Identification of regional water security issues in China, using a novel water security comprehensive evaluation model

Jiping Yao, Guoqiang Wang, Baolin Xue, Gang Xie and Yanbo Peng

ABSTRACT

In order to solve regional water security issues, such as shortage of water resources, the aggravation of water pollution, the destruction of the ecological environment, etc., this study proposed the flood control security index, resource security index and ecological security index, respectively, according to the construction principle of human development index. Based on the above security indexes, a novel water security comprehensive evaluation model is established by combining the coupling coordination degree model and the state space model. The proposed model has the advantage of simple operation and fast data speed, which is convenient for water security evaluation in different periods and regions. Taking China as an example, the water security conditions were evaluated from 2007 to 2016 for 31 provincial-level administrative regions in China, including flood control security index, resource security index, ecological security index and water security level of each region, and the specific problems of water security in each region were obtained. The evaluation results are consistent with the actual situation in each region, which provides the scientific basis for the local government authorities to formulate the corresponding regional water security policy.

Key words | ecological security index, flood control security index, regional water security, resources security index, water security evaluation model

INTRODUCTION

Water is essential for maintaining the balance of life and the living environment. It is a basic natural resource and strategic resource to promote human economic development and social progress (Masseroni et al. 2019; Wang et al. 2019; Yao et al. 2019a, 2019b). Water security refers to the capacity of water resources with quantity and quality guarantee required for human survival and development, which can maintain the basin sustainability and human and ecological environment health, and ensure people’s life and property from water disasters (floods, landslides and droughts) (Ren et al. 2012; Fang et al. 2018a; Wang et al. 2018, 2019a; Yang et al. 2016; Yao et al. 2019c). However, in recent years, frequent floods, water shortage, pollution and water ecological damage have become serious global challenges (Parry et al. 2012; Emam et al. 2015; Awan et al. 2016; Han et al. 2018; Liu et al. 2018a; Ledingham et al. 2019). In 1972, the United Nations Conference on Environment and Development predicted that a water crisis would take place following the oil crisis (Biswas 1999). In 2000, the Hague and the World Water Week took ‘water security in the 21st century’ as the theme of the world Ministerial Level Conference (Falkenmark 2002). In 2009, United Nations Educational, Scientific and Cultural Organization pointed out in its World Water Resources Development Report that the contradiction between supply and demand of water resources in human society is more prominent,
coupled with climate degradation and rapid population growth, which leads to more serious water security problems (Russo et al. 2014; Jiang 2015; Kumar 2015; Li et al. 2016; Fang et al. 2018b). Therefore, it is necessary to study water security and propose solutions to related issues from different perspectives.

Many scholars study water security and related issues from different perspectives. Harris & Kennedy (1999) pointed out that urban water supply should be integrated into the actual urban development planning from the perspective of water supply, and further explored the evolution of urban water security. Rijsberman & van de Ven (2000) revealed the development of urban water security from a new perspective of water resources carrying capacity. Sullivan (2002) proposed a water poverty index similar to the Consumer Price Index to reflect the water shortage on human beings. Falkenmark & Lundqvist (2009) paid attention to the water quantity problem, comprehensively considering the shortage of natural water resources and water quality shortage caused by water pollution, and provided a more objective and real basis for local relevant departments to formulate water security protection policies. Ou et al. (2012) used the established entropy weight-fuzzy matter element model to evaluate the rural water safety situation, which effectively reduced the influence of uncertainty and fuzziness in the evaluation process on the authenticity of water safety. Tian & Gang (2012) used the pressure state response conceptual model to evaluate regional water security from the perspective of ecological security. Norman et al. (2013) evaluated the water security situation of a community in Canada with the method of water security index evaluation, and obtained good results. Considering the uncertainty of drought events, Dong & Xia (2014) introduced the Dempster Shafer evidence theory and evidence reasoning algorithm to assess the risk of water security during drought. Gain et al. (2016) put forward a framework that can quantitatively reflect the impact of human activities and natural water resources on water security by combining the factors that affect freshwater resources with the factors of social and economic development. Larson (2017) took water security as the leading mode to study natural resource policy, and comprehensively explored the situation of human water security by combining climate change with other pressing global sustainable development challenges. Actually, the water security issues are caused by the comprehensive influence of society, economy, resources, environment and ecology (Awan et al. 2016). However, at present, the water security evaluation is only based on the characteristics of the research area or the focus of the research problem, and puts forward the methods to solve the water security problem from different angles. The theory and methods of water security evaluation are not comprehensive enough, and the universality of the proposed evaluation method is relatively low.

In the 1990 Human Development Report, the United Nations proposed the Human Development Index (HDI), which comprehensively reflects the level of human development among different countries and regions by using three variables: human life index, education level index and GDP index (Kawada et al. 2019). The index plays an important role in guiding the development strategies of developing countries. Therefore, this paper puts forward a flood control security index, resource security index and ecological security index similar to HDI from flood control, resources and ecology, and establishes an evaluation model that can comprehensively reflect the regional water security situation. The water security of the 31 provinces of China is analyzed and evaluated by the proposed water security evaluation model, and the distributions of flood control security index, the resource security index and the ecological security index are respectively obtained. Additionally, the distributions of water security index which can comprehensively reflect the water security status of each region are obtained. All of the above indexes provide a scientific and reliable basis for a comprehensive understanding of water security problems in various regions of China and for the formulation of targeted strategies to solve water security problems.

MATERIALS AND METHODS

Study area and data

According to the three key factors of water security, namely flood control security, resource security and ecological security, the current situation and changes of water security
in China from 2007 to 2016 are comprehensively evaluated. In this paper, 31 administrative regions in mainland China are taken as the research units of regional water security to study the temporal and spatial evolution of water security in China (Figure 1), and the key factors affecting the water security status of China and each research unit are analyzed. Due to the lack of relevant data, Taiwan, Hong Kong and Macao were not included in the study. The dataset of this study came from the China Water Conservancy Bulletin, China Water Development Statistical Yearbook, China Statistical Yearbook, China Environmental Statistical Yearbook and the China Flood and Drought Disaster Bulletin during the period 2007–2016 (Liu et al. 2018a).

Methods

Determination of security indexes of the regional water security evaluation model

Based on the three key factors of flood control safety, resource security and ecological security, which can comprehensively reflect the regional water security, this paper establishes the flood control security index, resource security index and ecological security index respectively. The three indexes are used to establish the water security evaluation model. The specific calculation methods are discussed below.

The key points of flood control security are casualties caused by flood, economic loss of water conservancy facilities and disaster area loss caused by flood in the region. Therefore, the flood control security index (FS) established includes three data sets: loss rate of disaster area $R_a$, regional flood disaster population rate $R_c$ and the ratio of economic loss of water-saving facilities to direct economic loss $R_e$, which reflects the regional social development water. The specific calculation formula is as follows:

$$\begin{align*}
R_a &= \frac{R_{ad}}{R_{as}} \\
R_c &= \frac{R_{cf}}{R_{cp}} \\
R_e &= \frac{R_{ew}}{R_{ed}}
\end{align*}$$

(1)

where $R_{ad}$ denotes flood damage areas (km$^2$), $R_{as}$ denotes flood disaster areas (km$^2$), $R_{cf}$ denotes the number of flood-affected population (10,000 people), $R_{cp}$ denotes the number of population affected by disasters (10,000 people), $R_{ew}$ denotes economic loss of water-saving facilities.
in floods (100,000,000 yuan), \( R_{ed} \) denotes direct economic losses in floods (100,000,000 yuan). Since floods are driven by disasters caused by natural and human events, the five-year moving average value is calculated based on the above data to reduce the impact of the annual flood control security index. The regional flood control security index (FS) is defined as:

\[
FS = \begin{cases} 
1, & R_i \leq 0.01 \\
0.2 - 0.4 \times \frac{\sum \log R_i}{3}, & 0.01 < R_i \leq 0.1 \\
0.3 - 0.3 \times \frac{\sum \log R_i}{3}, & 0.01 < R_i \leq 1 \\
0, & R_i > 1 
\end{cases} \quad (i = a, c, e)
\]

The resource security index (RS) reflects the coordination between the per capita water resources, urbanization level, and rural development level, and water supply capacity. The index reflects the relative guarantee strength among regional basic resources, economic development level, and water supply capacity. The resource security index (RS) includes per capita water resources, urbanization rate, and per capita water demand, and its calculation formula is as follows:

\[
RS = \begin{cases} 
1, & W_r \geq 2W \\
1 - \left( \frac{1}{3} \times [(1 - W)^2 + (1 - U)^2 + (1 - C)^2] \right)^{1/2}, & W_r < 2W 
\end{cases} \quad (3)
\]

where \( W \) denotes the normalized water resource factor (see Equation (4)), \( U \) denotes the urbanization rate (%), and \( C \) is the per capita water storage capacity.

\[
W = \begin{cases} 
1, & W_r > 2W \\
\frac{\log W}{\log \frac{W_r}{W_{r\text{min}}}}, & W_{r\text{min}} < W_r \leq 2W \\
0, & W_r \leq W_{r\text{min}} 
\end{cases} \quad (4)
\]

where \( W_r \) denotes the per capita water resources volume, \( W \) is the global per capita water resources volume (6,123 m³), and \( W_{r\text{min}} \) is the lower limit of global per capita water resources volume. The per capita water resources of Israel (a country with a serious water shortage), 97 m³, is taken as the lower limit of per capita water resources in this study (Liu et al. 2018b).

The ecological security index (ES) focuses on the environmental conditions related to water, which reflects the security of water ecology through the ecological conditions of rivers, lakes, and reservoirs. The index includes the ratio of the length of a river above Class III to total river length (\( RW \)) and the ratio between the number of non-eutrophication lakes to the total number of lakes (\( RE \)). The calculation formula for the ecological security index (ES) is as follows:

\[
ES = \sqrt{\frac{RW^2 + RE^2}{2}} \quad (5)
\]

**Construction of regional water security model**

Based on the flood control security index, resource security index and ecological security index, the water security index is proposed to reflect regional water security. Due to the complementary relationship among flood control, resources and ecology (Wilkinson & Bathurst 2008), this paper introduces the coupling coordination model (Cheng et al. 2019) to characterize the interaction between flood control, resources and ecology, and the specific calculation formula is as follows:

\[
\begin{align*}
D_{FS-RS} &= \sqrt{\frac{FS \times RS}{(FS + RS)^2}}^{1/2} \times (a \times FS + b \times RS) \\
D_{RS-ES} &= \sqrt{\frac{RS \times ES}{(RS + ES)^2}}^{1/2} \times (b \times RS + c \times ES) \\
D_{FS-ES} &= \sqrt{\frac{FS \times ES}{(FS + ES)^2}}^{1/2} \times (a \times FS + b \times ES)
\end{align*} \quad (6)
\]

where \( D_{FS-RS}, D_{RS-ES} \) and \( D_{FS-ES} \) respectively represent the coupling coordination degree of the interaction between the flood control security and the resource security, the coupling coordination degree of the interaction between the resource security and the ecological security, and the coupling coordination degree of the flood control security and the ecological security interaction. \( a, b \) and \( c \) are the undetermined coefficients of the flood control security.
index, resource security index and ecological security index respectively, the value of which should be \( a = b = c = \frac{1}{2} \) (Cheng et al. 2019).

On the basis of the above-mentioned security interactions, the state space model (Li et al. 2019) is used to obtain a water security index (WSI) that can comprehensively consider the impact of flood control security, resource security and ecological security interaction on water security. Based on the above steps, a water security evaluation model is established. The specific calculation formula is as follows:

\[
WSI = \sqrt{\frac{D_{FS-RS}^2 + D_{RS-ES}^2 + D_{FS-ES}^2}{3}} \quad (7)
\]

In order to scientifically and effectively show the advantages and disadvantages of water security in various regions, this paper classifies water security into five levels: unsafe, relatively unsafe, general security, relative security and security according to the water security classification standard (Ren et al. 2017) (see Table 1).

**RESULTS AND DISCUSSION**

Considering that the flood control security index, resource security index and ecological security index are affected by interannual changes, only relying on the evaluation results of a single year to determine the current situation of water security in each region of the study area will lead to a large deviation between the evaluation results and the actual situation. Consequently, based on the average values of the water security evaluation indexes data for 2007–2016, the proposed water security evaluation model is used to obtain the flood control security index, the resource security index, the ecological security index and the water security index (Tables 2–4). The spatial distribution characteristics of water security status in 31 administrative regions of the study area were analyzed (Figures 2–5).

**Characteristics of flood control security in the study area**

Table 2 shows the average value of flood control security index (FS) of each administrative region in the study area
from 2007 to 2016, which is obtained from flood control security evaluation factors ($R_w$, $R_u$, $R_c$). Based on Table 2, the spatial distribution of the average flood control security index in the study area from 2007 to 2016 was obtained (Figure 2). The flood control security index for Heilongjiang, Shanghai, Jiangsu, Zhejiang, Henan and Shandong exceeds 0.6, which indicates that the flood control security level of these areas is higher. This is mainly due to the fact that these areas are prone to more rainfall and flood events, are more developed in society and economy, have more investment in infrastructure, and are more advanced in technology, so they have better performance in this regard (Liu et al. 2018b). On the contrary, the flood control security index of other provincial administrative areas is lower than 0.6, which indicates that the flood control security level in these areas is lower. In particular, the flood control security level of Xinjiang and Qinghai in the west of the study area is the lowest at 0.4088. This low level is due to the rare rainfall,
rare flood and insufficient flood control infrastructure in western China (especially the northwest) (Zhang et al. 2019). In this case, people are more vulnerable to floods and suffer more losses. These areas require a higher level of flood control alarms. Relevant government departments of the study area need to strengthen the unified management of water resources and flood control, and speed up the preparation or revision of emergency operation plans for flood control operation of important rivers. In addition, relevant departments need to speed up the formulation of water distribution plans and water conservancy renovation plans for major rivers, improve the unified dispatching management scheme, clarify the dispatching project and authority, and strengthen the flood risk management.

**Characteristics of resources security in the study area**

Resource security reflects the coordination of regional basic resources, economic development and water supply capacity. Table 3 shows the average value of the resource security index (RS) for each administrative region in the study area from 2007 to 2016, which was obtained from resource security evaluation factors (W, U, C). Based on Table 3, the spatial distribution of the annual average resource security index in the study area from 2007 to 2016 was obtained (Figure 3). In all administrative regions of the study area, the resource security index (RS) of Tibet is equal to 1, which indicates that the level of resource security in the region is very high. This is mainly due to the
relatively high per capita water resources in Tibet, which is twice as large as that in the rest of the world. In addition, the low urbanization rate, sparse population and relatively high per capita water resources in this area make Tibet have a superior resource security effect (Liu et al. 2018b). The resource security index (RS) of Qinghai, Hubei, Guangxi and Yunnan is higher than 0.6, which indicates that the resource security water in these areas is higher. The resource security indexes of Beijing, Tianjin, Hebei, Shanxi, Shanghai, Jiangsu, Shandong, Henan, Shaanxi and Gansu are lower than 0.4, which indicates that the resource security level of these areas is relatively low. This is mainly because the urbanization rate of Beijing and Tianjin is very high (U > 0.8), and the per capita water resources are scarce (W < 0.12), which leads to the lack of per capita water resources. Especially, the per capita water resources of Tianjin are lower than that of the world minimum standard of water resources per capita (97 m³). Additionally, the water supply capacity of Hebei, Shanxi, Shanghai, Jiangsu, Shandong, Shaanxi and Gansu is very low (C < 0.14). This indicates that the above-mentioned administrative regions are facing great challenges in resource security, these regions need to reasonably adjust the industrial structure, optimize the industrial layout, and improve the efficiency of water resource allocation according to the natural conditions and relevant development plans of water resources in each region.
Characteristics of ecological security in the study area

Ecological security fully reflects the water quality and ecological characteristics of rivers, lakes and reservoirs. Table 4 shows the average value of the ecological security index (ES) for each administrative region in the study area from 2007 to 2016, which was obtained from ecological security evaluation factors (RW, RE). Based on Table 4, the spatial distribution of the annual average ecological security index in the study area from 2007 to 2016 was obtained (Figure 4). The results show that the ecological security indexes of Beijing, Zhejiang, Jiangxi, Guangxi, Hainan, Guizhou, Shaanxi, Tibet, Gansu, Qinghai and Xinjiang all exceed 0.8, which indicates that the ecological security of these areas is at a high level. According to the data in the China Water Development Statistical Yearbook and China Water Resources Bulletin, the results of regional ecological security assessment during the period of 2007–2016 show that the above-mentioned areas have better environmental governance, and the proportion of rivers above class III and non-eutrophication lakes and reservoirs that meet the requirements of RW and RE is relatively large. However, the ecological security index related to water quality of rivers, lakes and reservoirs in Tianjin and Shanxi is lower than 0.2. This indicates that the ecological security of Tianjin and Shanxi is at a low level, which may be...
caused by the serious water pollution and eutrophication of lakes and reservoirs in these two areas. The ecological security index of Shanghai, Jiangsu and Ningxia varies between 0.2 and 0.4 and this indicates that the ecological security of these areas is at the general level. In addition, the ecological security index of the remaining areas is more than 0.5, which indicates that the ecological security of these areas is at a relatively high level. In general, since the release of the Water Pollution Control Action Plan by the State Council in April 2015, the water ecological security situation in the study area has been improved, and the water ecological environment protection has been strengthened (Liu et al. 2018b). In order to ensure the sustainable and healthy development of ecological security in the study area, the relevant departments of environmental protection need to formulate effective measures to reduce the total amount of pollutants, control the movement rate of pollutants, improve the efficiency of sewage treatment, realize the comprehensive treatment of major rivers, and improve the ecological security early warning system.

**Characteristics of water security in the study area**

Table 5 shows the average value of the water security index (WSI) for each administrative region in the study area from 2007 to 2016, which was obtained from FS, RS and ES. Based on Table 5, the spatial distribution of the annual average water security index in the study area from 2007 to 2016...
was obtained (Figure 5). The results show that the water security index of Guangxi is the highest among all administrative regions in the study area ($WSI = 0.7257$), which indicates that the water security in this area is in a safe state. The water security indexes of Zhejiang, Jiangxi, Hubei, Hainan, Guizhou, Yunnan, Tibet, Qinghai and Xinjiang vary from 0.6 to 0.8, which indicates that these areas are in a relatively safe state, while the water security indexes of Tianjin, Hebei, Shanxi and Ningxia are less than 0.4, which indicates that the water security of these regions is in an unsafe state. This is mainly due to the low level of resource security and ecological security in Tianjin, Hebei, Shanxi and Ningxia, which may be caused by the serious water shortage and low control rate of ecological water functional areas in these areas.

To sum up, the northern part of the study area (Beijing, Tianjin, Hebei, Shanxi and Inner Mongolia) suffers from serious water shortage, and the water quality of lakes and reservoirs is poor, which is reflected by the lower resource security index and ecological security index in these areas. The above problems are the main reasons for the unsafe water security in these areas. The northeast of the study area (Heilongjiang, Jilin and Liaoning) is relatively balanced in flood control security, resource security and ecological security, which leads to the overall high-water security index in these areas, and the water security is in a general state of security. The east part of the study area (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shanxi and Shandong) has strong flood control capacity and a high-water security index. However, the resource security level and ecological security level of Shanghai and Jiangsu are relatively low. The water security indexes of the central regions (Henan, Hubei and Hunan) in the study area are similar to that of the eastern regions. Henan is the most populous area in the study area, which leads to the most serious problem of resource shortage. The south (Guangdong, Guangxi, Hainan) and southwest (Chongqing, Sichuan, Guizhou, Tibet) of the study area have a high water security index, and the lakes, rivers and reservoirs in these areas have good water quality. The water security situation in the northwest of the study area (Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang) is generally good. However, Ningxia is facing relatively unsafe water resources and environmental conditions, which need more attention. The above conclusions are consistent with the published articles (Liu et al. 2018b; Wang et al. 2019c; Zhao et al. 2019), which indicates that the water security evaluation model proposed in this paper has scientific and reliable application value.

### CONCLUSIONS

Based on flood control security, resource security and ecological security, which can comprehensively reflect the water security indexes of regions in the study area from 2007 to 2016.

<table>
<thead>
<tr>
<th>Region</th>
<th>FS</th>
<th>RS</th>
<th>ES</th>
<th>WSI</th>
<th>Security level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>0.4258</td>
<td>0.2630</td>
<td>0.9124</td>
<td>0.5337</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Tianjin</td>
<td>0.4737</td>
<td>0.2303</td>
<td>0.0648</td>
<td>0.2563</td>
<td>Relatively unsafe</td>
</tr>
<tr>
<td>Hebei</td>
<td>0.5344</td>
<td>0.2496</td>
<td>0.4286</td>
<td>0.4042</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Shanxi</td>
<td>0.5636</td>
<td>0.2602</td>
<td>0.1901</td>
<td>0.3380</td>
<td>Relatively unsafe</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>0.4797</td>
<td>0.4434</td>
<td>0.5264</td>
<td>0.4832</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Liaoning</td>
<td>0.4629</td>
<td>0.4273</td>
<td>0.7723</td>
<td>0.5541</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Jilin</td>
<td>0.5137</td>
<td>0.5531</td>
<td>0.5654</td>
<td>0.5441</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>0.6020</td>
<td>0.5050</td>
<td>0.5521</td>
<td>0.5530</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Shanghai</td>
<td>0.6145</td>
<td>0.2603</td>
<td>0.3384</td>
<td>0.4044</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>0.7709</td>
<td>0.3051</td>
<td>0.2661</td>
<td>0.4474</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>0.6285</td>
<td>0.5490</td>
<td>0.8194</td>
<td>0.6656</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Anhui</td>
<td>0.5813</td>
<td>0.4141</td>
<td>0.5838</td>
<td>0.5264</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Fujian</td>
<td>0.5303</td>
<td>0.4938</td>
<td>0.7738</td>
<td>0.5993</td>
<td>Relatively unsafe</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>0.5549</td>
<td>0.5100</td>
<td>0.9690</td>
<td>0.6780</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Shandong</td>
<td>0.6385</td>
<td>0.2345</td>
<td>0.4646</td>
<td>0.4459</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Henan</td>
<td>0.6406</td>
<td>0.2990</td>
<td>0.5946</td>
<td>0.5114</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Hubei</td>
<td>0.5494</td>
<td>0.6572</td>
<td>0.7967</td>
<td>0.6678</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Hunan</td>
<td>0.5369</td>
<td>0.5056</td>
<td>0.6945</td>
<td>0.5790</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Guangdong</td>
<td>0.5410</td>
<td>0.4476</td>
<td>0.7645</td>
<td>0.5843</td>
<td>Generally safe</td>
</tr>
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<td>Guangxi</td>
<td>0.5634</td>
<td>0.6343</td>
<td>0.9795</td>
<td>0.7257</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Hainan</td>
<td>0.5750</td>
<td>0.5313</td>
<td>0.8141</td>
<td>0.6402</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Chongqing</td>
<td>0.5246</td>
<td>0.4268</td>
<td>0.7020</td>
<td>0.5511</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Sichuan</td>
<td>0.5253</td>
<td>0.4364</td>
<td>0.7823</td>
<td>0.5813</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Guizhou</td>
<td>0.5197</td>
<td>0.5030</td>
<td>0.9118</td>
<td>0.6448</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Yunnan</td>
<td>0.4712</td>
<td>0.6399</td>
<td>0.7716</td>
<td>0.6276</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Tibet</td>
<td>0.4661</td>
<td>0.4622</td>
<td>0.9974</td>
<td>0.6419</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Shaanxi</td>
<td>0.4707</td>
<td>0.3364</td>
<td>0.8550</td>
<td>0.5540</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Gansu</td>
<td>0.4929</td>
<td>0.3148</td>
<td>0.8832</td>
<td>0.5656</td>
<td>Generally safe</td>
</tr>
<tr>
<td>Qinghai</td>
<td>0.4088</td>
<td>0.6879</td>
<td>0.9875</td>
<td>0.6947</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Ningxia</td>
<td>0.4464</td>
<td>0.2363</td>
<td>0.2597</td>
<td>0.3141</td>
<td>Relatively unsafe</td>
</tr>
<tr>
<td>Xinjiang</td>
<td>0.4088</td>
<td>0.5131</td>
<td>0.9984</td>
<td>0.6401</td>
<td>Relatively safe</td>
</tr>
</tbody>
</table>
security situation, this paper establishes the corresponding security indexes, and uses the coupling coordination model and state space model to organically combine these security indexes, and constructs a water security comprehensive evaluation model. The proposed model is used to study the flood control security, resource security and ecological security of each administrative region in 2007–2016 in China. The water security level of each administrative region in the study area is characterized according to the above-mentioned security and the water security issues between each region are analyzed and compared by using the water security level. The results show that, in terms of flood control security, except for the relative security of Heilongjiang, Shandong, Henan, Jiangsu, Shanghai, Zhejiang, the flood control security capacity of other administrative regions needs to be further improved. In terms of resource security, Beijing, Tianjin, Hebei, Shanxi, Shaanxi, Gansu and Ningxia have a relatively low level of resource security due to their low resource base conditions, these areas need to improve the efficiency of resource utilization and establish a sound resource security system. In addition, the uncoordinated level of resources, population and economic development in Shanghai, Jiangsu, Shandong and Henan also leads to the relatively low level of resource security, these areas need to establish appropriate resource optimization allocation programs to improve the coordination between social and economic development and resource utilization. In terms of ecological security, the level of ecological security in Tianjin, Shanxi, Shanghai, Jiangsu and Ningxia is relatively low, so it is urgent to strengthen the restoration and protection of ecological water environment in these areas. Compared with the traditional water security evaluation system, which needs multi-layer design, a complex calculation method and different evaluation indexes, the water safety evaluation model proposed in this paper has clear theory, simple structure, easy interpretation, strong robustness, and good promotion and application.

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