1. Introduction

The water stress has been rising in large cities of northern China since the 1980s. Even though some temporary solutions have been taken, the water scarcity problem is still serious [1]. To make balance of water availability in China, the South to North Water Transfer Project (SNWTP) was launched in 2002. About $44.8 \times 10^9$ m$^3$ of water will be diverted from the wetter regions of southern China to northern China annually. This project involves three routes, namely, the western, eastern and central routes, to the drier northern regions [2]. The main channel is so long that it spans several climate zones. The Diversion region and benefited region are affected by the climate condition, hydrologic characteristics and human activities. The precipitation and runoff possess the characteristic of wetness-dryness alternation and have great variation [3]. The wetness-dryness encountering means the combined event of dry and wet in different regions that is the result of the imbalance spatial-temporal distribution of water resources. The wetness-dryness alternation in diversion region may have influence on the transferable water and it may affect the water requirement and guarantee rate of water supply. However, the wetness-dryness encountering will affect the economic benefits of SNWTP [4, 5]. The worst condition of the project is that suffer from continuing drought in both diversion region and benefited region. There would be no enough water in diversion region and the water demands would increase in benefited region. Many methods have been used to quantify the characteristic of

Drought-waterlog encounter probability research between the diversion region and benefited region in the Middle Route of South-to-North Water Transfer Project

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Abstract. One of the major risk factors in managing water resources in the South to North Water Transfer Project will be due to spatial and temporal variations in precipitation. This is because the synchronous encounter probability of drought and waterlog can be different at the diversion region and benefited region. This study analyzed the statistical characteristic of drought and waterlog in the diversion region and benefited region and the wetness-dryness encountering probability among the diversion region and benefited region. Besides, the wetness-dryness encountering probability and the surface water resource in the diversion region were also projected based on the outputs of GCMs. The results showed that: (1) The concurrence of drought or waterlog in diversion region and benefited region is uncommon and it benefits the water transfer. (2) In the future, the synchrony of drought/waterlog will increase in wet season while it will decrease in dry season. But the synchrony of drought/waterlog between the north of Haihe River Basin and diversion region will decrease in the late spring, early summer and autumn. (3) The surface water resource is projected to be increased by 8.1~11.5% compared to the period from 1961 to 2011. The climate change in the future would benefit the water transfer.
wetness-dryness encountering probability in diversion region and benefited region. Feng et al took the Xianshui River, Zumuzu River, Zhuosijia River and the Yellow River as study areas. With the 4-dimensional joint distribution model, the wetness-dryness encountering probability among these regions was calculated. It can be found that the favorable probability for water transfer is 43.8-77.8% [6]. Zhang et al analyzed the drought-waterlogging encounter probability of water source area and Hai River receiving area and the results showed that the profitable frequency of the drought-waterlogging encounter for water transfer was 56.7%, and the disadvantageous frequency was 24.9% [7]. Kang et al (2011) found that the risk probability is less than 25% for water transfer to receiving areas (Tangbaihe River Basin, Huaihe River Basin, South of Haihe River Basin and North of Haihe River Bas) based on a risk analysis model [8]. However, there are three problems in the previous studies. More specifically, (1) most studies focus on the wetness-dryness encountering probability in terms of inter-annual variation. The study of variation within the year is scanty. (2) Previous researches only analysis the characteristic of wetness-dryness encountering through meteorological factor (eg. precipitation). Limited research considered the water source quantity in diversion region; (3) Most of the studies only focused on the historical characteristic of wetness-dryness encountering. In fact, climate change potential effects in future can be assessed with the outputs from GCMs.

The main argument presented here is analyzing drought-waterlogging encounter probability of water source area (Danjiangkou Catchment) and Haihe River Basin in the history and future. The results of this study will benefit the planning and management of the SNWTP.

2. Materials and methods

2.1. Study area

The water diversion of SNWTP is in Danjiangkou reservoir which is located in Hanjiang River. This water diversion project went through Fangchengyakou that is the divide of Yangtze River Basin and Huaihe River Basin. The diversion canal is excavated along the edge of the west of Huanghuaibai Plain and cuts through the Yellow River in Gubaiju by tunnel or aqueduct. Then the canal heads towards the north along the west side of Beijing-Guangzhou railway. The water can flow automatically to Beijing and Tianjin (figure 1). The area of benefited region is 1.5×10⁶ km². The water-transmission line from the Danjiangkou reservoir to TuanCheng Lake in Beijing is as long as 1267 km. The lengths of sections in south of Yellow River, crossing the Yellow River and in the north of Yellow River are 477 km, 10 km and 780 km. The length of section from Xushui, Hebei province to Tianjing is 154 km. This study focuses on the benefited region in Haihe River Basin, which is divided into three parts. The information of each part is listed in table 1.

![Figure 1. The route of SNWTP.](image-url)
Table 1. The cities in benefited region.

| Region           | City                                |
|------------------|-------------------------------------|
| Benefited region 1 | Nanyang, Pingdingshan, Xuchang, Zhengzhou |
| Benefited region 2 | Xinxiang, Hebi, Anyang, Handan, Xingtai |
| Benefited region 3 | Shijiazhuang, Baoding, Beijing, Tianjin, Langfang |

2.2. Data

The data used in this study were the daily precipitation data (from 1961 to 2011) of meteorological stations which are located in the study area (the stations near the boundary are also included). The study period 1961 to 2010 was chosen because it has good representativeness in the station data. Pre-1961 records of precipitation were less consistent than that during the 1961 to 2011 period. For some stations which contain partial or no data, they were deleted from the analysis of precipitation. In order to improve the precision of spatial analysis, stations with less than 80% temporal coverage during the 51-year period were omitted. Finally, data of 331 meteorological stations were used in this research (figure 2).

![Figure 2. Meteorological stations of study area.](image)

Runoff data used in this research come from the hydrological station of Dangjiangkou reservoir. The discharge in Dangjiangkou reservoir from 1961 to 2011 and the annual mean monthly discharge in Dangjiangkou reservoir are shown as figure 3.

![Figure 3. (a) The discharge in Dangjiangkou reservoir from 1961 to 2011 and (b) The annual mean monthly discharge in Dangjiangkou reservoir.](image)

Data of the regional climate change scenarios comes from ISI-MIP (The Inter-Sectoral Impact Model Intercomparison Project, http://www.isi-mip.org) [9, 10]. The general circulation models are list
as table 2. The scenarios of RCP2.6, RCP4.5 and RCP8.5 are used in this study.

**Table 2.** List of general circulation models (GCMs) used in this study.

| Centre | Country | Name | Properties |
|--------|---------|------|------------|
| Geophysical Fluid Dynamics Laboratory (GFDL) | United States | GFDL-ESM2M | 1951/1/1 -2050/12/31 |
| Hadley Centre for Climate Prediction and Research, Met Office | United Kingdom | HADGEM2-ES | 70.25° E-140.25° E, 15.25° N-55.25° N, 0.5°×0.5° |
| L’Institut Pierre-Simon Laplace (IPSL) Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies | France | IPSL-CM5A-LR | |
| Norwegian Climate Centre | Norway | NORESM1-M | |

2.3. **Assessment of drought/waterlog magnitude**

In this study, the standard deviation method was used to assess the magnitude of drought/waterlog. The method assumes that the precipitation obeys the normal distribution. Then the standard deviation of precipitation is used to assess the magnitude. The formula is shown as the follow.

\[ K = \frac{P_i - \overline{P}}{\sigma} \] (1)

\( P_i \) is the monthly precipitation, \( \overline{P} \) is the annual mean monthly precipitation, \( \sigma \) is mean square error of precipitation. Standard is as follows (table 3).

**Table 3.** The Flood and Drought magnitude of K.

| K   | Magnitude       |
|-----|----------------|
| Z ≥ 2 | Severe Waterlog |
| 1 < Z ≤ 2 | Moderate Waterlog |
| -1 < Z ≤ 1 | Normal |
| -2 < Z ≤ -1 | Moderate Drought |
| Z ≤ -2 | Severe Drought |

2.4. **Set pair analysis**

Set pair analysis (SPA) method [11] was adopted for the dividing of alternate drought /waterlog-prone region in the study area. The key of the method is to bring two correlated groups from the system for set pair (A, B) and analyze the identity (I), discrepancy (D) and contradiction (C) of the two. After these, the connection degree (\( \mu \)) can be calculated which can reflect the relationship of set A and set B. The connection degree is defined as

\[ \mu_{A-B} = s + f + i + p j \] (2)

where \( s, f, j \) and \( p \) are the number of the identical terms, the discrepant terms and the contradictory terms, respectively. \( i \) means the uncertainty coefficient of discrepancy, a numeric value between 0 and 1; \( j \) means the uncertainty coefficient of contradictory, taking -1 usually in study. \( I = s/n, D = f/n \) and \( C = p/n \) are the identity degree, the discrepancy degree and the contradictory degree, respectively. So,
equation (7) can be redefined as

$$\mu_{A-B} = I + Di + Cj$$  \hspace{2cm} (3)

3. Results

3.1. The drought and waterlog features in diversion region and benefited region from 1961 to 2011

The frequency of drought and waterlog is high from the 1960s. From the figure 4 we can conclude that the frequency of drought and waterlog is higher in the period from May to September. The drought occurred frequently in May and July. The frequencies of drought in these months from 1961 to 2011 are 11.8-21.6% and 13.7-19.6% respectively. However, the waterlog occurred frequently in September. It is in conformity of the drought and waterlog in terms of temporal dimension. Figure 5 shows the connection degree of drought/waterlog in the diversion region and benefited region of Haihe River Basin. The degree is lower in the period from May to September. It means that concurrence of drought or waterlog in diversion region and benefited region is uncommon. Besides, this period is drought-prone time in Haihe River Basin. This feature is benefits the water transfer.

Figure 4. The frequency of drought and waterlog in diversion region and benefited region.

Figure 5. The connection degree of drought/waterlog in the diversion region and benefited region.

3.2. The drought-waterlogging encounter in diversion region and benefited region from 2011 to 2050

Based on the monthly precipitation of diversion region and benefited region from 2011 to 2050 and equations (2) and (3), the connection degree of diversion region and benefited region in the future can be calculated (figure 6). Take RCP4.5 as example, the connection degree will increase significantly in the period of July to September. In benefited region 1, the degrees will increase by 29.8%, 20.0% and 14.5% in July, August and September respectively in terms of Muti-average of model outputs, while the degrees will decrease by 17.3%, 13.4%, 11.4% and 22.4% in January, February, May and
June. In Benefited region 2, the connection degree will increase significantly in February, March, April and August, especially in March and April, rate of increase is more than 20%. However, the connection degree will decrease significantly in May, June, September and November. In Benefited region 3, the change situation is in accordance with benefited region 2. The rate of increase in March, May, July, August and September is more than 20%. But it will be decreased by more than 10% in October and November. In conclusion, the synchrony of drought/waterlog between the south of Haihe River Basin and diversion region will increase in wet season while it will decrease in dry season. But the synchrony of drought/waterlog between the north of Haihe River Basin and diversion region will decrease in the late spring, early summer and autumn.

**Figure 6.** The connection degree of drought/waterlog in the diversion region and benefited region from 2011 to 2050.

3.3. **Projection of surface water resource diversion region**

**Figure 7.** (a) The annual precipitation and runoff in diversion region and (b) The relationship of the annual precipitation and runoff in diversion region.

The annual average precipitation and annual average runoff in in diversion region are 847.8 mm and
36.7×10⁸ m³, respectively. Both the precipitation and runoff had decreased since the 1980s. But the precipitation and runoff have been increasing since early 21st century (figure 7(a)). The runoff has a linear dependence relation with the precipitation factor (R=0.9526P+442.96). Correlation coefficient (R²) is more than 0.9 (figure 7(b)). So, we can project the future surface water resource by the precipitation that comes from the outputs of GCMs.

Based on the relationship of the annual precipitation and runoff in diversion region, we can calculate the future surface water resource from 2011 to 2050 (figure 8). It could be found that there was a decreasing trend of surface water resource in diversion region during the last 50 years. It had decreased 22.0×10⁸ m³ per 10-year from 1961 to 2011. However, the surface water resource will increase in the future (from 2011 to 2050). It will increase by 19.1×10⁸ m³/10a, 11.9×10⁸ m³/10a and 6.8×10⁸ m³/10a under RCP2.6, RCP4.5 and RCP8.5 scenarios respectively. Increase rate of surface water resource is larger in low emission scenarios than high emissions scenario. The multi-average results show that the annual mean surface water resource would increase by 8.1% (-1.1-18.7%), 11.5% (-5.8-26.1%) and 4.8% (-11.0-17.4%) compared to the period from 1961 to 2011. That means the climate change in the future would benefit the water transfer.

![Figure 8](image_url)

**Figure 8.** The surface water resource in the diversion region from 1961 to 2050.

4. Conclusions and discussion

The SNWTP is one of important projects to relieve the conflict of water supply and demand in the North China. This study analyzed the statistical characteristic of drought and waterlog in the diversion region and benefited region in SNWTP and the wetness-dryness encountering probability among the diversion region and benefited region. Besides, the wetness-dryness encountering probability and the surface water resource in the diversion region were also projected based on the outputs of GCMs.

In the benefited region in Haihe River Basin, the frequency of drought and waterlog is higher in the period from May to September. The drought occurred frequently in May and July, while the waterlog occurred frequently in September. In the diversion region, the drought often happened in July and September, while the August was waterlog-prone time. The connection degree is lower in the period from May to September. It means that concurrence of drought or waterlog in diversion region and benefited region is uncommon. So, this feature benefits the water transfer. In the future, the synchrony of drought/waterlog between the south of Haihe River Basin and diversion region will increase in wet
season while it will decrease in dry season. But the synchrony of drought/waterlog between the north of Haihe River Basin and diversion region will decrease in the late spring, early summer and autumn. The surface water resource is projected to be increased by 8.1% (RCP2.6), 11.5% (RCP4.5) and 4.8% (RCP8.5) compared to the period from 1961 to 2011. The climate change in the future would benefit the water transfer.

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