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# Preliminary Study on Supporting Capacity of Social Development System in the Yellow River Basin under the Happy River Framework

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## Abstract

Ecological protection and high-quality development of the Yellow River Basin have been elevated to a major national strategy. Social development in the Yellow River Basin constitutes one of the primary factors influencing Yellow River governance and protection, making the analysis of its developmental patterns and the formulation of response strategies an urgent scientific issue. This study selects 12 socioeconomic characteristic indicators from four dimensions—population characteristics, residents' quality of life, economic growth level, and regional industrial structure—and employs the entropy weight method to calculate the Social Development Index (SDI), thereby quantitatively analyzing the evolutionary characteristics of social development in the Yellow River Basin over the past four decades. The findings indicate that the SDI of the Yellow River Basin has demonstrated an overall "decline-stability-rise" trend during this period, particularly since 2012, when the gradual maturation of economic transformation has led to an overall improvement in social development across the basin.

## Full Text

### Preliminary Study on Evolution Characteristics of the Social Development System in the Yellow River Basin under the Framework of a Happy River

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## Abstract

Ecological conservation and high-quality development of the Yellow River Basin has been elevated to a major national strategy. Socio-economic development in the Yellow River Basin represents one of the primary factors influencing Yellow River governance and protection, making it an urgent scientific challenge to discern the patterns of socio-economic development in the basin and propose corresponding strategies. This study selects 12 socio-economic characteristic indicators from four perspectives—population characteristics, residents' quality of life, economic growth level, and regional industrial structure—and calculates the Social Development Index (SDI) through the entropy weight method to quantitatively analyze the evolution characteristics of social development in the Yellow River Basin over the past 40 years. The research reveals that the SDI of the Yellow River Basin has exhibited an overall "decline–stability–rise" trend during the last four decades, particularly since 2012, as economic transformation has gradually matured, leading to an overall improvement in social development across the basin.

**Keywords:** Happy River; Yellow River Basin; Social Development System; Evolution Characteristics

## 1. Introduction

The great call to "make the Yellow River a happy river that benefits the people" in the new era has prompted river management practitioners to reflect on and research Yellow River governance and protection. The principal contradictions in current Yellow River management have undergone significant changes, and the connotation and requirements of a "Happy River" have also been profoundly transformed. The organic integration of the subjective feeling of "happiness" with the objective existence of the "river" serves as an important carrier and focal point for implementing the concept of harmony between humans and water. Therefore, correctly understanding and managing the relationship between economic and social development and water resources, water ecology, and water environment protection, adhering to water-based determination of urban development, land use, population capacity, and production scale, and rationally planning population, cities, and industrial development in the Yellow River Basin have become important topics in Happy River construction.

In recent years, central cities and urban agglomerations such as the Central Plains in the Yellow River Basin have been accelerating their development, yet the basin still faces tremendous pressure from insufficient socio-economic development, involving numerous contiguous poverty-stricken areas and lagging transformation and upgrading of traditional industries, which severely constrain the progress of Happy River construction. Consequently, understanding the current status of socio-economic development in Yellow River regions from a systematic basin perspective can provide macroscopic and objective reference bases for Happy River construction.

Existing research on economic and social development has primarily focused on two aspects. First, studies have predominantly examined national, urban agglomeration, and administrative scales. For instance, Hu et al. (2018) evaluated the economic and social development levels of countries along the Belt and Road Initiative in a special research topic; Liu (2018) constructed an evaluation index system for the economic and social development level of the Wanjiang City Belt from the perspective of the five development concepts of innovation, coordination, green development, openness, and sharing; and Zhang and Zhang (2011) analyzed the current status and related policies of economic and social development in ethnic minority regions. Second, research has mostly focused on the evolution characteristics, impacts, and correlation analysis of specific indicators or categories of indicators. For example, Zhu (2014) proposed that population density and socio-economic development exhibit a positive correlation but asynchronous pattern; Meng et al. (2018) established a screening model for economic and social development evaluation indicators based on principles of significant difference and redundant information elimination; and Zheng (2020) conducted regression analysis between long-term nighttime light index data and multiple socio-economic indicators to achieve spatiotemporal dynamic monitoring of national economic and social activities. Additionally, at the basin scale, research has addressed the coupled and coordinated development of environment-economy-society in basins and the coordinated development between basin socio-economic development and water environmental quality.

Regarding the Yellow River Basin specifically, Zhang et al. (2013) proposed major socio-economic development indicators for a certain period ahead, combining national development strategies and basin resource endowment characteristics. Current research methods have gradually shifted from qualitative to quantitative, from physical to informational, and from local to systematic. Since 2019, when ecological conservation and high-quality development of the Yellow River Basin became a major national strategy, there has been an urgent need for systematic, targeted, and interdisciplinary in-depth research from a strategic and systematic perspective to provide scientific support for this major national strategy.

Socio-economic development indicators can reflect basin resident characteristics, measure resident well-being, and comprehensively characterize the current status and growth vitality of basin economic development, making them indispensable content in basin social development research. This study selects 12 socio-economic characteristic indicators from four perspectives—population characteristics, residents' quality of life, economic growth level, and regional industrial structure—and calculates the Social Development Index (SDI) through the entropy weight method to quantitatively analyze the evolution characteristics of social development in the Yellow River Basin over the past 40 years. The aim is to objectively and comprehensively grasp the scale and current status of basin system socio-economic development, provide reasonable and effective decision-making bases for relevant regions and departments to formulate basin economic development strategies, better support Happy River construction practices, and serve the major national strategy of ecological conservation and high-quality development in the Yellow River Basin.

## 2. Basin Overview

The Yellow River Basin is located between 95°53 –119°05 E and 32°10 –41°50 N, stretching from the Bayan Har Mountains in the west to the Bohai Sea in the east, reaching the Yin Mountains in the north and the Qinling Mountains in the south, and spanning four geomorphic units: the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, and North China Plain. The Yellow River is China's second largest river, originating from the Yueguzonglie Basin at 4,500 m elevation on the northern foothills of the Bayan Har Mountains on the Qinghai-Tibet Plateau. It flows through nine provinces (autonomous regions)—Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong—before emptying into the Bohai Sea at Kenli County, Shandong Province. The main stream has a total length of 5,464 km and a drainage area of 795,000 km$^2$. The Yellow River Basin is mostly located in central and western China, where economic and social development is relatively lagging, with obvious gaps compared to eastern regions. The basin's land resources and mineral resources, especially energy resources, are extremely abundant and occupy a crucial position nationally. In recent years, with the implementation of strategies such as Western Development and Central China Rising, national economic policies have tilted toward central and western regions, and the Yellow River Basin's economy and society have developed rapidly.

## 3. Methods

### 3.1 Data Sources

The raw data required for this study were obtained from nearly 40 years of statistical yearbooks and bulletins of Yellow River regions, official websites of provincial statistics bureaus, China Water Resources Bulletins, satellite imagery, and the National Geographic Data Center. Missing or unreasonable raw data were corrected using interpolation methods, and data with inconsistent calibers were converted. The indicators of the socio-economic system evaluation system are shown in Table 1 .

**Table 1** Description of Socio-Economic System Evaluation Indicators

| No. | Indicator Name | Unit | Description |
|---|---|---|---|
| 1 | Population Quantity | 10,000 persons | Statistics of permanent resident population facilitate administrative management and socio-economic development planning. |
| 2 | Urbanization Rate | % | The process of rural population transforming into urban population (demography). |
| 3 | Per Capita Disposable Income of Urban Residents | Yuan | The portion of a resident household's total cash income that can be used to arrange daily family life. Per capita disposable income = (Total household income - Income tax paid - Social security contributions by individuals - Accounting subsidies) / Household population. |
| 4 | Per Capita Park Green Space Area | $m^2$/person | The average area of public green space occupied by each urban resident. Per capita park green space area = Park green space area / Urban population. |
| 5 | GDP Growth Rate | % | The longitudinal change in percentage from one period to the next. GDP growth rate = (Current period GDP - Previous period GDP) / Previous period GDP × 100%. |

| No. | Indicator Name | Unit | Description |
|---|---|---|---|
| 6 | Per Capita GDP | Yuan/person | The ratio of gross domestic product realized during an accounting period (usually one year) to the resident population within the scope. Per capita GDP = Total GDP / Total population. |
| 7 | Proportion of Tertiary Industry | % | The proportion of tertiary industry GDP in total GDP. Tertiary industry proportion = (Tertiary industry GDP) / GDP × 100%. |
| 8 | Irrigated Area | 10,000 hectares | The sum of paddy fields and irrigated dry land in plains with relatively flat plots, certain water sources, and supporting irrigation facilities that can conduct normal irrigation in ordinary years. |
| 9 | Night Light Index | - | The average nighttime light intensity in the region, with a value range of 0–63. |
| 10 | Water Consumption Rate | % | The percentage of water consumption to water use. |
| 11 | Total Water Use in Basin | 100 million $m^3$ | The total amount of surface water, groundwater, and water transferred from outside the region that can be developed and utilized within a certain area and period. |

| No. | Indicator Name | Unit | Description |
|---|---|---|---|
| 12 | Water Use per 10,000 Yuan of Industrial Added Value | $m^3$/10,000 yuan | The amount of water used to achieve 10,000 yuan of industrial added value within a certain measurement period. Water use per 10,000 yuan of industrial added value = Annual water consumption of project / Industrial added value of project. |

**Data Sources:** Official statistics bureaus of provinces (nearly 40 years of statistical yearbooks), DMSP satellite sensors, China Water Resources Bulletins.

### 3.2 Analysis Methods

### (1) Social Development Index (SDI)

This study employs the novel information entropy algorithm regarding possibility-degree functions from the research results of Zhang Jinliang's team, "A Novel Theoretical Method for Comprehensive Assessment of Basin System Development Quality—A Case Study of the Yellow River Basin," to obtain annual entropy values of relevant indicators, and then uses the entropy weight method to calculate the social development system entropy. Based on these results, the Social Development Index (SDI) is defined.

### Entropy Weight Calculation

Information entropy measures information quantity and uncertainty. The greater the information quantity brought by an indicator, the lower its entropy value and uncertainty, and thus the larger the weight that can be assigned. This method calculates indicator weights more scientifically, avoiding differences arising from subjective weight judgments by different experts. The greater significance of the entropy weight method lies in that as the information entropy values of indicators change, the weight of each indicator in the system also changes. These indicators interact and dynamically influence each other, enabling real-time monitoring of changes in indicator importance within the system and providing a basis for comprehensive system indicator evaluation. Compared with traditional constant artificial weighting, this approach offers certain dynamic and systematic characteristics.

Based on the information entropy value $S_i$ of each indicator $i(i = 1, 2, \dots, N)$, its weight (denoted as $\omega_i$) is obtained using Equation (1):

$$\omega_i = \frac{1 - S_i}{\sum_{i=1}^{N}(1 - S_i)}$$

Using the entropy values and weights of each indicator, the total system entropy of the river can be calculated through weighted summation, as shown in Equation (2):

$$S_{sys} = \sum_{i=1}^{N} \omega_i S_i$$

### Social Development Index

The Social Development Index (SDI) is an important indicator in the basin development index system and a key kernel of the social development subsystem as an organic component of the basin mega-system. SDI quantitatively studies related factors such as population characteristics, residents' quality of life, economic growth level, and regional industrial structure from a social development perspective. It is a comprehensive indicator for evaluating basin social development based on system theory and entropy weight analysis. This study uses the entropy weight method to perform weighted summation of 12 Yellow River Basin social development subsystem indicators, obtaining the system entropy value, i.e., the SDI value, to evaluate the evolution status of basin social development. The SDI calculation formula is as follows:

$$SDI = 1 - \sum_{i=1}^{n} \omega_i S_i$$

where $n$ is the number of indicators under SDI, $S_i$ is the entropy value of each indicator, and $\omega_i$ is the corresponding entropy weight.

### (2) Cubic Spline Function Method

The cubic spline function method refers to the technique of smoothly connecting measured point coordinates to obtain a smooth trend curve. It originated from lofting workers using slender wooden splines and iron in lofting platforms to create function curves with certain smoothness. Since then, cubic spline function interpolation has been applied in increasingly more industries for discrete point fitting. For example, combined with the Multiscale Finite Element Method (MSFEM), a new method (Cubic Spline Multiscale Finite Element Method, MSFEM-C) was developed to describe groundwater flow in heterogeneous media, which retains the efficiency of the finite element method while ensuring the continuity of the first derivative of basis functions, thereby obtaining continuous first derivatives of hydraulic head. The basic calculation method is as follows.

Given measured point coordinates $(x_i, y_i)$, the original measured values are maintained at the original measurement points, and the first and second derivatives of all points within the curve (except endpoints) are continuous, as shown below:

$$S''(x_i^-) = S''(x_i^+), \quad S'(x_i^-) = S'(x_i^+), \quad i = 2, 3, \dots, n-1$$

After obtaining the function values, first derivatives, and second derivatives of the original measurement points, infinite function values, first derivatives, and second derivatives can be interpolated between two measurement points as needed.

Given a closed interval $[a, b]$ with $n$ measurement points ($n-1$ segments), i.e., $a = x_1 < x_2 < x_3 < \dots < x_{n-1} < x_n = b$, its internal cubic spline function is $S_p(\forall, 3)$, where $\forall$ represents the closed interval $[a, b]$.

There are three types of cubic spline interpolation functions. Type I is more common and frequently used in curve fitting. The constraints are as follows:

Internal conditions:

$$S(x_i) = y_i, \quad i = 2, 3, \dots, n-1$$

Boundary conditions:

$$S(x_i) = y_i, \quad i = 1, n$$

The form of the cubic spline function is:

$$S_i(x) = a_{0i} + a_{1i}x + a_{2i}x^2 + a_{3i}x^3, \quad i = 1, 2, \dots, n-1$$

Evidently, the cubic spline function method ensures that the curvature of the interpolation curve (approximately the second derivative of the curve) changes linearly, thereby preventing abrupt changes in the curve that could cause interpolation uncertainty.

### (3) Mann-Kendall Non-parametric Trend Test Method

The Mann-Kendall method is primarily used for trend analysis and mutation testing of environmental data and hydrometeorological data under time series. The specific method is as follows:

For time series $x_1, x_2, \dots, x_n$, where $n = 1, 2, \dots$ is the sample size, construct the known sequence:

$$S_k = \sum_{i=1}^{k} r_i, \quad \text{where } r_i = +1 \text{ when } x_i > x_j, \text{ and } r_i = 0 \text{ when } x_i < x_j \; (j = 1, 2, \dots, i)$$

Under the independence assumption of the time series, define the statistic:

$$UF_i = \frac{S_i - E(S_i)}{\sqrt{Var(S_i)}}, \quad i = 1, 2, \dots, n$$

where $UF_i$ follows a standard normal distribution. At a given significance level $\alpha$, if $|UF_i| > \alpha$, the series exhibits a significant trend change. Using the time-inverse series $x_n, x_{n-1}, \dots, x_1$ and repeating the above calculation yields $UK_k = -UB_k$ $(k = n, n-1, \dots, 1)$, with $UB_1 = 0$. Plotting the $UK_k$ and $UB_k$ curves, values greater than 0 indicate an upward trend, while values less than 0 indicate a downward trend. When values exceed critical values, the upward or downward trend is highly significant. If the two curves intersect and the intersection point lies between critical values, it indicates the starting time of mutation. It should be noted that in some cases, there may be more than one intersection point, requiring additional methods to further determine the mutation timing.

### (4) Maximum Entropy Spectral Analysis Method

Maximum entropy spectral analysis is based on the principle of maximum entropy without any additional information interference, providing a solid physical foundation, reasonable and natural results, high accuracy, and simple, convenient calculation. It overcomes the shortcomings of traditional spectral analysis, such as low resolution, subjective selection of maximum time lag for autocorrelation functions, and unrealistic assumptions about 展演 data. It offers unique advantages including short, smooth spectra and high resolution, with extracted primary and secondary cycles being more realistic.

The Burg algorithm is used to establish an autoregressive model. For variable $x$, establish the autoregressive model:

$$x_t = a_{1x_{t-1}} + a_{2x_{t-2}} + \dots + a_{kx_{t-k}} + \varepsilon_t$$

In the Burg algorithm, parameters in spectral estimation are calculated directly from the time series without pre-calculating autocorrelation coefficients, which compensates for the shortcomings of subjective selection of autocorrelation function time lag in power spectral analysis.

Assuming zero mean, the $k$-th order prediction error (for $k = 1, 2, \dots, n-1$) and corresponding coefficients can be derived. The maximum entropy spectrum is:

$$S_E(k) = \frac{\sigma_k^2}{\left|1 - \sum_{l=1}^{k} a_{kl} e^{-i2\pi fl}\right|^2}$$

where the order $k_0$ of the autoregressive model can be determined by the Final Prediction Error (FPE):

$$FPE(k) = \frac{n+k}{n-k}\sigma_k^2$$

The minimum $FPE(k)$ value indicates the optimal order of the autoregressive model.

# 4. Results

## 4.1 SDI Change Pattern Analysis

### (1) Trend Analysis

Figure 1 [Figure 1: see original paper] shows the annual SDI values and cubic spline fitting curve for the Yellow River Basin over 40 years. The cubic spline interpolation curve fits well with the annual SDI values, intuitively reflecting the changing trend of SDI values over the past 40 years. Statistical analysis of SDI values from 1980 to 2019 reveals that the average SDI value over 40 years is 63.9, with a maximum value of 71.4 in 2019 and a minimum value of 56.4 in 1995. The linear trend line indicates that SDI in the Yellow River Basin from 1980 to 2019 showed an overall “decline–stability–increase” trend. During 1980–1995, the decline was significant, with an average annual decrease of 0.66. From 1996–2011, SDI entered a relatively stable state, fluctuating around 61.6. During 2012–2019, there was a clear upward trend, with an average annual increase of 1.4.

### (2) Mutation Analysis

The Mann-Kendall method was used to test for mutation points in SDI. Figure 2 [Figure 2: see original paper] shows the MK curves of the Yellow River Basin Social Development Index (SDI). The UF and UB curves are mostly outside the confidence interval, indicating that the trend changes in SDI are highly significant. The intersection points of the curves suggest the timing of mutations.

### (3) Periodicity Analysis

Maximum entropy spectral analysis was employed to analyze the periodicity of SDI values in the Yellow River Basin. Based on this method, periodic extraction was performed on SDI values from 1980–2019. Figure 3 [Figure 3: see original paper] shows two obvious peaks in the 40-year time series: $SE(11.5) = 1.4$, indicating that the basin social development subsystem experiences short-cycle changes on a 12-year time scale; and another peak $SE(26) = 7.485$, indicating long-cycle changes on a 26-year time scale. However, overall oscillation periods are not obvious.

The trend, mutation, and periodicity analyses of Yellow River Basin socio-economic development indicate that over the past 40 years, the basin’s socio-economic development has been in good overall condition and trending positively. Through quantitative analysis, the past four decades can be divided into three stages: Stage 1 (1980–1995) was a turbulent development period, with socio-economic development showing fluctuating patterns at a good level; Stage 2 (1996–2011) was a stable development period, with socio-economic development demonstrating a good development trend; and Stage 3 (2012–2019) was a rapid development period, with socio-economic development showing a good and rapid development momentum.

### 4.2 Sensitivity Analysis

Figure 4 [Figure 4: see original paper] presents the entropy weight calculation results for each SDI indicator in the Yellow River Basin. From the perspective of multi-year average entropy weights, significant differences exist among indicators. The top three indicators by entropy weight are the ratio of basin per capita GDP to national average, per capita park green space area, and resident average income, with weights of 0.098, 0.090, and 0.089, respectively. The three smallest weights belong to total basin water use, GDP growth rate, and water use per 10,000 yuan of industrial added value, with weights of 0.081, 0.068, and 0.056, respectively.

From the perspective of interannual entropy weight changes, resident average income, per capita park green space area, tertiary industry proportion, and water use per 10,000 yuan of industrial added value show significant increasing trends; population quantity, irrigated area, ratio of basin per capita GDP to national average, and night light index show decreasing trends; while GDP growth rate, water consumption rate, and total basin water use maintain consistent changes with SDI values.

Based on the entropy weight calculation results of each factor of Yellow River Basin socio-economic development, the sensitivity of indicators in the socio-economic development system at different stages was analyzed.

**Stage 1:** The top three indicators contributing to the socio-economic system were the ratio of basin per capita GDP to national average, irrigated area, and population quantity, which were sensitive factors for socio-economic development. Analysis shows that the SDI value during this period was 65.5, and the Yellow River Basin socio-economic system was in a relatively good state. This stage belonged to an extensive development period, targeting GDP growth, population quantity, and agricultural development. The proposal in 1978 to "shift the focus of the Party's work and the attention of the entire nation to socialist modernization construction" officially launched China's reform and opening-up policy. Subsequently, the entire Party and society were "single-mindedly focused on development and wholeheartedly engaged in construction." In 1987, the basic line of the primary stage of socialism further elevated socio-economic development issues to a "central" position, creating unprecedented enthusiasm for national economic construction.

**Stage 2:** The top three indicators contributing to the socio-economic system were water consumption rate, tertiary industry proportion, and per capita park green space area, which were sensitive factors for socio-economic development. Analysis shows that the SDI value during this period was 61.6, and the Yellow River Basin socio-economic system was in a moderately good state. This stage faced economic transformation. Benefiting from inherent demographic advantages and cheap labor, China's manufacturing sector gained development opportunities in the globalization division of labor system led by the United States. Particularly after China's accession to the WTO in 2001, international trade could proceed under a multilateral, stable most-favored-nation treatment principle. While enjoying the benefits of tariff reductions and market opening in other countries and regions, China, as a developing country, could also enjoy certain special treatment, providing full protection for the development of foreign trade during this period. After the initial accumulation of reform and opening-up, China, with its manufacturing foundation and still prominent demographic dividend, could more actively, rationally, and effectively utilize foreign investment to create rare opportunities, including increased foreign investment entities and expanded foreign capital utilization scope.

**Stage 3:** The top three indicators contributing to the socio-economic system were resident average income, per capita park green space area, and urbanization rate, which were sensitive factors for socio-economic development. Analysis shows that the SDI value during this period was 66.6, and the Yellow River Basin socio-economic system was in a relatively high good state. This stage entered a healthy and rapid development phase, where people pursued material wealth and spiritual urban development, aspiring to a happy life. Particularly since the 18th National Congress of the Communist Party of China, Xi Jinping has directly addressed the contradictions between economic development and ecological protection, repeatedly proposing the concept of ecological civilization and green development pathways. In practicing ecological civilization exploration, Xi Jinping's new concepts and strategies for ecological civilization have gradually matured. Meanwhile, the concept of new urbanization strategy has been proposed in China's new development stage, and remarkable progress has been made in promoting new urbanization, playing an important role in deepening supply-side structural reforms and forming a strong domestic market, continuously releasing economic growth potential. In the new era, people's needs have undergone new changes, shifting from demand-based to development-based and enjoyment-based needs. Socio-economic policies focus on the main social contradictions, strive to solve unbalanced and inadequate development problems, and endeavor to enable people to obtain more lasting happiness.

**Table 2** Weights of Each Indicator in Different Stages of Socio-Economic System

| Indicator | Stage 1 Weight | Stage 2 Weight | Stage 3 Weight |
|---|---|---|---|
| Resident Average Income | 8.23% | 8.13% | 9.21% |
| Per Capita Park Green Space Area | 8.00% | 8.30% | 9.62% |
| Tertiary Industry Proportion | 12.70% | 7.12% | 8.44% |
| Ratio of Basin Per Capita GDP to National Average | 9.14% | 8.20% | 2.91% |
| GDP Growth Rate | 8.62% | 8.92% | 8.50% |
| Night Light Index | 8.67% | 9.01% | 8.33% |
| Total Basin Water Use | 8.11% | 6.14% | 9.87% |
| Water Use per 10,000 Yuan of Industrial Added Value | 8.44% | 8.35% | 7.04% |

| Indicator | Stage 1 Weight | Stage 2 Weight | Stage 3 Weight |
|---|---|---|---|
| Population Quantity | 11.00% | 11.01% | 7.00% |
| Irrigated Area | 10.34% | 9.78% | 5.91% |
| Water Consumption Rate | 7.56% | 7.67% | 8.08% |
| Urbanization Rate | 6.10% | 7.47% | 8.09% |

### 4.3 Correlation Analysis

The correlation analysis between each SDI indicator and the system in the Yellow River Basin is shown in Table 3 . In Stage 1, each indicator showed good correlation with the social development system, with six indicators including resident average income, per capita park green space area, and urbanization rate showing negative correlation with SDI, causing the obvious declining trend of SDI in Stage 1. In Stage 2, indicators showed poor correlation with the social development system, with only tertiary industry proportion, water consumption rate, and water use per 10,000 yuan of industrial added value showing significant correlation. In Stage 3, indicators showed extremely high correlation with the social development system, with previously negative-correlation indicators such as resident average income, per capita park green space area, urbanization rate, tertiary industry proportion, and water use per 10,000 yuan of industrial added value shifting to positive correlation. Socio-economic development transformed from disorder to order, showing a good development trend.

**Table 3** Correlation Analysis Between SDI Indicators and System in the Yellow River Basin (1980–2019)

| Indicator | Stage 1 Correlation | Stage 2 Correlation | Stage 3 Correlation |
|---|---|---|---|
| Resident Average Income | Negative | Weak | Positive |
| Per Capita Park Green Space Area | Negative | Weak | Positive |
| Tertiary Industry Proportion | Negative | Positive | Positive |

| Indicator | Stage 1 Correlation | Stage 2 Correlation | Stage 3 Correlation |
|---|---|---|---|
| Ratio of Basin Per Capita GDP to National Average | Positive | Weak | Positive |
| GDP Growth Rate | Positive | Weak | Positive |
| Night Light Index | Positive | Weak | Positive |
| Total Basin Water Use | Positive | Positive | Positive |
| Water Use per 10,000 Yuan of Industrial Added Value | Negative | Positive | Positive |
| Population Quantity | Positive | Weak | Positive |
| Irrigated Area | Positive | Weak | Positive |
| Water Consumption Rate | Positive | Positive | Positive |
| Urbanization Rate | Negative | Weak | Positive |

## 5. Conclusions

(1) The social development of the Yellow River Basin can be divided into three stages: Stage 1 (1980–1995) was a turbulent development period, with socio-economic development showing fluctuating patterns at a good level; Stage 2 (1996–2011) was a stable development period, with socio-economic development demonstrating a good development trend; and Stage 3 (2012–2019) was a rapid development period, with socio-economic development showing a good and rapid development momentum.

(2) The sensitive factors of the socio-economic development system differed

significantly across stages. The sensitive factors in Stage 1 were the ratio of basin per capita GDP to national average, irrigated area, and population quantity. In Stage 2, they were water consumption rate, tertiary industry proportion, and per capita park green space area. In Stage 3, they were resident average income, per capita park green space area, and urbanization rate.

(3) From the correlation analysis, indicators with strong correlation shifted from negative correlation in Stage 1 to positive correlation in Stage 3, indicating that Yellow River Basin socio-economic development has transformed from disorder to order, demonstrating a good development trend.

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## Author Contribution Statement

**ZHANG Jinliang:** Conceived the research idea and designed the study framework;
**JIN Xin:** Collected, cleaned, and analyzed the data;
**YAN Dengming:** Drafted the manuscript;
**CUI Changyong:** Revised the final version of the paper.

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*Note: Figure translations are in progress. See original paper for figures.*

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