A Quantitative Assessment on Ecological Compensation Based on Water Resources Value Accounting: A Case Study of Water Source Area of the Middle Route of South-To-North Water Transfer Project in China

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As an economic means to adjust the contradiction between ecology and development, ecological compensation plays an important role in promoting the good operation of interbasin water transfer projects and the sustainable development of regional economy. The accounting of ecological compensation is the key and difficult point of ecological compensation as well as the basis of ecological compensation policy and practice. Watershed ecological compensation based on water resources value accounting is an early exploration field of ecological compensation research, and water resources value calculation needs to consider both water quantity and water quality comprehensively. Taking the water source area of the Middle Route of South-to-North Water Transfer Project (SNWTP) as an example, this article tries to establish the payment standard of watershed ecological compensation from the perspective of water resources value. The results show that: 1) The water resources value of the six core regions in the water source area has shown an overall upward trend since 2000, and the northern regions have demonstrated higher value of water resources than the southern regions. 2) The LSTM neural network model is used to forecast the value of water resources in the six regions from 2020 to 2022, and it is found that the value of water resources would increase in the next few years. 3) The compensation price of the six regions in the water source area is predicted in the range of 0.5–1.5 yuan/m^3 from 2020 to 2022, and an upward trend in the ecological compensation amount is forecast. Based on the above conclusions, this article puts forward suggestions to establish an ecological compensation accounting system in line with the Middle Route water source area from the perspectives of ecological compensation legislation, allocation of ecological compensation amount, and introduction of market mechanism.
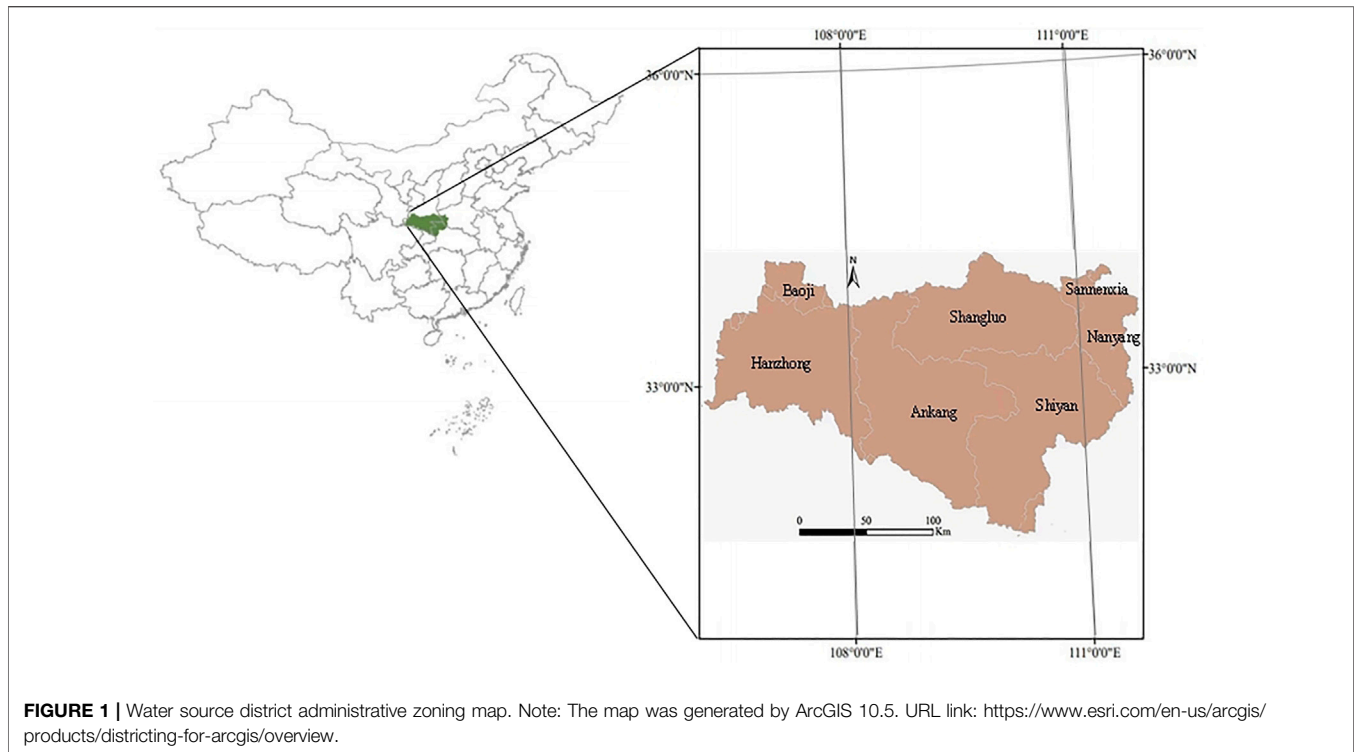
Keywords: water resources value, ecological compensation accounting, the middle route of water transfer, machine learning, China

1 INTRODUCTION

Ecological compensation is an important economic measure to ensure the sustainability of water quality and quantity in the interbasin water transfer project, which is beneficial to realize the efficiency and equity in the process of water supply and consumption in water source area and water-receiving area. One of the key points of ecological compensation lies in the accounting of ecological compensation. Different accounting methods produce different implementation effects, which have very important practical significance for the sustainability of water transfer projects and economic development of water source area. The existing studies on ecological compensation accounting methods mainly are carried out from the perspectives of ecosystem service value, beneficiary's profit, conservator's input and loss, payment, and compensation willingness (Xepapadeas, 2011; Hu, 2016). The common compensation accounting can be divided into protection compensation and cross-basin compensation (Wang and Hou, 2013). So far, compensation accounting methods in water source area have included ecosystem service value method (Zhang et al., 2002), water quality accounting method (Xu et al., 2008), water resources value method and willingness to pay method (Costanza, 2012), water ecological restoration cost method (Martinez-Paz et al., 2013), etc. And the ecosystem service value method is the most important accounting method. In the 1970s, the value assessment of ecosystem services begins to receive more attention from different countries and regions. Value quantity and physical quantity are mostly used to measure the value of ecosystem services internationally. Pimentel et al. (1995) proposed two methods (i.e., ecosystem optimal model and maintenance of biological balance model) to estimate the functional value of global biodiversity based on willingness to pay. Ouyang and Wang, 2000a; Ouyang et al., 2000b) divided the value of ecosystem services into four categories, namely direct use-value, indirect use-value, selection value, and heritage value, and calculated the value of six terrestrial ecological services. In the study of global environment and natural services, ecosystem service value is divided into use-value and non-use-value (Rawlins et al., 2018). Specifically, use-value includes direct use-value, choice use-value, and indirect use-value, while non-use-value is divided into existence value and heritage value (Gomez-Baggethun et al., 2010). By simulating the flow path and quantity of water supply services, Xu et al. (2019) provided a scientific theoretical basis for ecosystem service management and ecological compensation. Ma and Wang (1984) studied the complex ecosystem of Society-Economy-Nature, which marked ecologists' march into the field of economics. Subsequently, empirical studies based on specific regions and basins began to emerge. Zhang et al. (2001) studied the service value evaluation method and divided it into three categories, namely actual market, alternative market, and simulated market. Zi (2010) evaluated the economic value of ecosystem services of water tourism resources in Heilongjiang Province, and believed that reasonable water tourism resources planning should be made with emphasis on the protection of wetlands, rivers, lakes, and other water bodies. Based on the

existing achievements in this field, Xie (2012) compiled a table of equivalent factors of ecosystem service value in China. Based on the Research Report of the United Nations Environment Programme (UNEP) and combined with the theory of ecological economics, Ouyang et al. (2013) obtained the ecosystem service value evaluation methods of alternative market and simulated market. According to the existing problems in the ecological environment of the Chishui River, Qiu and Zhai (2014) established the ecological compensation mechanism. Based on the perspective of agricultural development, Hu (2015) concluded that the factors affecting the ecological compensation mechanism mainly include the loss of development opportunities, environmental protection cost, and public awareness. Yang et al. (2020) analyzed the current situation of ecological compensation in the Yellow River basin, and described the framework of water-related ecological compensation in the Yellow River Basin in detail. Xu et al. (2021) constructed a universal framework for interregional ecological compensation on the basis of considering differences among regional development.

The value of water resources was first discussed in the 1970s, and it was expressed as the maximum payment amount willing to transfer a unit of water. In the late 1980s, with the deepening of water resources crisis, water resources price has caused an upsurge of research by scholars. Lyman (1992) found that the maximum price of water resources fluctuated twice as much as the non-maximum price. Jiang (1998a) discussed the value basis of water resources from different perspectives, and his most significant contribution was to complete the calculation of the water resources value with the method of fuzzy mathematics. Wang and Qu (2001) incorporated the water resources indexes into the national economic accounting system. Piper (2003) explored the relationship between water quality and cost, and proposed the mechanism of water price affecting water quality. Wang et al. (2003) and Shen (2006) put forward the concept of "triple water price" and tried to use the general equilibrium model to calculate the actual water price in China. Subsequently, the value accounting of water resources began to cross departments and regions, and gradually tended to be market-oriented. Zhao et al. (2007) established a theoretical model of emission rights trading market based on experimental methods, and proposed the system construction scheme of resources trading market with optimal efficiency. Wei et al. (2008) analyzed the different profit levels of water conservancy departments under different water prices, so as to explore the maximization of income under the condition of the lowest water price. Du (2015) explored the improvement scheme of the real water price setting mechanism in view of the problems existing in the current water price scheme of SNWDP in China. Jia et al. (2018) used the improved fuzzy comprehensive evaluation model to calculate the maximum affordable water price of residents. Taking Taipu River as an example, Yang et al. (2019) adopted the game theory method to study the incentive policy, ecological compensation, and water quality accounting, and explored the establishment of trans-regional cooperation mechanism of water resources.

FIGURE 1 | Water source district administrative zoning map. Note: The map was generated by ArcGIS 10.5. URL link: https://www.esri.com/en-us/arcgis/products/districting-for-arcgis/overview.

To sum up, there are many studies on ecological compensation accounting and value of water resources, but few ones connect the two to discuss, resulting in the lack of effective connection between the existing ecosystem service value accounting methods and water resources social-economic pricing. Considering that it is more easy to accept the cost (i.e., value of water resources) paid for protecting water resources as the compensation standard by both the water source area and the water receiving area, the paper takes the water source area of the Middle Route of SNWDP in China as the research object, and studies the ecological compensation accounting from the perspective of water resources value accounting, which could promote the research on the ecological compensation accounting method of water source area. The novelty of this study is that the machine learning method (i.e., K-means clustering model and LSTM model) in computer science is applied to the evaluation of water resources value in the field of ecosystem. It gives full play to the advantages of machine learning method in dealing with complex nonlinear social science topics and makes the research results more consistent with the reality.

2 MATERIALS AND METHODS

2.1 Study Area

The water source area of the Middle Route of the SNWDP mainly refers to the basin area above the Danjiangkou Reservoir, which is located at the junction of Shaanxi, Henan, and Hubei provinces. The geographical coordinates of the water source area boundary are between $106°30'$-$112°18'$E and $31°20'$-$34°10'$N. The water source area of the middle route covers a total area of 130,906

square kilometers, with a total population of 24.26 million. The core cities in the water source area mainly include Shiyan of Hubei Province, Hanzhong, Ankang and Shangluo of Shaanxi Province, Nanyang and Sanmenxia of Henan Province (**Figure 1**). This area belongs to the north subtropical subhumid monsoon climate zone, with uneven distribution of precipitation. The average annual temperature is $16°C$, and the annual average precipitation is about 800 mm. Han River is the main river, crossing the whole territory from west to east. The river water system in this area is relatively abundant, and large-scale water conservancy projects such as Xi River Reservoir and Shimen Reservoir have been built.

To protect the ecological environment of the water source area, all polluting enterprises and mines on both sides of the water source area have been closed, and garbage treatment and sewage purification plants in some cities with relatively concentrated populations have been set up by the local government. An area of 7,681 square kilometers has been brought under water and soil erosion control, more than 20,000 ha of basic farmland have been newly built and 270,000 ha of afforestation have been planted, which not only effectively controlled water and soil loss, but also promoted local economic development. In addition, the government of the water source region has actively implemented the natural forest protection project and stopped logging of natural forest commodities. Sixteen state-owned forest farms in 199 townships have been included in the project to protect natural forests, and provincial-level protected forests such as Hualongshan and Yinghu Wetland have been established. In these protected forests, the animal and plant communities are rich and complete, and the ecological environment is good as a whole. The drainage area is large and the rainfall is abundant;

TABLE 1 | Evaluation index system of water resources value.

Dimension	Indicator	Description	Attribute
Nature	X_1: Surface water resources (10×10^7 m^3)	Extract the data of surface water resources	–
	X_2: Groundwater resources (10×10^7 m^3)	Extract the data of groundwater resources	–
	X_3: Annual precipitation (10×10^7 m^3)	Collect rainfall monitoring data from national meteorological stations	–
	X_4: Water quality	Collect water quality monitoring data	+
	X_5: Total soil erosion (t)	Calculate the total amount of soil erosion per unit area per year	+
	X_6: Carbon fixation and oxygen release (t)	Calculate the carbon retention per unit area per unit time	+
	X_7: Surface runoff coefficient	Calculate the ratio of surface runoff to rainfall	+
Economy	X_8: Per capita GDP (yuan)	Calculate the ratio of GDP to population	–
	X_9: Per capita income of residents (yuan)	Extract the data of per capita income	–
	X_{10}: Per capita consumption expenditure (yuan)	Extract the per capita expenditure data	–
	X_{11}: Per capita urban maintenance and construction funds (yuan)	Extract the per capita urban construction cost	+
	X_{12}: The registered urban unemployment rate (%)	Extract the unemployment rate data	+
	X_{13}: Water consumption per 10,000 yuan GDP (m^3)	Extract the water consumption of 10,000 yuan GDP	–
	X_{14}: Utilization ratio of water resources (%)	Calculate the ratio of water supply to total water resources	–
Society	X_{15}: Population density (people/km^2)	Extract the population density data	+
	X_{16}: Urban area green coverage rate (%)	Extract the greening coverage rate data	+
	X_{17}: Ratio of students in ordinary colleges and universities (%)	Calculate the ratio of the number of students in colleges and universities to total population	–
	X_{18}: Number of beds in public health institutions (PCs./ 1,000 persons)	Extract the data of medical beds	–
	X_{19}: Poverty rate (%)	Calculate the ratio of population receiving minimum living security in urban and rural areas to total population	+
	X_{20}: Per capita water resources (m^3)	Extract the per capita water resources	–
	X_{21}: Sewage treatment rate (%)	Extract the sewage treatment data	+

Note: "+" represents that the indicator is positive, and "–" represents that the indicator is negative.

therefore, the water supply is sufficient, the self purification capacity is strong, and the water quality is excellent (Li et al., 2021).

The construction of the SNWDP has improved the irrigation conditions, promoted the development of fishery, forest industry, and its processing industry, and promoted the adjustment of agricultural industrial structure in the water source area. Take Nanyang, one of the core cities in the water source area, as an example. After the completion of the supporting water conservancy infrastructure related to the SNWDP, the water diversion for Nanyang can be increased by nearly 600 million cubic meters every year, with an effective irrigation area of 2,673 square kilometers, accounting for 31% of the total irrigation area of the city, which can effectively alleviate the current situation of agricultural water shortage and improve crop output in Nanyang (Wu, 2009; Yu, et al., 2021).

2.2 The Index System Construction

Referring to the existing evaluation index system of water resources value research (Fu, 2008; Hajkowicz and Higgins, 2008; Shen et al., 1998), the value of the water resources evaluation system for ecological compensation is constructed. And 21 indicators from three dimensions of nature, economy, and society are selected, as shown in **Table 1**. Specifically, the natural dimension indicators are considered from the perspectives of water quantity, water quality, and water development, which reflect the ecological environmental value of water resources. The economic dimension indicators reflect the economic value of water resources by considering the utilization

efficiency of water resources, per capita income, and economic scale. Social dimension indicators are considered from the aspects of population, policy, social background, etc.

2.3 Methods

This part mainly consists of three parts: 1) introduce the methods of water resources value measurement and comprehensive evaluation, 2) introduce the method to forecast the value of water resources in the next few years, and 3) introduce the accounting method of ecological compensation.

2.3.1 Value of Water Resources Measurement Model Based on K-Means Clustering Algorithm

The K-means clustering algorithm (Zhao et al., 2021; Liu et al., 2022) is used to measure the value of water resources in this study. Select the initialized n samples as the initial clustering center and divide n data into K sets (i.e., $C = \{C_1, C_2 \cdots C_k\}$) to minimize the Within-Cluster Sum of Squares (WCSS), so as to form cluster C_i.

$$\arg \min_s \sum_{i=1}^{n} \sum_{x \in S_i} \|x - \mu_i^2\| \tag{1}$$

$$\mu_i = \frac{1}{|C_i|} \sum_{x \in C_i} x \tag{2}$$

$$C_i^{(t)} = \left\{ x: \left\| x - m_i^{(t)} \right\|^2 \leq \left\| x - m_j^{(t)} \right\|^2 \forall i, 1 \leq j \leq n \right\} \tag{3}$$

$$dist\left(x_i, x_j\right) = \sqrt{\sum_{d=1}^{n} \left(x_{i,d} - x_{j,d}\right)^2} \tag{4}$$

where x is the sample value, μ_i is the centroid of all points in $C^{(t)}$, $C^{(t)}$ is the new cluster formed after t times of update, $m^{(t)}$ is the sample mean vector, and $dist\,(x_i, x_j)$ represents the dissimilarity of x_i and x_j.

The clustering obtained from **Eq. 4** causes the data object x to be allocated to the nearest centroid. Taking the center of the observed value in the clustering as the new centroid, the family partition (i.e., $C = \{C_1, C_2 \cdots C_k\}$) is obtained by reciprocating division.

2.3.2 Comprehensive Evaluation Method of Water Resources Value Based on Entropy Weight Method

Entropy weight method is an objective weight assignment method to determine the index weight according to the change range of information entropy (Zou et al., 2005). The indicators are divided into positive and negative, and different algorithms are needed for standardization.

When indicators are positive

$$x_{ij}' = \frac{x_{ij} - \min\left\{x_{1j}, \cdots, x_{nj}\right\}}{\max\left\{x_{1j}, \cdots, x_{nj}\right\} - \min\left\{x_{1j}, \cdots, x_{nj}\right\}} \tag{5}$$

When indicators are negative

$$x_{ij}' = \frac{\max\left\{x_{1j}, \cdots, x_{nj}\right\} - x_{ij}}{\max\left\{x_{1j}, \cdots, x_{nj}\right\} - \min\left\{x_{1j}, \cdots, x_{nj}\right\}} \tag{6}$$

Then, the information entropy and weight of indicator j are calculated as follows:

$$P\left(x_{ij}'\right) = x_{ij}' \Big/ \sum_{i=1}^{n} x_{ij}' \tag{7}$$

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{n} P\left(x_{ij}'\right) \ln P\left(x_{ij}'\right), j = 1, \cdots, m \tag{8}$$

$$\omega_j = \frac{1 - e_j}{\sum\limits_{j=1}^{m} 1 - e_j}, j = 1, \cdots, m \tag{9}$$

The comprehensive score of sample i is

$$S_i = \sum_{j=1}^{m} \omega_j x_{ij}' \, i = 1, \cdots, n \tag{10}$$

Calculate the total score of each cluster of samples, and sort them according to the score, so as to distinguish the level of water resources value.

2.3.3 Value of Water Resources Prediction Model Based on LSTM Algorithm

As an improved algorithm of recurrent neural network (RNN), long short-term memory network (LSTM) model can preserve valid data information in long-term time series, which has good support for the persistence of data information. The LSTM model has both forward and back propagation functions. By changing part of the data into training set, the parameters are constantly updated in the learning process, and the processing and discarding of historical data are controlled by internal algorithm. Therefore, the LSTM model is suitable for dealing with time series problems (Omlin and Giles, 1996; Wang et al.,

2018). When establishing the value of water resources prediction model based on LSTM to predict the evaluation index X_i, m, and d are taken as the current time and the sliding window size, respectively:

$$X_i(m) = [x_i(m - d + 1) \ldots x_i(m - 1), x_i(m)] \tag{11}$$

The sequence $X_i(m)$ is adopted to predict the value (i.e., $\hat{x}_i(m + 1)$) at time $m+1$.

The selection of sliding window d is very critical. In this article, referring to the existing literature (Gers et al., 2000; Wang et al., 2018) and combining with the data of the water source area, the size of the sliding window is set as 5. On the basis of first-order difference, regularization, and other preprocessing of the data, the data from 2000 to 2005 are used as the training set to predict the value of water resources grade in 2006, the data from 2001 to 2006 are used as the training set to predict the value of water resources grade in 2007, and so on, the data from 2015 to 2019 are used as the training set to predict the value of water resources grade in 2020.

The main steps of water resources value prediction using LSTM are as follows:

1) To improve the stability of the time series and solve the over-fitting phenomenon that may occur in the process of prediction, the data set is stabilized (i.e., difference) and regularized;
2) The training set D is constructed according to the size of the sliding window d;
3) Establish the value of water resources prediction model based on LSTM and initialize the model parameters;
4) The prediction model is trained by the training set D. The gradient descent method is used to back propagate, and update the model parameters until the prediction accuracy requirements are met;
5) Input the first d historical observation value sequence $X_i(m)$ of X_i into the LSTM prediction model of water resources value completed by training, and obtain the predicted value $\hat{x}_i(m + 1)$ at time $m+1$.

2.3.4 Calculation Method of Ecological Compensation Amount Based on Value of Water Resources

In this article, the difference between the upper limit of water price and the cost of current water price is taken as the upper limit of compensation amount, and then the ecological compensation amount is calculated according to the value of water resources. The upper limit of water price presents the water price when it reaches the maximum water price bearing index. In the calculation of ecological compensation in water source area, to convert the dimensionless evaluation level of water resources value into the scalar value of corresponding water price, it is necessary to introduce the price vector (Jiang, 1998b; Li et al., 2010; Zhu et al., 2017). The water price is calculated as follows:

$$P = V \cdot S^T \tag{12}$$

where P is the price of water resources, V is the value level of water resources, and S^T represents the value vector of water resources.

The price of water resources is calculated according to the water price bearing index method, which reflects the affordability of consumers to pay for water commodities.

$$A = SW/AE \qquad (13)$$

where A is water cost bearing index, SW is water cost expenditure, and AE is income of residents. According to the international standard of water price bearing index for developing countries, 3% of residents' per capita income is generally taken as the maximum water price bearing index for households (Gakidou et al., 2017).

At present, the current water price in China mainly includes water resources fee, water supply cost, and sewage treatment fee. The upper limit of the water resources compensation price is calculated as follows:

$$PU = E \cdot \frac{A}{B} - C - D - F \qquad (14)$$

where PU is the upper limit of water resources compensation price, E is per capita disposable income of residents, B is per capita water consumption, C is water supply cost, D is water resources fee, and F is sewage treatment fee.

The compensation price upper limit PU is divided according to arithmetic series, and the compensation price vector is calculated as follows:

$$S = [0, 0.25PU, 0.5PU, 0.75PU, PU] \qquad (15)$$

Finally, the ecological compensation in the water source area is calculated as follows:

$$W = P \cdot QW \cdot G \qquad (16)$$

where W is the amount of ecological compensation (100 million yuan/year), P is compensation price (yuan/m^3), QW is the annual water regulation (10^8 m^3/year), and G is the water quality adjustment coefficient.

2.4 Data Sources

The data of regions in the core water source area of the Middle Route of the SNWDP from 2000 to 2019 is collected and analyzed. The data are cited from Water Resources Bulletin of the study area (2000–2019), China Statistical Yearbook (2001–2020), and China Urban Construction Yearbook (2000–2019).

3 RESULTS

3.1 Calculation of Water Resources Value in Water Source Area of the Middle Route of SNWTP

3.1.1 Classification of Water Resources Value Based on K-Means Algorithm

Since value of water resources accounting belongs to high-dimensional data clustering in clustering algorithm, dimension reduction is required. Feature extraction has become a common method, and its principle is to map the original feature set from high-dimensional space to low-dimensional space using the linear mapping method (Yu and Li, 2009). In this paper, principal component analysis (Cui et al., 2020) is adopted to extract features from high-dimensional data, and the two indicators of surface water resources and groundwater resources are finally selected to measure their dissimilarity, namely x_i and x_j in **Eq. 4**. The K-means clustering results are shown in **Figure 2**.

The optimal K value is determined by the elbow method. Based on the deviation sum of squares (SSE) index, when SSE decreases gently with the increase in K, it indicates that the K value corresponding to elbow is the optimal cluster number (Hou et al., 2005). SSE is calculated as follows:

$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \qquad (17)$$

The errors of water resources value accounting based on the K-means clustering algorithm under the selection of different cluster numbers are shown in **Figure 3**. When the curvature is the highest, the K value corresponding to the elbow is 5. Therefore, the value of water resources in the water source region is divided into five categories. At this time, there is no grade relationship between the five categories.

After obtaining the classification results of the water resources value data in the water source area based on the K-means algorithm, the entropy weight method could be used to comprehensively score each category. The total scores are sorted in order, namely, V_1-V_5, where V_1 represents the lowest grade and V_5 represents the highest grade. The scoring results of V_1-V_5 are shown in **Table 2**.

3.1.2 Comprehensive Evaluation of Water Resources Value Based on Entropy Weight Method

The entropy weight method was used to calculate the weight of indicators in the value of water resources evaluation system constructed based on the three dimensions of nature, economy, and society. The results are shown in **Figure 4**.

By using the entropy weight method, the value of water resources of six regions in the core water source area of the Middle Route of the SNWDP from 2000 to 2019 is evaluated (**Figures 5–7**). As shown in **Figures 5–7**, the blue dotted line represents the trend line of water resources value from 2010 to 2019, the value of water resources of the six core regions in the water source area has shown an overall upward trend from 2000 to 2019. The value of water resources in northern regions (e.g., Sanmenxia, Nanyang, and Shangluo) was higher than that in the southern regions (e.g., Shiyan, Ankang, and Hanzhong) in terms of spatial distribution. The increasing rate of water resources value in different regions varied significantly in terms of time distribution. The value of water resources of Shiyan showed an obvious upward trend, while that of Hanzhong and Ankang had a gentle upward trend.

Specifically, as can be seen from **Figure 5**, the value of water resources in Shiyan has shown an obvious upward trend since 2013. The value of water resources of Shiyan was basically stable
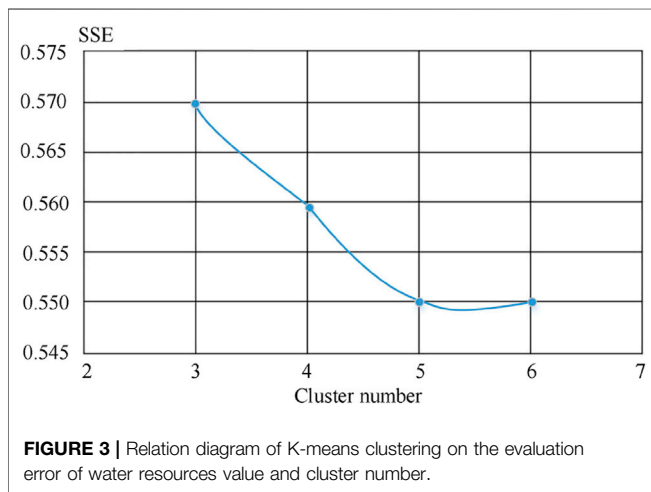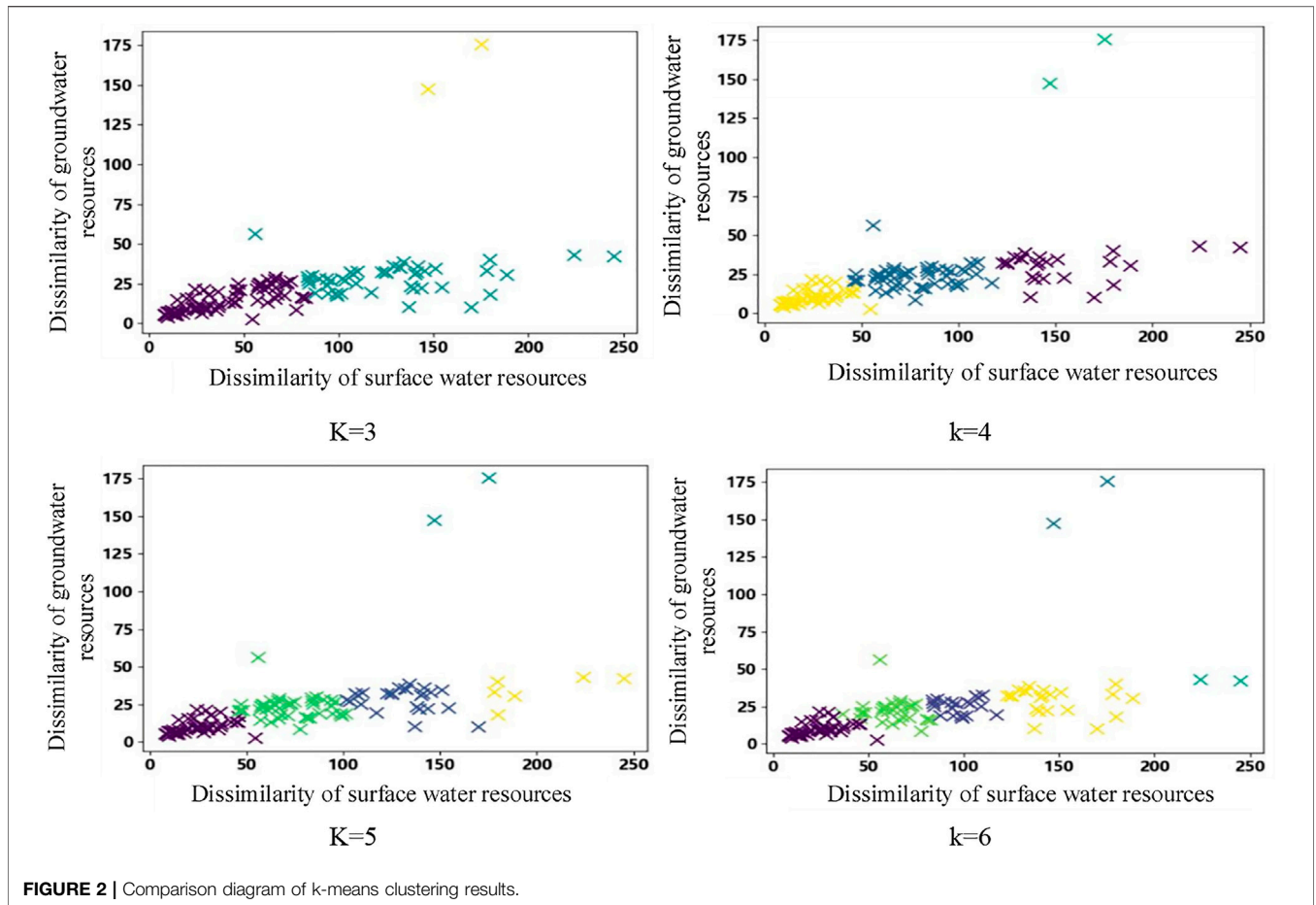
FIGURE 2 | Comparison diagram of k-means clustering results.

FIGURE 3 | Relation diagram of K-means clustering on the evaluation error of water resources value and cluster number.

TABLE 2 | Comprehensive evaluation results based on the entropy weight method.

Grade	V_1	V_2	V_3	V_4	V_5
Value	7.8	18.7	50.0	79.0	95

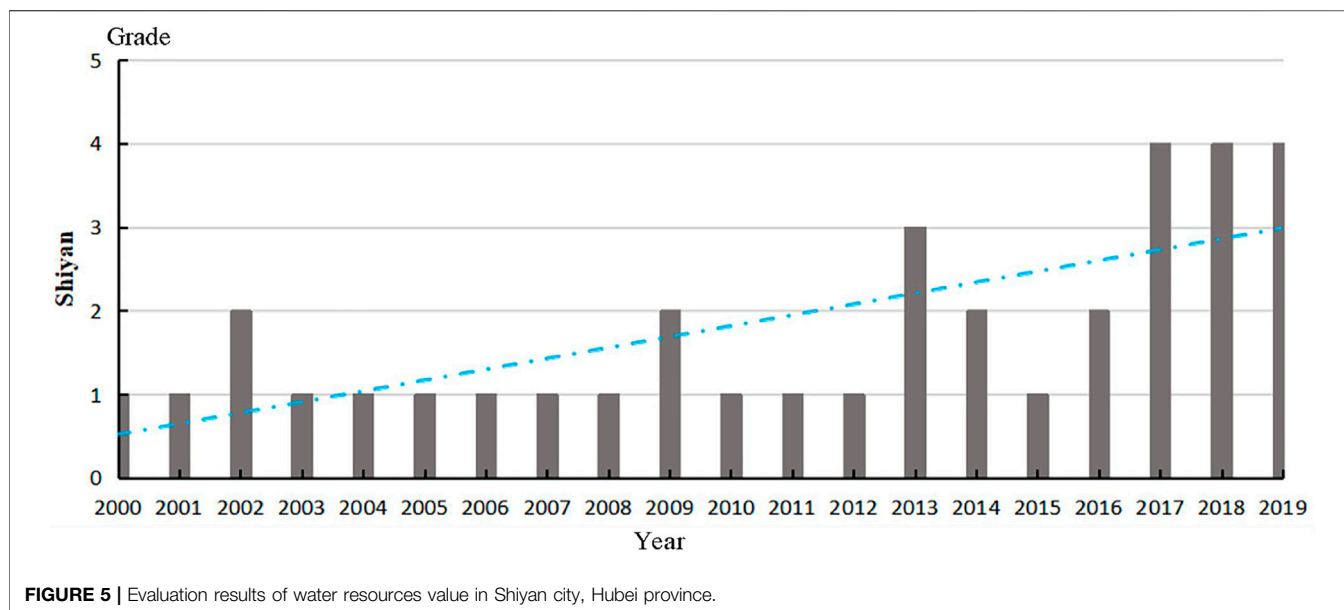FIGURE 4 | The result of index weight evaluation based on the entropy weight method.
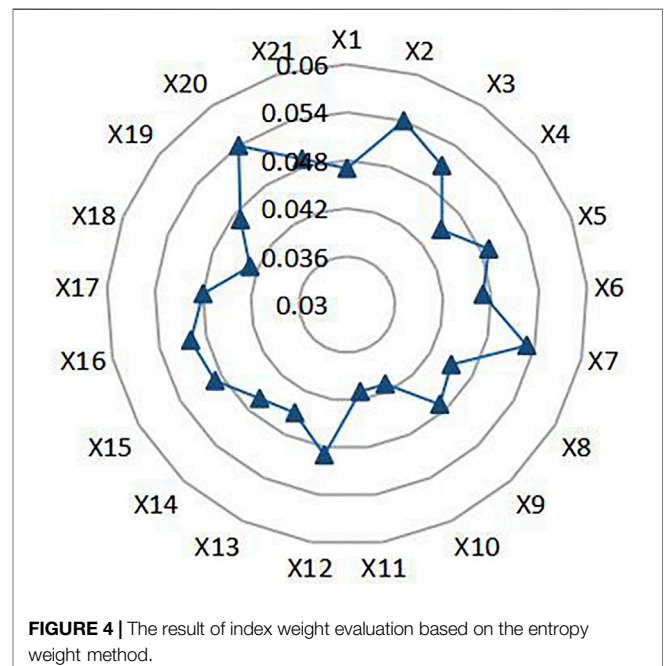
FIGURE 5 | Evaluation results of water resources value in Shiyan city, Hubei province.
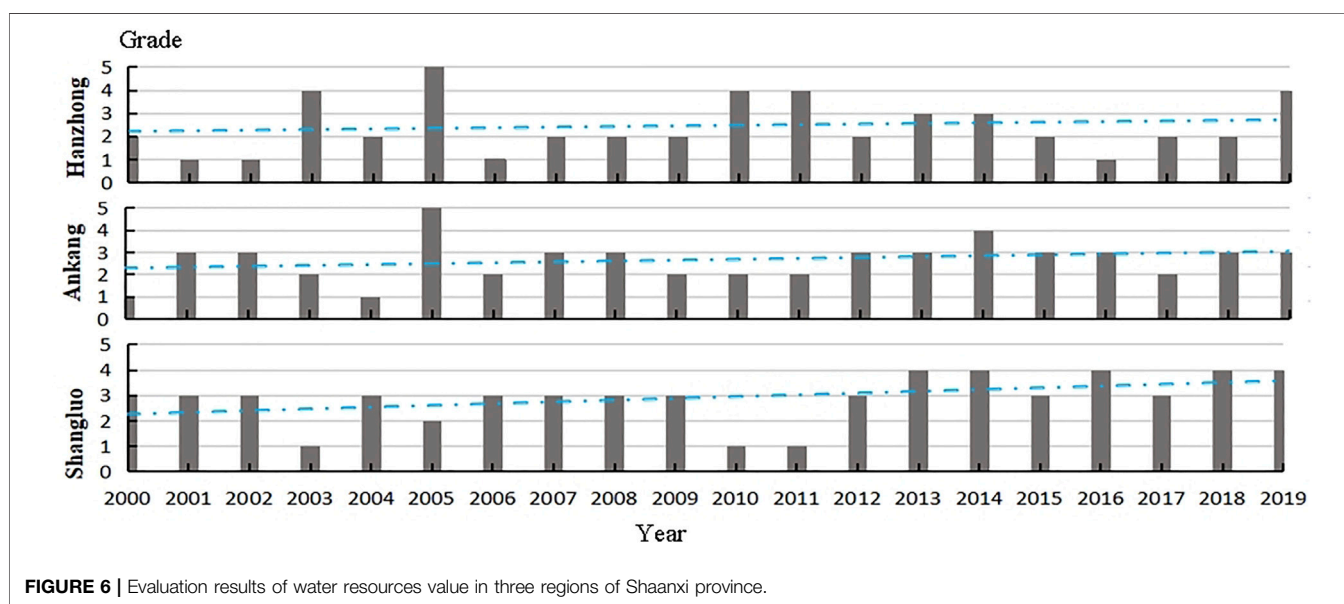

FIGURE 6 | Evaluation results of water resources value in three regions of Shaanxi province.

at V_1 level from 2000 to 2012, and only increased to V_2 level in 2002 and 2009. After 2013, it basically stayed above V_2 level, then rose and stayed at V_4 level for a long time from 2017 to 2019. There was little difference between the three regions in southern Shanxi in terms of water resources value, among which, Shangluo had the highest value of water resources, Ankang took the second place, and Shangluo had the lowest value, as shown in **Figure 6**. The value of water resources in Hanzhong was generally stable. The value of water resources in Ankang was at V_2 level before 2012. Thereafter, it increased to V_3 level. The value of water resources in Shangluo increased the most, which stabilized at V_3 level before 2013, and rose to V_4 level after 2013. The value of water resources in Sanmenxia was obviously higher than that in

Nanyang (**Figure 7**). The value of water resources of Nanyang was mostly at or below V_3 level, while that of Sanmenxia reached at or above V_3 level.

3.2 Value of Water Resources Forecast in Water Source Area of the Middle Route of SNWTP

The prediction results of the water resources value in the water source area of the Middle Route of the SNWTP from 2020 to 2022 are shown in **Table 3**.

The overall level of water resources value in each region will experience an upward trend in varying degrees in the future.
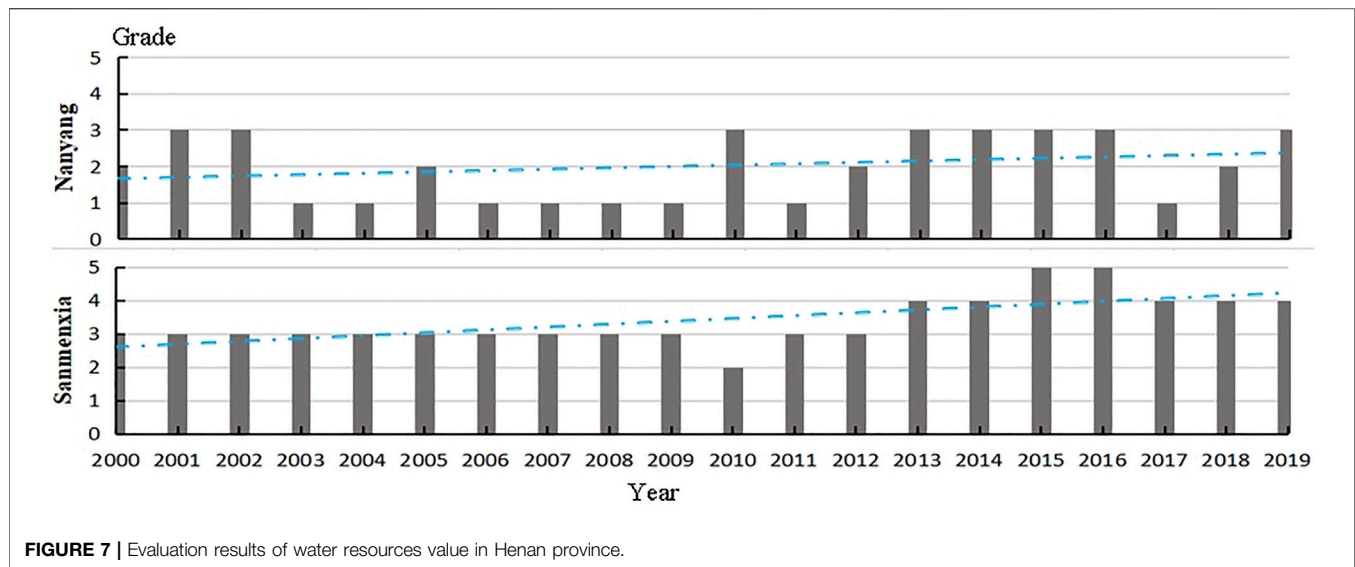
FIGURE 7 | Evaluation results of water resources value in Henan province.

TABLE 3 | Water resources value of regions in water source area in 2020–2022.

RegionYear	Shiyan	Hanzhong	Ankang	Shangluo	Nanyang	Sanmenxia
2020	V_4	V_2	V_4	V_3	V_2	V_3
2021	V_3	V_3	V_3	V_3	V_3	V_5
2022	V_5	V_4	V_3	V_3	V_3	V_5

However, the value of water resources in Hanzhong in 2022 may be lower than that in 2021, which is due to the fact that natural precipitation is the main source of water resources in Hanzhong, and its annual precipitation has an oscillation cycle of 13~14 years. After 2020, when the next rainy period is entered, the amount of water resources will increase. It should be noted that the value assessment of water resources is a high-dimensional and complex research subject, which is affected by many factors such as water quantity and quality, ecological environment, economic development, continuous investment cost of water transfer project, etc. Any change in the above factors may lead to changes in the overall valuation of water resources value.

Overall, the prediction results could basically reflect the actual situation of water resources value of core regions in the water source area from 2020 to 2022. However, with the increase in domestic and industrial water consumption, the value of water resources will be further improved in the water source area.

3.3 Accounting for Ecological Compensation in the Water Source Area of the Middle Route of SNWTP
3.3.1 Ecological Compensation Price Accounting
In terms of water supply cost and normal profit, the total cost of water supply of the Middle Route project is 3.142 billion yuan, and the average unilateral comprehensive water supply cost is 0.305 yuan/m³ (Tan and Zhu, 1998). The Middle Route Project spans several watersheds, and the management costs vary

between different provinces and regions. Generally speaking, the water resources fee of the whole project is roughly stable between 0.02 and 0.2 yuan/m³ (Zhang et al., 2006). Combined with the experts' suggestions and the general situation of the water source area, the water resources fee is calculated at 0.2 yuan/m³ in this paper. As for sewage treatment fee, the average treatment costs of sewage plants in Hanzhong, Ankang, and Shangluo are 0.97 yuan/m³, 1.74 yuan/m³, and 1.05 yuan/m³, respectively, whereas the average collection of sewage treatment fee in these three regions is only 0.47 yuan/m³ (Ma, 2014). Considering the situation of other regions in the water source area, 0.5 yuan/m³ is taken as the sewage treatment fee in this paper.

The ecological compensation prices of Shiyan, Sanmenxia, Nanyang, Shangluo, Ankang, and Hanzhong are calculated based on the predicted value of water resources grade results from 2020 to 2022 (**Table 3**). Taking the data of Shiyan in 2020 as an example, the annual disposable income of residents is 21,435 yuan, and the total water consumption of the city is 9.09 yuan × 10⁸ m³, the total population is about 3.5 million. Therefore, the upper limit of compensation price in Shiyan in 2020 can be calculated as follows:

$$PU = \frac{21435 \times 3\%}{9.09 \times 10^8 / (350 \times 10^4)} - 0.305 - 0.2 - 0.5 \approx 1.468$$

The LSTM model is adopted to predict that the value of water resources of Shiyan in 2020 is at V_4 level, and the compensation price of Shiyan in 2020 is calculated as follows:

TABLE 4 | Ecological compensation prices of regions in water source areas in 2020–2022. Unit: yuan.

RegionYear	Shiyan	Hanzhong	Ankang	Shangluo	Nanyang	Sanmenxia
2020	1.101	0.227	0.573	1.440	0.445	2.018
2021	1.144	0.627	0.603	1.091	0.937	2.643
2022	1.529	0.478	0.899	1.521	1.480	2.724

TABLE 5 | The rule of water quality adjustment coefficient value.

C value	Condition
$1 < C < 2$	When the water quality is better than class I
$C = 1$	When the water quality is between class II and class I
$0 < C < 1$	When the water quality is between class III and class II
$C = -1$	When the water quality is poor V or above

$$P = [0, 0, 0, 1, 0][0, 0.367, 0.734, 1.101, 1.468]^T = 1.101$$

The calculation results of ecological compensation prices of regions in the core water source area of the Middle Route in 2020–2022 are shown in **Table 4**.

As can be seen from **Table 4**, the compensation prices of regions in the water source area show an overall upward trend from 2020 to 2022. There would be obvious fluctuations in compensation prices in some regions. For instance, the compensation prices in Shangluo will drop in 2021. The regions with the highest and lowest compensation prices will be Sanmenxia and Hanzhong, respectively. From the perspective of time, the compensation prices in the water source area from 2020 to 2022 will have the largest change range in Nanyang, and the smallest change range in Shangluo. The compensation prices of six regions in the water source area in 2020–2022 will be mostly in the range of 0.5–1.5 yuan/m³. Taking 1 yuan/m³ and 2 yuan/m³ as different compensation gradient boundaries, the compensation prices in Hanzhong and Ankang will be lower than 1 yuan/m³ from 2020 to 2022. The compensation prices in Nanyang will be less than 1 yuan/m³ in 2020 and 2021, and then show an upward trend in 2022. The compensation prices in Shiyan and Shangluo will be between 1 and 2 yuan/m³ in the next few years. Sanmenxia will have the highest compensation prices, which are predicted basically to be above 2 yuan/m³ from 2020 to 2022.

3.3.2 Ecological Compensation Accounting
As for the water quality adjustment coefficient C, the principle of "high quality, high price" shall be followed, and the adjustment coefficient is determined according to the water quality situation. **Table 5** shows the rule of water quality adjustment coefficient value.

According to the monitoring of relevant departments in China, the water quality in Danjiangkou reservoir area has been stable above the national class II standard for many years. Therefore, the C value is taken as 1.

Based on the compensation prices of water resources per cubic meter in the six regions in the water source area from 2020 to 2022, the ecological compensation amount is calculated in combination with the annual average water transfer and water quality of each city (**Table 6**). For instance, Shiyan is rich in water resources, and the average annual water inflow into Danjiangkou Reservoir is 3.62×10^9 m³. The annual water diversion from Danjiangkou reservoir accounts for about 26% of the total water inflow. Therefore, the annual water diversion from Shiyan is about 9.41×10^8 m³. Based on **Eq. 16**, it can be calculated that the ecological compensation amount of Shiyan in 2020 is 1.036 billion yuan.

As can be seen from **Table 6**, the accounting results of ecological compensation amount of regions in the water source area show an upward trend from 2020 to 2022, and the overall change trend is the same as that of ecological compensation prices of regions. As the calculation of ecological compensation amount needs to comprehensively consider the compensation price, water quality, and quantity, the compensation prices and amount in some regions do not match very well. For instance, the compensation prices of water resources in Sanmenxia are predicted high with a relatively low compensation amount. And the compensation prices of water resources in Shangluo are in the opposite situation that the compensation prices of water resources are predicted low with a relatively high compensation amount.

The annual compensation amount in the water source area from 2020 to 2022 will be the highest in Shangluo and the lowest in Hanzhong. According to the prediction results, the ecological compensation amount from 2020 to 2022 is divided into three gradients. The first gradient will include Ankang and Nanyang, with the compensation almost in the range of 0.5–1 billion yuan. The second gradient will include Shiyan, Hanzhong, and Sanmenxia, whose compensation is in the range of 1–2 billion yuan. The third gradient will include Shangluo, with the compensation in the range of 2–4 billion yuan. In 2021, the epidemic has affected the production and life of residents, resulting in reduced water demand. Therefore, the growth trend of ecological compensation amount in some regions slowed down or even fell back, which was also reflected in the prediction results.

4 DISCUSSION
4.1 Trend Analysis of Water Resources Value
By comparing the historical data and the calculation results of water resources value of core regions in the water source area, it can be seen that the change of water resources value in the water source area had experienced three stages.

TABLE 6 | Amount of ecological compensation for regions in water source areas in 2020–2022. Unit: 10^9 yuan.

Year/Region	Shiyan	Hanzhong	Ankang	Shangluo	Nanyang	Sanmenxia
2020	1.036	0.477	0.802	3.169	0.418	0.827
2021	0.691	1.381	0.905	2.509	0.975	1.348
2022	1.439	1.099	1.438	3.651	1.689	1.389

4.1.1 Initial Rising Stage of Water Resources Value

The first stage is from 2000 to 2005, during which the reservoir area had suitable climate, abundant water resources, and suitable ecological environment. The value of water resources was relatively stable and low, basically at V_1 or V_2 levels. The Middle Route project started in 2005. To make the water quality reach the high level, polluting enterprises have been rectified or even shut down. The value of water resources was coming into focus and increased obviously since that year.

4.1.2 Unstable Change Stage of Water Resources Value

The second stage is from 2006 to 2013. At the end of 2008, the Danjiangkou Reservoir area immigration pilot was officially launched. As of September 2010, there were 65,000 immigrants and the poor population increased. The Middle Route of the SNWDP was completed in 2013 and was put into operation by the end of 2014. Although experiencing the dual pressure of natural environment and social-economic development, the value of water resources in the water source area generally showed a trend of declining first and then rising with the emergence of importance of the Middle Route project to the allocation of national water resources.

4.1.3 Steady Rising Stage of Water Resources Value

The third stage is from 2014 to 2019, during which the value of water resources in the water source area was basically at V_3 or V_4 levels, and the value of water resources kept rising gently. To protect the water quality of the water source area, the State Council has successively approved a number of plans related to water pollution prevention, and soil and water conservation in Danjiangkou reservoir area, so as to ensure that the water environment of the core water source area can be at high level.

4.2 Analysis on Price Difference of Water Resources Ecological Compensation for SNWDP

The compensation prices in regions have produced obvious differences (**Table 7**). The average compensation prices of regions in the water source area could be obviously different due to the diversity of natural environment, social and economic development. Among regions with the average compensation prices less than 1 yuan/m^3, we take Hanzhong as an example for analysis. Hanzhong is located in the basin with abundant rainfall. It is the water conservation area of the water diversion project and the birthplace of the Han River. Covering an area of 27,247 square kilometers, Hanzhong is the largest city in the water source area

of the Middle Route project, with a permanent population of 3.437 million in 2019. Per capita water consumption in Hanzhong reaches 450 m^3, ranking first among regions in the water source area. The industrial pillars of Hanzhong are equipment manufacturing, modern materials, and green food and medicine. Among the three regions in southern Shanxi, Hanzhong is least affected by the water transfer project. Therefore, the compensation price of Hanzhong is low. Among regions with average compensation prices between 1 and 2 yuan/m^3, Shangluo is taken as an example for analysis. As a northern city in the water source area, Shangluo covers an area of 19,851 square kilometers and has a permanent population of 2.38 million in 2019. The annual water transfer of Shangluo accounts for more than 20% of the total planned water transfer of the SNWDP, slightly lower than that of Ankang. In recent years, the ecological environment quality has been improved significantly, and the registered urban unemployment rate of Shangluo has stabilized at around 3%. The relocation of migrants and re-employment problems has been properly dealt with as well. Owing to the abundant rainfall and the increase of total water resources in Shangluo, the value of water resources will not be very high in the next few years. Among regions with average compensation prices higher than 2 yuan/m^3, we take Sanmenxia as an example for analysis. Sanmenxia belongs to the eastern extension of loess Plateau, and the problem of soil erosion is serious. With an area of 10,309 square kilometers, Sanmenxia is the smallest city in the water source area of the middle Line project, with a resident population of 2.28 million. The rainfall is at low level in the regions of the water source area, and the amount of water resources is less than other regions. The construction of water diversion project and water environment improvement have led to the closure of a large number of seriously polluting enterprises, increasing the poor population and the unemployment rate. The economic development is seriously affected by the water transfer project. Therefore, the compensation price is relatively high.

4.3 Measures to Improve the Accounting System of Ecological Compensation in Water Source Area

To establish a market ecological compensation accounting system in line with the water source area of the Middle Route, the following countermeasures and suggestions are put forward. First, establish and improve the legislation of ecological compensation in water source area, and define the subject and scope of accounting according to law. Ecological compensation in water source area is a long-term and arduous task. The object, scope, method, and standard of compensation should be

TABLE 7 | Average ecological compensation price of core cities in water source area in 2020~2022.

Ecological compensation price range	City
Less than 1 yuan/m^3	Hangzhong, Ankang, Nanyang
Between 1 and 2 yuan/m^3	Shiyan, Shangluo
Above 2 yuan/m^3	Sanmenxia

established in legal form, which can lay a legal foundation for the appropriate and sustainable development and utilization of the water resources and environment. The second is to establish the ecological compensation distribution accounting system in water source area. On the basis of establishing the standard of water price and water resources fee which is in line with the common interests of water source area and water receiving area, the differences of natural environment, productivity level, technological level, capacity, and scale of ecological protection input should be comprehensively considered to determine the allocation amount of ecological compensation. Taking the problem of soil erosion in southern Shanxi as an example, the rate is 44.6% in Hanzhong, 53% in Ankang, and 66% in Shangluo. The control expense of soil erosion in Shangluo is obviously higher than that in the other two regions. If such factors are not fully considered in the allocation of compensation, the enthusiasm of ecological protection in Shangluo would be reduced and the effect of compensation incentive cannot be achieved. The third is to introduce market mechanism and fully consider the specific situation of resource taxes and fees in water source area when calculating the compensation amount. In 2016, Beijing, Tianjin, Henan, and other regions became the pilots of water resources tax reform in China, with the water resources tax rate ranging from 0.4 yuan/m^3 to 1.8 yuan/m^3. When forecasting the amount of ecological compensation, the water-receiving area should make market compensation for the water source area according to the water resources tax rate of the water source area as reference.

5 CONCLUSION

Based on the relevant data of regions in the core water source area of the Middle Route of SNWDP from 2000 to 2019, this paper uses value of water resources accounting as the entry point of compensation accounting to predict the ecological compensation amount of the Middle Route water source area from 2020 to 2022. The main conclusions are summarized as follows:

1) Based on entropy weight method and K-means clustering, the value of water resources assessment model is constructed to calculate the value of water resources from 2000 to 2019 in the water source area. The results reveal that the value of water resources of the six core regions in the water source area has an overall upward trend, and the value growth curve of regions is slightly different. 2) Based on the value of water resources and its dynamic changes, the ecological compensation payment standard

is established, and the value of water resources in the water source area from 2020 to 2022 is predicted by using the LSTM neural network model. It is found that the value of water resources in the water source area will increase in the future, and the number of the high value regions will increase. 3) The ecological compensation amount from 2020 to 2022 in the water source area is predicted. For example, in 2020, among the six regions in the water source area, the highest and lowest ecological compensation amounts are expected to reach 3.651 billion yuan in Shangluo and 0.418 billion yuan in Nanyang. To maintain the sustainability of the water transfer project, it is necessary to establish the ecological compensation accounting system in line with water source area of the Middle Route.

Water source area is a concept of geographical region. This paper takes the main regions in the water source area as the research scope, including Ankang, Hanzhong, and Shangluo in Shanxi Province, Shiyan in Hubei Province, Nanyang and Sanmenxia in Henan Province. Some regions (e.g., Baoji) are not included in the analysis. After consulting information from various sources, it is found that there are differences between administrative region and geographical region. However, the statistical data adopted in this paper are mostly divided by administrative regions, and less by geographical regions. Therefore, it is impossible to accurately calculate the value of water resources and ecological compensation amount within geographical regions. The calculation of the relevant data within the geographical regions shall be analyzed after the water source area is divided into independent administrative units.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://www.stats.gov.cn/tjsj/ndsj/; http://slt.henan.gov. cn/bmzl/szygl/szygb/; http://slt.hubei.gov.cn/sjfb/; http://slt.shaanxi. gov.cn/site/sxsslt/search.html?keyWord=%E6%B0%B4%E8%B5% 84%E6%BA%90%E5%85%AC%E6%8A%A5.

AUTHOR CONTRIBUTIONS

JC: Conceptualization, Methodology, Formal analysis, Investigation, Validation, Writing-original draft, Writing-review and editing. QW: Conceptualization, Super-vision, Writing-original draft, Writing-review and editing. QL: Resources, Data curation, Software, Visualization.

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