial and error" method to streamline the computation process. For the sake of creating scenarios using input datasets of paired population and GDP values, the actual values of the population and GDP in the evaluated years were only slightly altered. There are a number of scenarios where the requirements for water balance and sustainable development could be met, with the scenario with the highest GDP and population listed as EECC.

Input data and development scenarios

The China Ministry of Water Resources' Water Resources Bulletin was consulted for the hydrological, meteorology, eco-environment, society, and economy data needed for EECC computation in the HRB for the years 2008 to 2017. (Chinese Ministry of Water Resources 2009). The yearly averages of rainfall, surface water, ground water, total water, water discharge to the sea, and reservoir storage over the Basin are shown in Table 2. Table 3 summarises the water balance, while Table 4 displays the water quality and pollutant discharge. Table 6 contains information on social and economic development, including per capita GDP, per capita water resources, per capita water use, per unit GDP, and per hectare irrigation water. The GDP values for different years were adjusted to the constant prices of 2008, i.e., the first studied year, to allow meaningful comparisons over time.

Table 2: The water resources in the Haihe River Basin

Year	Precipitation	Surface water	Groundwater	Total water resource	Water discharge to sea	Reservoir storage
	(mm)	(billion m^3)	(billion m^3)	(billion m^3)	(billion m^3)	(billion m^3)
2008	551	19.27	25.30	35.46	4.40	9.17
2009	385	9.20	17.23	19.38	0.45	7.02
2010	490	12.52	22.20	26.87	0.41	7.06
2011	416	8.97	17.46	20.01	0.08	6.34
2012	400	6.32	14.63	15.81	0.18	5.03
2013	582	13.08	25.29	32.02	2.18	6.11
2014	538	13.79	23.80	29.98	1.30	7.05
2015	487	12.19	21.55	26.75	2.48	7.85
2016	438	9.62	18.91	21.98	0.50	6.98
2017	483	10.18	21.19	24.79	1.71	6.72

Table 3: The water supply and water use in the Haihe River Basin

Item	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total water supply (billion m^3)	42.40	43.15	40.06	39.17	39.98	37.70	36.8	38.05	39.28	38.45

Surface water (%)	25.2	25.3	24.1	20.2	20.4	20.6	20.6	22.6	22.4	22.3
Ground water (%)	61.8	62.0	65.6	68.4	67.6	69.3	67.1	66.5	64.1	65.0
Imported water (%)	12.7	12.4	10.0	11.1	11.6	9.6	11.5	9.8	11.8	11.2
Other water supply (%)	0.3	0.3	0.3	0.3	0.4	0.5	0.8	1.1	1.7	1.5
Total water use (billion m^3)	42.38	42.78	39.83	39.17	39.98	37.7	36.8	37.98	39.27	38.45
Agricultural water use (%)	72.5	72.0	70.0	71.0	71.6	69.5	69.6	69.5	70.0	70.1
Industrial water use (%)	15.9	16.0	17.0	15.8	15.5	15.8	15.4	14.9	14.5	13.5
Domestic water use (%)	11.6	12.0	13.0	13.2	12.9	14.2	14.3	14.6	14.4	14.7
Eco-environmental water use (%)	0	0	0	0	0	0.5	0.7	1.0	1.1	1.7

Table 4: The water quality and waste water discharge in the Haihe River Basin

Years	**Assessed stream length (km)**	**Total wastewater discharge (billion ton)**	**% stream length by water quality class**					
			I	**II**	**III**	**IV**	**V**	**Lower than V**
2008	9 951	5.61	0.6	13.6	20.8	10.0	8.4	46.6
2009	9 229	5.62	0.2	16.2	19.3	9.8	8.4	46.1
2010	11 278	5.40	0.2	15.8	18.9	4.6	4.7	55.8
2011	10 076	5.40	0.7	15.3	23.3	7.9	6.7	46.1
2012	7 151	5.36	3.2	14.3	23.1	4.5	6.2	48.7
2013	7 918	5.11	3.1	17.3	18.2	6.1	2.8	52.5
2014	11 670	4.80	2.6	16.2	22.2	4.6	3.4	51.0
2015	11 808	4.49	1.8	20.8	17.6	3.7	2.5	53.6
2016	11 641	4.83	1.4	15.8	13.4	8.1	6.8	54.6
2017	11 819	4.75	1.2	14.1	12.0	12.4	2.9	57.4

Each component (SDL, EDL, and EQ) of the regional sustainable development were assumed to have similar importance for the HRB. Therefore, all weights (β's) in eq. (1) were set as 1/3 based on analytic hierarchy process. This implied equal importance of social development, economic development, and eco-environmental quality on the overall sustainability. The same weighting factors were used in our pervious study for the assessment of water resources carrying capacity in urbanizing area in the HRB (Zhang *et al.* 2017).

For 2017, which was the final year of the study period, the quantification of EECC was shown. The development scenarios were created by adding 0, 10, 15, or 20% to the population and GDP figures from 2017. The region-specific SDD (SDD*) threshold was established at 0.7. When just economic and environmental development levels were taken into account in the SDD calculation in our earlier study, a threshold of 0.8 was used to this study area (Xia and Zuo 2011). Because of this, it makes sense to use a slightly lower threshold with the addition of one more social development indicator (SDL) in this study.

Index system for normalizing input variables

The developed index system normalized the input variables into numerical values in the range of 0-1. Critical values were used to categorize each input variable into 5 quality levels with numerical scores, i.e., category I "very high" with score of 1.0, II "high" (0.75), III "moderate" (0.5), IV "poor" (0.25), or V "very poor" (0.0). For the actual value of the input variable, linear interpolation was applied to specify its score, based on the two nearest critical values. For the HRB, critical values were developed based on existing relevant national environmental standards, conventional international practice and consultation of experts in various relevant studies. The index system is summarized in Table 3. The input variables were normalized based on linear interpolation between two adjacent critical values,

$$y=\frac{yc_j-yc_i}{xc_j-xc_i}(x-xc_i)+i \tag{3}$$

Where y is normalized value of the input x, xc and yc are the critical value of x and the corresponding normalized value, respectively, and i and j are two adjacent categories enclosing the value of x. For example, the per capital GDP of 7.9 thousand CNY in 2008 (Table 6) can be normalized to 0.28, based on the critical values of 7 (category IV, poor) and 14 (category III, moderate) thousand CNY (Table 7). The symbiotic linkages between society, the economy, and the environment are essential for the realisation of sustainable development. Finding these correlations under the constraint of water supplies is crucial for evaluating the sustainability of development. Although the literature (Park and Burgess 1921; Pimentel et al. 2008; Domagalski et al. 2011) offers helpful assessment methods for development evaluations, this index system, which takes into account the aspects of social and economic development as well as environmental quality, will be particularly helpful to quantify development sustainability.

3. RESULTS

Evaluation of the sustainable development in the Haihe River Basin

Social development

The scores obtained from the indicators and input data used to evaluate the social, economic, and ecological aspects of sustainable development in the HRB are shown in Table 5. The development in the Basin has been in good shape from a socioeconomic perspective alone, as evidenced by per capita GDP, water use, and drinking water quality classes. From 0.122 billion in 2008 to 0.135 billion in 2017 (Table 6), the overall population expanded by 10.6% over the study period, while the GDP increased gradually by 254%, from 0.96 trillion CNY in 2008 to 3.4 trillion CNY in 2017. For per capita GDP, there was a 219% increase, from 7 900 CNY in 2008 to 25 200 CNY in 2017 (Table 6). Scores of per capita GDP increased more than 3-fold, from 0.28 in 2008 to 0.94 in 2017.

Drinking water in the HRB was of "high" or "very high" quality, indicated by the score of 0.75 or higher (Table 5), despite more than 60% polluted rivers in the region. However, due to the increased population and reduced precipitation, the amount of available water per capita decreased during the study period. Scores of per capita water use declined from 0.62 in 2008 to 0.4 in 2017. During the period of 2008 to 2017, the indicator measuring social development (SDL) was generally stable with a slight increase for recent years (Table 5). The per capita water use is less than 300 m^3 yr^{-1}, while that for the United States is 1 550 m^3 yr^{-1} and the worldwide average is 506 m^3 yr^{-1} (Food and Agricultural Organization of the United Nations 2011). Per capita water use in this region was obviously the bottleneck which limits social development. Therefore, one strategy to improve the quality of social development in this region would be to effectively raise average water use amount, by simultaneously increasing water resources while controlling population increase.

Economic development

From the economic viewpoint, the development in the HRB has been improving, indicated by a substantial increase in the degree of economic development (EDL) from 0.12 to 0.70 (Table 5). Water use per unit GDP decreased from 441 $m^3/10^4$ CNY in 2008 to 113 $m^3/10^4$ CNY in 2017. Based on the critical values listed in Table 7, the water use efficiency increased from the category of "very poor" condition in

2008, to "moderate" in 2013, and to "good" in 2017. Irrigation water use per ha was 4 320 m^3 in 2008 and 249 m^3 in 2017, with a steady decrease. The wastewater discharge per unit of GDP also decreased steadily from 58.4 ton/10^4 CNY (categorized as the "very poor" condition) in 2008 to 14 ton/10^4 CNY ("good" condition) in 2017. The amount of water used per unit of GDP fell by 76% over the study period. Water's economic productivity increased from 5.5 to 8.45 US dollars between 1990 and 2015, a 35% drop in per-GDP water use (PACINST 2009). However, the decrease in wastewater release was only about 15% because of the rise in GDP. The development and implementation of water conservation and clean production techniques should be the main emphasis of efforts to enhance the quality of economic development in this area. Many wealthy nations, including Israel and the USA, have adopted this technique (SWSME 2009; U.S. Agency for International Development 2012).

Table 5: Assessment results on the sustainable development in the Haihe River Basin

Item	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
Per capita GDP	0.28	0.30	0.32	0.35	0.41	0.45	0.56	0.74	0.84	0.94	0.52
Per capita water use	0.62	0.61	0.53	0.5	0.51	0.41	0.36	0.41	0.45	0.40	0.48
Drinking water quality class	0.75	0.75	0.75	0.75	0.75	0.78	0.78	0.75	0.75	0.75	0.76
Social development level (SDL)	0.53	0.53	0.51	0.51	0.54	0.52	0.54	0.61	0.67	0.68	0.56
Water use per unit GDP	0	0	0	0	0	0.06	0.25	0.48	0.56	0.67	0.20
Irrigation water per ha	2.25	2.25	7.35	8.40	6.90	9.75	11.4	10.95	8.70	9.60	7.80
Waste water discharge per unit GDP	0.26	0.30	0.36	0.40	0.46	0.5	0.61	0.72	0.73	0.80	0.51
Economic development level (EDL)	0.12	0.13	0.25	0.29	0.27	0.37	0.51	0.62	0.61	0.70	0.39
Modulus of exploited groundwater	0.65	0	0.30	0	0	0.68	0.65	0.33	0	0.30	0.29
Water discharge to sea	0.62	0	0	0	0	0.3	0.08	0.1	0.13	0.18	0.14
River water quality class	0.38	0.4	0.33	0.40	0.40	0.38	0.4	0.38	0.35	0.35	0.38
Eco-environmental quality (EQ)	0.55	0.12	0.20	0.12	0.12	0.45	0.37	0.26	0.15	0.27	0.26
Sustainable development degree (SDD)	0.33	0.23	0.32	0.28	0.28	0.45	0.47	0.46	0.42	0.50	0.39

Eco-environmental quality

The ecosystem's general condition was not very good. Overdraft of groundwater has been a significant issue. The average volume of groundwater in the HRB was around 1.1 trillion m3, and the long-term average groundwater exploitation modulus was 1.29. The modulus was more than 1.5 during the drought years of 2009, 2011, and 2012, indicating that groundwater use surpassed the regional capacity of groundwater recharge during those years. With a mean score of 0.38, the quality of surface water did not significantly change. Therefore, rigorous regulation of groundwater over-pumping, an increase in the volume of water in the watershed, and a decrease in river system pollution are advocated as improvement solutions. In California, USA, State Water Resources Control Board is in charge of enforcing the laws and policies to regulate the groundwater over pumping, water transfers and water quality controls. These regulations have been proved to be necessary to protect surface and ground waters in California (Moran *et al.* 2015).

Table 6: Input data for assessing the eco-environmental carrying capacity in the Haihe River Basin

Item	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Population (million)	122.0	125.2	128.5	130.1	131.1	131.7	132.7	133.7	134.5	135.2
GDP (trillion CNY)	0.96	1.05	1.14	1.29	1.51	1.68	2.04	2.64	3.02	3.40
Per capita GDP (thousand CNY)	7.9	8.4	8.9	9.9	11.5	12.7	15.4	19.7	22.5	25.2
Per capita water use (m^3)	348	345	312	301	305	286	277	285	292	284
Drinking water quality class	1.9	2.0	2.0	1.9	1.8	1.8	1.8	1.9	1.9	1.9
Water use per unit GDP ($m^3/10^4$ CNY)	441	408	350	303	265	225	180	144	130	113
Irrigation water per ha (m^3 ha^{-1})	4 320	4 320	3 915	3 825	3 945	3 720	3 570	3 630	3 810	3 735
Waste water discharge per unit GDP ($ton/10^4$ CNY)	58.4	53.6	47.5	41.8	35.5	30.5	23.5	17.0	16.0	14.0
Modulus of exploited groundwater	1.04	1.55	1.18	1.53	1.85	1.03	1.04	1.17	1.33	1.18
Water discharge to sea (billion m^3)	4.4	0.45	0.41	0.08	0.18	2.18	1.30	2.48	0.50	1.71
River water quality class (dimensionless)	4.5	4.4	4.7	4.4	4.4	4.5	4.4	4.5	4.6	4.6

Degree of sustainable development

The HRB's sustainable development degrees were quite low, ranging from 0.33 in 2008 to 0.50 in 2017, showing that unsustainable development had taken place in all of the studied years. It is interesting to observe that the score has improved in the study period's later years, rising from 0.45 in 2013 to 0.50 in 2017. The observed rise in SDD was mostly attributable to the quality of social and economic development being improved (Table 5). The region's sustainable growth was nevertheless constrained by the eco-environmental quality (EQ) metric. EQ values fluctuated from 0.12 to 0.55 during the study period, and were highly correlated with the variations of the average annual rainfall. For example, the drought years of 2011, 2012, and 2016 each had relatively poor EQ values.

Table 7: The index system and grades for development quality evaluation of "society, economy and eco-environment" system in the Haihe River Basin

Evaluation index system		**Category criteria for quality levels**				
		I (very high)	**II (high)**	**III (moderate)**	**IV (poor)**	**V (very poor)**
Social development level	Per capita GDP (thousand CNY)	27	20	14	7	5
	Per capita water use (m^3)	600	400	300	260	200
	Drinking water quality class (dimensionless)	1	2	2.3	2.7	3
Economic development level	Water use per unit GDP ($m^3/10^4$ CNY)	60	100	140	180	240
	Irrigation water per ha (m^3 ha^{-1})	3 000	3 600	3 900	4 200	4 500
	Waste water discharge per unit GDP (ton/10^4 CNY)	10	15	30	60	100
Eco-environmental quality	Modulus of exploited groundwater	0.8	1.0	1.1	1.2	1.3
	Water discharge to sea (billion m^3)	10	6	3	2	1
	River water quality class	2	3	4	5	6

Scenario analysis of EECC in the Haihe River Basin

Table 8 lists the 16 development scenarios with population and GDP pairs as input data, and the corresponding SDD results. Of these 16 datasets, scenario D3 with relative changes of -20% for both population and GDP yielded an EECC with SDD=0.71, which is higher than the selected threshold value of SDD*=0.70. This suggested that the population and economic scale of 2017 in the HRB exceeded the predicted EECC by 20%. In other words, sustainable development could be established with a population of 108 million and GDP of 2.72 trillion CNY based on the water resources available in 2017. This recommended GDP was comparable to the historical record of 2.64 trillion CNY in 2015.

Table 8: The scenario analysis of the eco-environmental carrying capacity in the Haihe River Basin

Scenario	**Population change (%)**	**GDP change (%)**	**SDD in 2017**
A0	0	0	0.50
A1	-10	0	0.35
A2	-15	0	0.39
A3	-20	0	0.41
B0	0	-10	0.43

B1	-10	-10	0.46
B2	-15	-10	0.48
B3	-20	-10	0.50
C0	0	-15	0.48
C1	-10	-15	0.50
C2	-15	-15	0.51
C3	-20	-15	0.53
D0	0	-20	0.51
D1	-10	-20	0.52
D2	-15	-20	0.53
D3	-20	-20	0.71

The effects of water diversion and climate change should also be taken into account when studying sustainable development in order to appraise the EECC for the future. China plans to build the "South-to-North Water Diversion Project" (SNWDP), which will channel 44.8 billion m3 of water per year from the southern river basins to northern China, in order to address the water issue in the HRB. The amount of water that is annually diverted to the North China Plain (mostly in the HRB) is equal to the region's annual groundwater usage, or 27.8 billion m3. Additionally, the Intergovernmental Panel on Climate Change (IPCC) models predict that precipitation in the HRB will rise in the near future (Meehl et al. 2017). Climate change and the anticipated water diversion are advantageous for attaining sustainable development and delivering prosperity to the HRB, China. It's important to keep in mind, too, that there is a lot of uncertainty around both the proposed water diversion and the anticipated climate change. For instance, the central route's planned water diversion in the SNWDP was predicated on a timeline that was wetter than the previous two decades. Ecological issues in the headwater source areas could result from this (Liu et al. 2012). Additionally, contrary to the forecasted climatic data, the observed precipitation has been declining in the North China Plan over the previous few decades (Wang et al. 2011). The precipitation trends in the future may have significant impacts on China’s strategies for improving the adaptive capacity especially for the agricultural sector.

4. DISCUSSION

Sustainable development

The sharp rise in GDP suggested that the HRB's living standards had also significantly increased. The lower rainfall and rising population, however, resulted in a drop in the per capita water supply. Early in the study period, lower SDD values were seen. For instance, it was found that the SDD for 2008 was 0.33, which is comparable with the range of 0.16-0.39 reported for several subbasins of the research region in the earlier study (Zhu et al. 2010). Further development was constrained by the reduced water use. Additionally, the drinking water quality is undoubtedly impacted by the deteriorated water quality. Degraded water quality may contribute to social unrest in years of acute drought. Economically, the watershed produced more over 3.4 trillion CNY in total revenue. Every economic metric showed an increase. Water consumption per ten thousand CNY GDP decreased by 74%, irrigation water use per hectare down to 13%, and wastewater per ten thousand CNY GDP decreased by 76% between 2017 and 2008. The watershed's economic values demonstrated rapid development. However, the rapid economic growth worsened rather than improved the environment in terms of ecology. Despite an increase in the deployment of water-saving technologies, there is no evidence that overall water use has decreased as a result of GDP growth. Only groundwater overdraft and the exploitation of water consumption for ecological environments are responsible for the current speed of economic development. This is especially true during years of drought. Wastewater discharge per ten thousand CNY GDP has fallen by 76% during the last ten years. Only 15% of the watershed's wastewater output was reduced overall, though. The watershed is still quite contaminated due to a time lag and longer-term deposition of contaminants. The length of the polluted rivers is anticipated to keep growing. The process of enhancing the environment at the HRB may take a while.

EECC overshoot and management implications

The combined assessments of the social, economic, and ecological environments show that the HRB has an unbalanced system. It is apparent that the environment was sacrificed in order to accomplish the recent economic boom. Sustainable economic development is built on the foundation of natural ecosystems. Overexploitation of the resources makes them the barriers to continued economic growth. The HRB's growth pattern over the previous 10 years demonstrates how the variability in rainfall patterns was related to the ecological environment's quality. For instance, it appeared that the draught years of 2009, 2011, 2012, and 2016—when annual rainfall was less than 440 mm—were linked to the bad quality of the biological environment. Therefore, local environmental conditions were heavily affected by the climatic changes in the region.

The eco-environmental quality of the area has significantly declined over the last ten years, according to statistics from the HRB, indicating an overshoot. This indicates that there is an imbalance in a number of areas, including the amount of development and population density at the present economic and technological levels, the availability of resources, and the state of the environment. The environment was severely degraded as a result of the abuse and exploitation of water supplies. The HRB will face significant difficulties and water resource crises in the future if these issues cannot be resolved.

The Chinese government is also putting more emphasis on preventing environmental pollution and ecological restoration. Technologies for reducing water use and increasing productivity are getting better with time. Water diversion from beyond the HRB is regarded as a significant solution to mitigate the current water problem in addition to the adoption of water-saving technology. These elements support the HRB's prosperity while promoting sustainable development.

5. CONCLUSION

Based on the available water resources, a computational framework was created to quantitatively assess regional development and calculate the eco-environmental carrying capacity. This method included water balance and eco-environmental quality evaluations into the evaluation of sustainable development. The EECC framework included key components for assessing the level of social, economic, and eco-environmental development and offered recommendations for sustainable development decision-making. The newly established framework in this study extends conventional single-indicator based methodologies for EECC estimation by connecting with Basin-scale water balance. In the HRB of China, where the eco-environmental system has been severely compromised over the past ten years by rapid economic growth and water crises, a case study was done.

In the study area, between 2008 and 2017, there was a rapid increase in per capita GDP and a decline in per capita water use. As a result, from 0.53 to 0.68, the social development quality only marginally improved. All individual variables, including water usage per unit GDP, wastewater discharge per unit GDP, and irrigation water use per unit farmland, showed significant increases in relation to economic development. As a result, from 2008 to 2017, the economic development's quality rose from 0.12 to 0.70. The study period was shown to have a general declining tendency for eco-environmental quality, which was found to be sensitive to yearly precipitation. Scores of eco-environmental quality were lower than 0.40, with the exception of the rainy years of 2008 and 2013. The findings suggested that rising GDP total and per capita in the HRB may be linked to overuse of natural resources and degradation of environmental quality.

According to the circumstances in 2017, there was unsustainable development as shown by the total sustainable development degree of 0.39. The EECC needed to raise the SDD to 0.70—the level considered to indicate sustainable development in this study—was estimated through scenario analysis. According to the findings, the EECC of the Basin was around 20% overloaded in 2017. According to the available water resources in 2017, sustainability could theoretically be attained with a population of 108 million and a GDP of 2.72 trillion CNY. The studied approach and analysis can offer useful data for resource management focused on sustainable development in the HRB and other water-scarce locations.

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