Water Shortage Risk Assessment in the Haihe River Basin, China

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Abstract: This paper studies water balance in the Haihe River Basin, China and assesses water shortage risk for the period 1994–2007. The authors identify that there is a water shortage problem in this area and propose that the non-intake water consumption (NIWC) is a very important water balance element. The NIWC in the Haihe River Basin flow is $5.91 \times 10^9$ m$^3$ in normal years. It was concluded from our evaluation that the water shortage risk during 1994–2007 was very high. Using international water risk assessment theory, multiyear risk indicators in Haihe River Basin can be calculated. Water risk rate, resiliency, stability, and vulnerability for the Haihe River Basin for the period 1994–2007 were 0.786, 0.000, 0.154 and 0.173 respectively. With the use of counter-force factors and adoption of different priorities to different water consumers, the water shortage risk can be decreased. The integrated water shortage risk indicators of the Haihe River Basin are 0.095-0.328. In this study, water availability from the South–North Water Diversion Project is also considered. By the year 2014, about $5 \times 10^9$ m$^3$ of water will be diverted from the Yangtze River, and the water shortage risk in the Haihe River Basin will drop from 0.229-0.297 to 0.152-0.234 under an inflow water frequency of 50%-75%. However, a risk of water shortage in this area will persist.

Key words: water risk; assessment; water shortage; Haihe River Basin; non-intake water consumption

1 Introduction

Water resources are important strategic resources and play a key role in the development of national economies. Water security has become a core concern for the development of the world in the 21st century. The study of water supply security is now the key field of water science (Wang 1994; Wang and Zhu 2002; Liu and Shao 2005; Zhang and Chen 2009). Since the concept was first presented in 1982, research on water shortage risk assessment in cities and arid regions has been undertaken around the world. Water shortage risk and water environment risk are now major focal areas for water risk studies. China is a water scarce region, especially in the north, where Beijing is located. This area has a large population and fast developing industry. The study of water shortage risk in Haihe River Basin of north China has aroused great attention in world academic circles as well as in China (Zhang et al. 2003; Wu 2007).

The study of water risk includes risk identification, risk evaluation and risk decisions. To analyze water balance issues in a specific region, the effective and fundamental way is to consider a river basin as the analytical unit. The study on this system is then divided into analyses of risk-causing factors and counterforce factors. Here, we establish a system to identify and evaluate water shortage risks in the Haihe River Basin and consider the impacts of South-to-North water diversion to the Haihe River Basin. Last, we then provide some measures to lessen water shortage risks. The study will be useful to the social and economic development of the region.

2 Water balance in Haihe River Basin

2.1 Water resource situation

The Haihe River Basin is a major watershed in north China (Fig. 1). Its drainage area is $3.18 \times 10^5$ km$^2$; the multiyear average rainfall is 535 mm; water resource amount is $3.70 \times 10^{10}$ m$^3$ including annual runoff of $2.16 \times 10^{10}$ m$^3$. Water security (especially water deficit) in this region was neither threatened nor of concern before the 1970s. With
social and economic development in the 1908s, water demand has been increasing and water resource scarcity has become an important issue. By the year 2007 per capita water resource in Haihe River was less than 300 m$^3$, approximately 4%–5% of the world average.

The China Water Resources Bulletin has been published annually since 1994. The hydrological series of 1994–2007 was selected as the study period, then a comparative analysis undertaken with the period of 1956–2000, which provides officially established standards (Ren 2007). The study reveals that at the turn of the century, water shortage was serious and that water shortage risk occurred frequently. There are three reasons to explain this.

First, climate change has brought about a decline in precipitation. In recent years, rainfall has been less than the long-term average. The average annual rainfall in 1994–2007 was 494 mm, a decrease of 7.6% compared to the 1956–2000 average. Second, there have been significant changes to the ground pad caused by human activities. With rainfall changing by as little as 7.6%, and runoff has declined by 28.7%. Third, the demand on water resources increases quickly. With the development of industry and population growth, the water intake amount is more than the multi-year average, and the water consumption increases at the same rate.

Increased abstraction of surface water and increased extraction of groundwater are major tactics employed to meet regional water demands. As a result, essential ecological water flows in the rivers are drying up, and the groundwater table in the Haihe River Basin is now 20 m lower than in the 1960s. Statistics show that the runoff discharge to sea has sharply reduced from 10–12 billion m$^3$ on average (56% of the natural runoff) to about 4 billion m$^3$ (19% of natural runoff) in 1994–2007. There was almost no runoff discharged into the sea in some years during the 1990s. Emergency water transfers from the Yellow River to the Haihe River in some years was used as an additional way to address water shortage problems. A new water engineering project named the South to North Water Diversion is currently under construction and will transfer 30 billion m$^3$ of water to north China annually. By 2030, 8 billion m$^3$ will be allocated from the Yangtze River to the Haihe River Basin as a permanent measure to address this water problem.

2.2 The water balance and non-intake water consumption (NIWC)

The water balance in Haihe River Basin can be stated as follows:

$$W+W'=Y_1+Y_2+\Delta W_g+\Delta W_k+Q$$

(1)

where $W$ represents water resources amount in a watershed; $W'$ is water amount transferred from another basin, and it is the water amount transferred from Yellow River basin to Haihe River Basin in this case; $Y_1$ is water consumption, including domestic and industrial water consumption; $Y_2$ is the non-intake water consumption (NIWC), which includes loss through percolation, phreatic evaporation, and water body evaporation such as river, lake, and wetland; $\Delta W_g$ is the yearly water amount changes of the groundwater aquifer; $\Delta W_k$ is the yearly water amount changes of reservoir storage; $Q$ is the water discharge into sea.

The concept of NIWC, which is not included among conventional water balance elements, is presented in formula (1). NIWC has always been taken as a calculation error rather than a key water balance factor. However, this is not only a significant factor in arid and semi-arid
regions, but also a theoretically essential element in water balance principles. Therefore, NIWC should be included in the water balance equation.

The NIWC in Haihe River Basin is therefore expressed as:

\[ Y_z = W^g + W' - Y_1 - \Delta W_3 - \Delta W_5 - Q \]  

(2)

Using data from 1994–2007 for the Haihe River Basin, the non-intake water consumption in the area can be calculated (Table 1).

Based on the results of calculation and analysis, a significant correlation can be identified between the NIWC and rainfall. The fitted formula is as follows:

\[ Y_2 = 0.2227P - 60.075, \quad r^2 = 0.7182 \]  

(3)

where \( P \) is the annual precipitation. According to the formula (3), using multi-year average rainfall indicators, non-intake water consumption is calculated at 5.91×10^9 m^3 for a normal year. This amount of water is the result of percolation loss, phreatic evaporation and water body evaporation under the multi-year average rainfall (535mm).

This figure is close to the 5.94×10^9 m^3 non-intake water consumption in 2004 (rainfall was 538mm).

The concept of NIWC can be illustrated by formula (3). NIWC is unstable and it varies in relation to climate parameters. Precipitation is the main factor influencing NIWC. The higher the precipitation, the greater NIWC is maintained and the balance between supply and demand will be satisfied; if not, the balance will not be maintained and the water supply system will be safe; if not, water shortage problems will be present.

Table 1 Water balance of Haihe River Basin.

<table>
<thead>
<tr>
<th>Year (mm)</th>
<th>( P ) (10^9 m^3)</th>
<th>( W ) (10^9 m^3)</th>
<th>( W' ) (10^9 m^3)</th>
<th>( \Delta W_3 ) (10^9 m^3)</th>
<th>( \Delta W_5 ) (10^9 m^3)</th>
<th>( Q ) (10^9 m^3)</th>
<th>( Y_1 ) (10^9 m^3)</th>
<th>( Y_2 ) (10^9 m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>577</td>
<td>42.62</td>
<td>5.73</td>
<td>2.30</td>
<td>1.04</td>
<td>10.27</td>
<td>28.14</td>
<td>6.60</td>
</tr>
<tr>
<td>1995</td>
<td>609</td>
<td>44.05</td>
<td>5.23</td>
<td>0.86</td>
<td>1.40</td>
<td>10.81</td>
<td>27.20</td>
<td>9.01</td>
</tr>
<tr>
<td>1996</td>
<td>599</td>
<td>52.23</td>
<td>5.50</td>
<td>0.70</td>
<td>3.90</td>
<td>17.36</td>
<td>28.45</td>
<td>7.33</td>
</tr>
<tr>
<td>1997</td>
<td>366</td>
<td>21.21</td>
<td>5.64</td>
<td>-4.15</td>
<td>-0.80</td>
<td>1.40</td>
<td>29.09</td>
<td>1.30</td>
</tr>
<tr>
<td>1998</td>
<td>551</td>
<td>35.39</td>
<td>5.37</td>
<td>0.94</td>
<td>-0.70</td>
<td>5.41</td>
<td>28.06</td>
<td>7.04</td>
</tr>
<tr>
<td>1999</td>
<td>385</td>
<td>19.25</td>
<td>5.36</td>
<td>-2.18</td>
<td>-7.50</td>
<td>0.45</td>
<td>28.60</td>
<td>5.24</td>
</tr>
<tr>
<td>2000</td>
<td>490</td>
<td>26.96</td>
<td>4.01</td>
<td>0.02</td>
<td>-2.80</td>
<td>0.41</td>
<td>27.20</td>
<td>6.14</td>
</tr>
<tr>
<td>2001</td>
<td>417</td>
<td>20.02</td>
<td>3.87</td>
<td>-0.49</td>
<td>-5.40</td>
<td>0.08</td>
<td>26.89</td>
<td>2.80</td>
</tr>
<tr>
<td>2002</td>
<td>398</td>
<td>15.90</td>
<td>4.64</td>
<td>-1.66</td>
<td>-7.83</td>
<td>0.20</td>
<td>27.90</td>
<td>1.93</td>
</tr>
<tr>
<td>2003</td>
<td>582</td>
<td>32.11</td>
<td>3.61</td>
<td>1.11</td>
<td>1.98</td>
<td>2.20</td>
<td>25.32</td>
<td>5.11</td>
</tr>
<tr>
<td>2004</td>
<td>538</td>
<td>29.96</td>
<td>4.23</td>
<td>0.84</td>
<td>-1.81</td>
<td>3.71</td>
<td>25.51</td>
<td>5.94</td>
</tr>
<tr>
<td>2005</td>
<td>487</td>
<td>26.71</td>
<td>3.73</td>
<td>0.77</td>
<td>-3.80</td>
<td>2.49</td>
<td>26.63</td>
<td>4.34</td>
</tr>
<tr>
<td>2006</td>
<td>438</td>
<td>21.98</td>
<td>4.62</td>
<td>-0.90</td>
<td>-4.39</td>
<td>1.39</td>
<td>27.21</td>
<td>3.29</td>
</tr>
<tr>
<td>Avg.</td>
<td>494</td>
<td>29.51</td>
<td>4.71</td>
<td>-0.16</td>
<td>-2.13</td>
<td>4.13</td>
<td>27.37</td>
<td>5.00</td>
</tr>
</tbody>
</table>

With the water budget analysis on water cycle factors (Table 1), such as water supply, water consumption and water discharge, the results indicate during 1994–2007, total local water resource in the Haihe River Basin was 29.51×10^9 m^3 (water diverted from the Yellow river was 4.71×10^9 m^3); available water was 34.22×10^9 m^3; the amount of over-exploited ground water was 2.13×10^9 m^3; water released from the reservoir was 0.16×10^9 m^3; industrial and domestic water consumption was 27.37×10^9 m^3; water discharge into the sea was 4.13×10^9 m^3; and non-intake water consumption was 5.00×10^9 m^3.

### 2.3 Study on water shortage

The above research on water balance indicates that for 1994–2007 water discharge into the sea was 4.13×10^9 m^3, which was 19% of the runoff. The result also shows that there was an overexploitation of groundwater. These results indicate that ecological water demand was and is not being met.

There are many ways to identify the status of water shortages. We therefore present two indicators to demonstrate the situation of water shortage in a river basin (Zhang and Jia 2003). The first indicator is whether the ecological flow reaches the minimum eco-environment water demand standard; the second is whether groundwater volume is stable or increasing. If the two indicators are met, the balance between supply and demand will be maintained and the water supply system will be safe; if not, water shortage problems will be present.

The second indicator can be easily identified by the groundwater exploitation status. If the groundwater table is lower than the previous year there is groundwater overexploitation. For the first indicator, two aspects should be studied: the recognised international standards, and river basin condition. The international standard for an acceptable ecological flow rate is 40%–60% of natural runoff, but in the Haihe River Basin 30%–40% of the
annual runoff as ecological flow is adopted by local river authorities (i.e. $64.8\times10^8 \text{m}^3$). In dry years and extreme dry years, this designed ecological flow discharge into the sea is $64.8\times10^8 \text{m}^3$. In an average year or rich water year, the ecological flow discharge into the sea is $86.4\times10^8 \text{m}^3$.

As a key parameter to describe the water shortage status for a river basin, water deficit is used and it comprises two parts: the shortage of runoff into the sea and overexploitation of groundwater. Since there has been a serious overexploitation in the past 30 years, the accumulated groundwater deficit has reached $100\times10^8 \text{m}^3$. This groundwater deficit cannot be changed because of limited amounts of water recharge in some occasional years. The groundwater overexploitation in a certain year can be expressed by:

$$
\Delta W_g = \begin{cases} 
0 & \text{when } \Delta W_g \geq 0 \\
\Delta W_g & \text{when } \Delta W_g < 0
\end{cases}
$$

(4)

Therefore, the water deficit can be expressed as follows:

$$
D_w = D_q + \Delta W_g
$$

(5)

$$
\mu_w = D_q / (Y_1 + Y_2 + Q_0)
$$

(6)

where $D_w$ is the total water deficit; $D_q$ is the shortage of ecological flow; $\Delta W_g$ is the negative change of the groundwater aquifer; $\mu_w$ is the water shortage rate. $Q_0$ is the designed ecological flow.

Results reveal that the water deficit in the Haihe River Basin in 1994–2007 reached $96.47\times10^8 \text{m}^3$ (annual average $6.89\times10^8 \text{m}^3$) (Table 2), in which the ecological flow deficit was $58.31\times10^8 \text{m}^3$ (average $4.17\times10^8 \text{m}^3$). Across the 14 years, water balance was reached without water deficit in three years (1994, 1995 and 1996), and there were water shortage problems that could cause water supply risk in 11 years. The total water shortage rate was 17.3%.

3 Water risk assessment

3.1 Water risk index

To evaluate water system security accurately and objectively a set of evaluation indices is needed. In 1982, Hashimoto used reliability, resiliency and vulnerability to indicate different risk aspects. The risk rate was derived from reliability, and stability was derived from resiliency. These indices are widely accepted in water resource risk assessment (Hashimoto et al. 1982; Feng 1998; Fang et al. 2006).

Reliability indicates the relationship between supply and demand directly, showing whether the system is reliable or not. It can be measured by how the available water amount meets water demand. For a specific set of data, reliability is expressed by the following formula:

$$
a = m/n
$$

(7)

where $a$ is reliability; $m$ is the number of years when water demand is met; $n$ is the number of years counted.

Risk rate is the frequency or probability of water shortage. Risk rate can be indicated through the frequency that available water supply cannot meet water demand. Take Prob as the probability of the water scarcity, $X_i$ as the number of years counted, $F$ as the set of all unsatisfactory outputs, $S$ is the satisfactory outputs, and then the risk rate is expressed by formula (8):

$$
r = (n-m)/n = Prob(X_i \in F)
$$

(8)

Reliability and risk rate satisfy the following equation:

$$
r = 1 - a
$$

(9)
When water supply cannot meet demand, and water supply system undergoes risks. It is very important for the function of the system to recover in order to guarantee water security. Resiliency describes how quickly a water system is likely to recover from failure, once it occurs. Resiliency is an important indicator for risk assessment. It is given a precise mathematical definition by the probability $\eta$:

$$\eta = \text{Prob}(X_{i+1} \in S | X_i \in F)$$  \hspace{1cm} (10)

Stability is another important index to assess water shortage risk. Stability means the probability that water supply not only meets demand in a specific year, but the same pattern follows in the coming year. In other words, it is the probability that water supply meets demand in two consecutive years. Stability and resiliency are two alternative possibilities for the specific year when water supply meets the demand in the coming year. Stability ($\omega$) is expressed as follows:

$$\omega = \text{Prob}(X_{i+1} \in S | X_i \in S)$$  \hspace{1cm} (11)

Another important index to indicate water scarcity is vulnerability, which refers to the degree of the failure of water supply system. The more serious the water shortage, the greater the damage. Vulnerability can be described by $\mu$ which is the water shortage rate given by formula (6).

Based on the above equations, water risk rate $r$, resiliency $\eta$, stability $\omega$ and vulnerability $\mu$, for the Haihe River Basin in the period 1994–2007 was calculated respectively as 0.786, 0.000, 0.154, and 0.173.

The above calculation of water risk rate, resiliency, stability and vulnerability are based on an annual scale. When the period of statistical data is further divided into smaller segments such as a month or day we can calculate water risk on a monthly or daily basis. Generally speaking, if there is a water supply surplus in a year, then water demand is also satisfied over shorter time scales (monthly or daily). For a water supply deficit year, water supply cannot be met in some months or days while it still can be satisfied for the rest of the time. With the downscaling of the time period selected, the risk rate will be lower, and stability, resiliency will increase. Vulnerability will remain constant.

3.2 Water risk classification

When a water supply system is affected by those risk-causing factors, a counterforce ability system can be employed to reduce negative effects. For the same water shortage rate $\mu$, i.e., vulnerability, the impact of water shortage risk can be minimized through system regulation before or after the risk occurs. For example, under the effect of the system counterforce, different water consumers could get their water allocation from different water supply schemes at a different guarantee rate and different priority. The top priority of water supply should be given to key consumers such as domestic and industrial water users. In this case, with the same vulnerability, the assessed loss could be considerably reduced for the whole area. Since the assessed loss of lower ranked consumers is less than that of the higher ranked consumers with the same amount of water deficit, the above water risk assessment indices can be improved by considering the function of system counterforce. Therefore it is necessary to consider water use priorities when classifying water risk.

Water risk caused by water shortage can be classified into four levels:

The first level is water supply crisis in the eco-environment. Eco-environment water consumption demand is not met, rivers dry up and groundwater levels decline.

The second level is water supply crisis in agriculture. Not only is the eco-environment water demand not met, but the water supply for agriculture is also restricted in order to guarantee industrial water supply and domestic water supply.

The third level is water crisis in industry and living water in rural areas. In this situation, industrial and living water demands in rural areas is not met.

The fourth level is water crisis in industry and domestic water supply in urban areas. In some extreme dry years, the available water supply is far less than demand, so the water use even in the urban area will be restricted. This failure of water supply is an extremely serious crisis.

To assess the integrated water risk quantitatively (Table 3), the water consumers, including ecological, industrial and domestic demand, are divided into four levels according to the degree of water shortage.

Ecological water risk can be defined by the ratio of the actual ecological flow to stream runoff, and then modified by groundwater aquifer status. i.e., the ratio of $Q/R$, where $Q$ is the volume of ecological flow; $R$ is the volume of natural runoff, considering the characteristics of north China, $R$ consists of local water generation and the inflow from upper reaches. The ecological risk degree can be divided into low, middle, high and extremely high based on the ratio of $Q/R$, which is divided into four groups of 40% or above, 20%–40%, 10%–20%, and less than 10%. In order to arrive at an integrated assessment of water risk for the Haihe River Basin, the ecological water risk should be transformed from the above ratios to a certain group of indices.

Industrial water use risk can be defined by the ratio of the economic loss of gross domestic production (GDP) caused by water shortage. This ratio is divided into four grades: 0%–0.1%, 0.1%–0.2%, 0.2%–0.3% and above 0.3% to fit for low, middle, high and extreme levels.

Domestic water use risk is hard to evaluate quantitatively. It can be indicated by incidents of water supply failures and fluctuation due to water shortage. The
domestic risk degree is measured by the frequency of failure, degree of fluctuation and impact. In the operational processes of the regulation system the first priority should be given to domestic use of water, the second is industrial water use, and ecological water use ranks the third.

Taking 2007 as an example, total water available was $32.62 \times 10^9$ m$^3$ (including local water resources of $24.78 \times 10^9$ m$^3$, Yellow River water of $4.37 \times 10^9$ m$^3$, reservoir release of $0.33 \times 10^9$ m$^3$, and groundwater over exploitation of $3.14 \times 10^9$ m$^3$), in which ecological flow use took up $1.70 \times 10^9$ m$^3$, agriculture and industry accounted for $23.37 \times 10^9$ m$^3$, domestic water use was $3.56 \times 10^9$ m$^3$, the NIWC was $3.99 \times 10^9$ m$^3$. These data indicate that the ecological flow was only 7.9% of annual natural runoff. Therefore ecological water is seriously appropriated. Since domestic, industry and ecological water supply have been given different priorities the overall risk can be mitigated effectively.

In the study of Haihe River Basin, it is found that when water supply changes, ecological, industry and domestic water risks respond slowly since ecological water demand is always in shortage and industrial water use and domestic water use are always well guaranteed. Agricultural water use risk is sensitive to the fluctuation of water supply.

While higher priority is given to domestic and industrial water consumers, considerable importance should also be attached to those lower priority consumers such as ecological and agricultural users. Multiple risks coexist in the water supply system. It is hard to indicate the risk objectively with a single risk assessment index. Fuzzy matrices and fuzzy methods prove to be effective and are widely used to assess water system integrated risk (Ruan and Han 2005; Jin and Zhang 2005; Zhang et al. 2005).

In reality, domestic water supply is the highest priority (represented by $\alpha$), then industry and agriculture (represented by $\beta$), the last is ecological water use (represented by $\gamma$). Based on the analysis of ecological, industrial and domestic guarantee rate, the Integrated Water Guarantee (IWG) index is considered as the function of water consumption guaranteed degree:

$$IWG = \omega_1 \ast \omega_2 \ast \omega_3 \ast \alpha \ast \beta \ast \gamma$$

where $\omega_1$, $\omega_2$, and $\omega_3$ represent the weights of ecological, industrial and domestic water use to IWG. Since IWG has the same meaning as reliability, according to formula (9), the integrated water shortage risk index can be calculated.

### 3.3 The Haihe River Basin water risk assessment for 1994–2007

In order to assess water risk for the Haihe River Basin, the related water guarantee rates ($\alpha$, $\beta$ and $\gamma$) to domestic, industrial and ecological water use need to be calculated. Then the weights of the above three water guarantee rates should be given.

With an expert grading system, the weights of $\alpha$, $\beta$ and $\gamma$ are defined as 0.2, 0.35 and 0.45 respectively. The water guarantee index can be assigned to different sectors.

The values of ecological water guarantee assignment is based firstly on the ratio of ecological flow to average stream runoff. Second, there is modification of the assignment by a maximum of 20% on the groundwater overexploitation situation. Third, modification of the assignment by a maximum of 10% on the state of precipitation condition. Last, the ecological water use guarantee value is above 0.05.

The value of industrial and domestic water guarantee assignment: (i) industrial water use: 0.8–0.9; (ii) domestic water use: 0.85–0.95.
The water risk of Haihe River Basin in the period of 1994–2007 is therefore calculated as follows (Table 4). The above assessment results indicate that the integrated water risk in Haihe River Basin in the period of 1994–2007 is between 0.095–0.328. The years 1994–1996 witnessed low risk water supply; the years 1998, 2003–2004 middle risk; the years 1997, 2005–2007 high risk; and the years 1999–2002 extreme high risk (Table 5).

4 Discussion: Risk effects of water transfer from other basins

Our analysis indicates that there will be a high water security risk in this region without the transfer of water from other basins. Since the dry period starting in the 1990s, the situation of water shortage will further deteriorate if no Haihe River Basin water resource can be further exploited. Therefore, water transfer from the Yangtze River Basin to Haihe River Basin is very necessary to lessen water risk.

The Haihe River Basin will be supplied with $7\times10^9$ m$^3$ of water by the South-to-North Water Diversion project that is currently under construction. This additional water supply will relieve the crisis and effectively reduce water risk. By 2014, it is expected that $5.0\times10^9$ m$^3$ of water will be transferred by the first phase of this project. According to data from 1994–2007, water use is undergoing zero increment in northern China. At this rate, and with consideration of the natural water frequency of 50% (normal period) or 75% (mean dry period), the integrated water risks can be calculated as follows: when the frequency is 50% (2004) the integrated water risk is 0.152 in the Haihe River Basin, the risk being lessened from middle risk to low risk. At a frequency of 75% (2007), the integrated water risk is 0.234, the risk being reduced from high to middle risk.

This proves that the first phase middle route of the South-to-North Water Diversion project will be effective in reducing risk in this region, but that risk will persist. It is anticipated that risk will be reduced considerably with the second phase middle route project by the year 2030.

5 Conclusions

From analysis of the water resource situation in the Haihe River Basin in the period of 1994–2007, the following conclusions are possible:

(1) Average rainfall in 1994–2007 was 92.4% of the long term statistical average, runoff was 71.3% of the normal year and there was an average water shortage of $6.89\times10^9$ m$^3$.

(2) The non-intake water consumption (NIWC) is a very important water balance element. It includes loss through percolation, phreatic evaporation and evaporation from water bodies such as rivers, lakes and wetlands. The NIWC in the Haihe River Basin is $5.91\times10^9$ m$^3$ in a normal year; this figure was $5.00\times10^9$ m$^3$ in the period studied.

(3) Using the international water resources risk...
assessment formula, multi-year risk indicators in Haihe River Basin can be calculated. Water shortage risk indices during 1994–2007 were all very high in this region. Water risk rate, resiliency, stability and vulnerability for the Haihe River Basin from 1994–2007 were 0.786, 0.154 and 0.173, respectively.

(4) Under current conditions, different priorities have been attached to different water consumers: domestic water supply is firstly guaranteed, then industry and agriculture, and last is ecological water use. Risk will decrease under this scheme. The integrated water shortage risk indicators of the Haihe River Basin were 0.095–0.328.

(5) The Haihe River Basin will receive $5.0 \times 10^9 \text{m}^3$ of water from the South-North Water Diversion Project around the year 2014. Given the inflow frequency of 50%–75%, water shortage risk will drop from 0.229–0.297 to 0.152–0.234. The risk of water resource shortages in this area will, however, persist.

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