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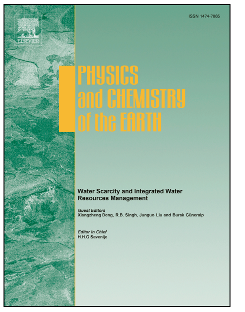

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Study on the Variation in Evapotranspiration in Different Period of the Genhe River Basin in China

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Abstract: Evapotranspiration is an important component and key link of river basin water cycles and plant hydrological processes, and is a core issue in global climate change research. It is not only an important way to understand the energy and water consumption of permafrost regions, but also is an important channel to master the water cycle and energy balance in cold regions. In this paper, multiple linear regression analysis method and weighted comprehensive analysis of major factors method were used to investigate the variation characteristics and impact factors of evapotranspiration in the Genhe River Basin. The results showed the following: (1) The monthly average evapotranspiration in the Genhe River Basin during the freezing-thawing periods in 1980–2017 was 28.29 mm. Compared with the freezing-thawing periods, the total evapotranspiration in the growing seasons was much higher than that in the freezing-thawing periods, with monthly average evapotranspiration of 67.71 mm; (2) The main factors affecting evapotranspiration in the Genhe River Basin were precipitation and temperature. During the freezing-thawing periods, the variation in evapotranspiration in May was mainly determined by temperature. In the growing season, precipitation was the main factors affecting evapotranspiration in June. This will lay a foundation for clarifying the relationship between permafrost–climate change–hydrologic cycle in the permafrost active layer during the land surface process, so as to provide some basic data and

important scientific basis for the comprehensive study of the hydrologic process and its impact on climate, ecology, water resources and environment in the permafrost area.

Key word: Evapotranspiration; Genhe River Basin; Permafrost region; Freezing and thawing period

1. Introduction

The evapotranspiration process is a key link in the hydrological cycle that links the atmospheric processes and land-surface processes of the climatic system. In contrast to precipitation, evapotranspiration is a process in which water vapor is transported from the surface to the atmosphere. As a core process of the climatic system, evapotranspiration closely links the hydrological cycle, the energy budget and the carbon cycle. Therefore, evapotranspiration studies are important to understand the changes in and effects of the climate and surface (Cammalleri et al., 2010; Vinukollu et al., 2011; Li, 2013). At the same time, the variation in and causes of evaporation have very important application value for the assessment of regional basin water resources, crop water requirements, production management, agricultural drought monitoring and ecological environmental problems (such as ecological water demand) (Liu et al., 2003).

Due to the special climate and environmental conditions in the cold temperate zone of high latitude, the region is less affected by human activities, and the eco-hydrological environment is relatively fragile. Evapotranspiration of water, soil and vegetation can reflect the climate change more truly (Li et al., 2019). Calanca et al. found that the actual evapotranspiration increased in the high altitude and the area south of the Alps but decreased in the low-altitude area in the northern foreland and the Alps (Calanca et al., 2006). Chen et al. analysed multi-factor combinations that dominated the half-hour evapotranspiration of evergreen coniferous forests across three different climate regions in North America and found that temperature was the most critical to the change in evapotranspiration during the growing season (Chen et al., 2018). Findell et al. by developing and applying objective indicators based on physics, found that high evaporation increased the possibility of regional rainfall (Findell et al., 2011). The possibilities of experimentally determining evapotranspiration in the boreal forests of the permafrost zone are limited due to their inaccessibility; therefore, the determination of moisture consumption for evapotranspiration in these regions is performed by computational methods (Budagovsky, 1989; Bondarik et al., 1999; Karpechko et al., 2010). Previous studies on evapotranspiration mainly included studies on the composition and variation trend of global terrestrial evapotranspiration, the influence mechanism of evapotranspiration and its measurement (Jung et al., 2010; Zhang et al., 2016). However, the study area mainly focused on the basins of the warmer regions, such as the middle temperate zone, temperate zone and subtropical zone (Cammalleri et al., 2010). Little attention has been paid by scholars to the variation in and influencing factors of evapotranspiration in the basins of high-latitude and cold regions. In permafrost areas, evapotranspiration of soil, meadow, ice and snow and wetland water surface, etc., is an important factor involved in water circulation such as water vapor transport, precipitation, soil infiltration, surface runoff and underground runoff (Li et al., 2019). How meteorological factors affect evapotranspiration in permafrost areas, the variation trend of evapotranspiration in permafrost areas in different periods (growing season and freezing-thawing period) and the variation characteristics are all scientific questions to be solved. Due to the existence of complex eco-hydrological processes and fragile ecosystems, alpine regions are extremely vulnerable to damage and are difficult to repair when they are affected by regional climate change and human activities. Therefore, it is of great significance to study evapotranspiration in high latitude and cold regions in order to study the response of climate change to water cycle and the eco-hydrological process in permafrost regions.

The Genhe River Basin is located on the western slope of the northern part of the Greater Xingan Mountains (Fig. 1). It is located in the permafrost region. Most of the basin is within the temperate, cold and humid forest climatic zone of the Greater Xingan Mountains. The southwestern part of the Genhe River Basin is a temperate and semi-humid region with a combination of animal husbandry and agriculture. There are complex ecological and hydrological processes and fragile ecosystems in the Genhe River Basin. In recent years, under the influence of climate warming and human activities (He et al., 2014), ecological environmental changes have complicated evapotranspiration in the basin. From the south to the north, the Genhe River Basin is gradually transformed from medium-temperature grassland to coniferous forest. Therefore, considering the distribution of natural ecosystems and the uniqueness of geographical location, it is of great significance to study the regional water cycle in the Genhe River Basin in high-latitude and cold regions. By analysing the variation characteristics of evapotranspiration in the freezing and thawing period and the growing season from 1980 to 2017 in the Genhe River Basin, this paper aims to explore the key factors affecting evapotranspiration and reveal the variation characteristics and influence mechanism of evapotranspiration.

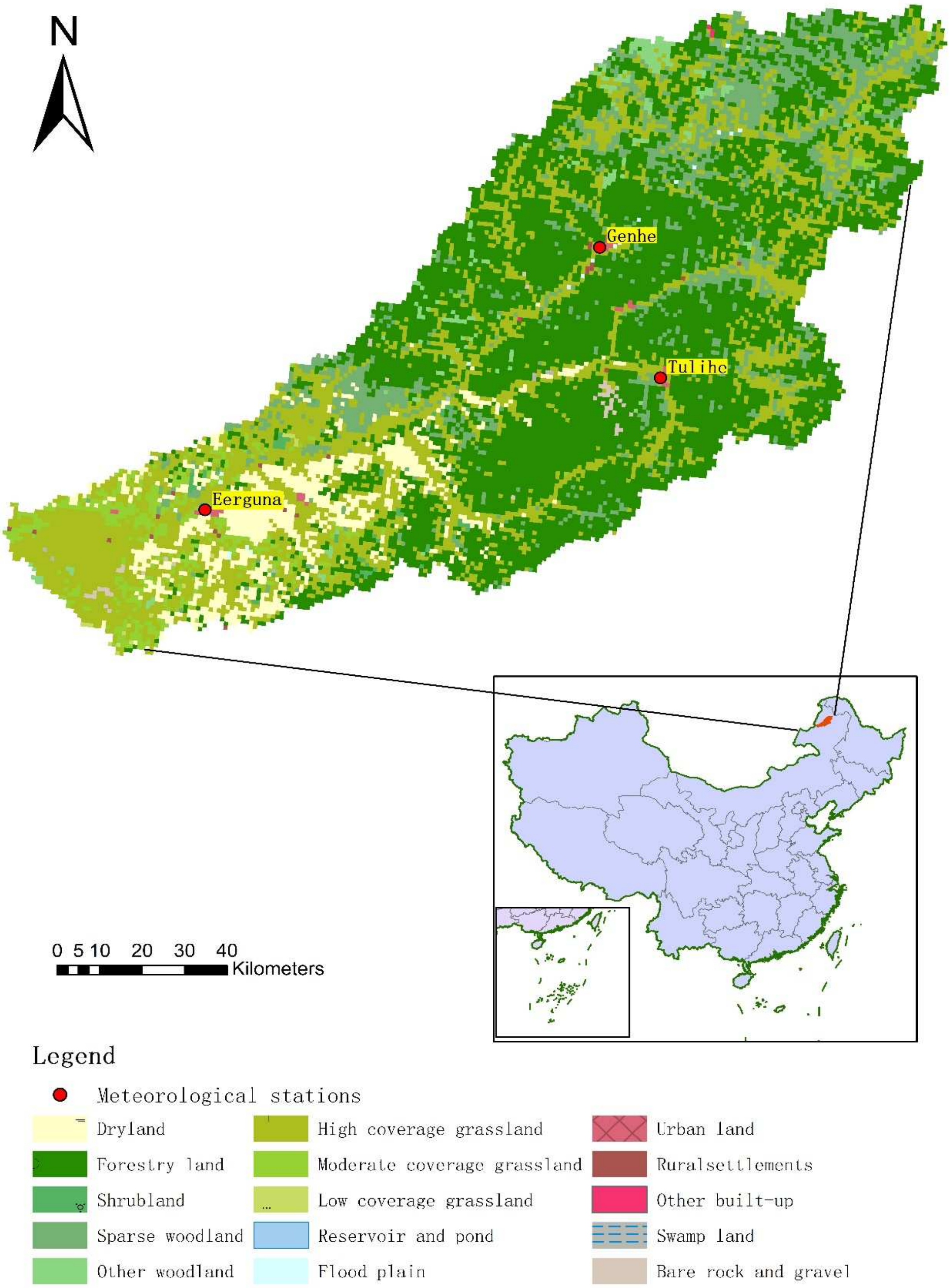


Fig. 1. Location and land use cover of the Genhe River Basin

2. Methodology

2.1 Data

2.1.1 Data Sources

The time series of meteorological data are from 1980 to 2017, and the data are from the National Meteorological Information Center (Central Meteorological Administration, 1979) (http://data.cma.cn/). The meteorological data set was obtained from the informatized files of the monthly reports submitted by the Inner Mongolia Autonomous Region, and was compiled based on the relevant regulations of the “Specifications for Surface Meteorological Observations”. For details, please refer to the relevant contents of "Specifications for Surface Meteorological Observations". The daily average value was calculated from the data extracted four times (02:00, 08:00, 14:00 and 20:00) per day from ground monthly meteorological report data or the real-time database mentioned above. The diurnal data include precipitation, temperature, solar radiation and wind speed. This paper conducts the necessary pre-processing on the data for each meteorological site, including data verification and data interpolation.

In this study, the Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2004) was used to simulate actual evapotranspiration and soil moisture content in the whole Genhe River Basin. The SWAT model is a semi-distributed basin-scale model that has been used around the world under different conditions (Schuol et al., 2008; Faramazi et al., 2009; Zang et al., 2012). In SWAT, the Genhe River Basin was divided into 29 sub-basins and 411 hydrological response units by overlaying elevation, land cover, soil attributes, management, and slope class. In the model, potential evapotranspiration was calculated using Penman formula (Liu et al., 1997). Surface runoff was simulated using a modified SCS curve number (CN) method and snow and melting water calculated by the energy balance equation. Firstly, collect digital elevation map of research area, spatial data of land use types, spatial data of soil types, attribute data, meteorological generators, etc. to build a SWAT model database. Various parameters were localized to simulate the monthly runoff from 1980 to 2017, and output sub-watershed output files (SUB), main channel output files (RCH), HRU output files, etc., and then parameter sensitivity analysis and model calibration were carried out.

In this study, the measured runoff data of the Genhe River Basin from 1995 to 1999 were used for model parameter calibration, and the measured data from 2000 to 2009 were used for model parameter verification. SWAT-CUP program was used for parameter sensitivity analysis and parameter calibration of runoff in Genhe River Basin (Abbaspour, 2007). The Nash-Sutcliffe coefficient (Ens) and the coefficient of determination (R^2) were selected to evaluate the goodness of the calibration and validation (Nash et al., 1970). The SUFI-2 method in the SWAT-CUP interface (Abbaspour, 2007) was chosen for parameter optimization. The results of the model simulation verification period (2000–2009) were shown in Fig. 2. R^2 was 0.82 and E_{ns} was 0.79. Therefore, the SWAT model was suitable for the simulation of the hydrological response in the Genhe River Basin.

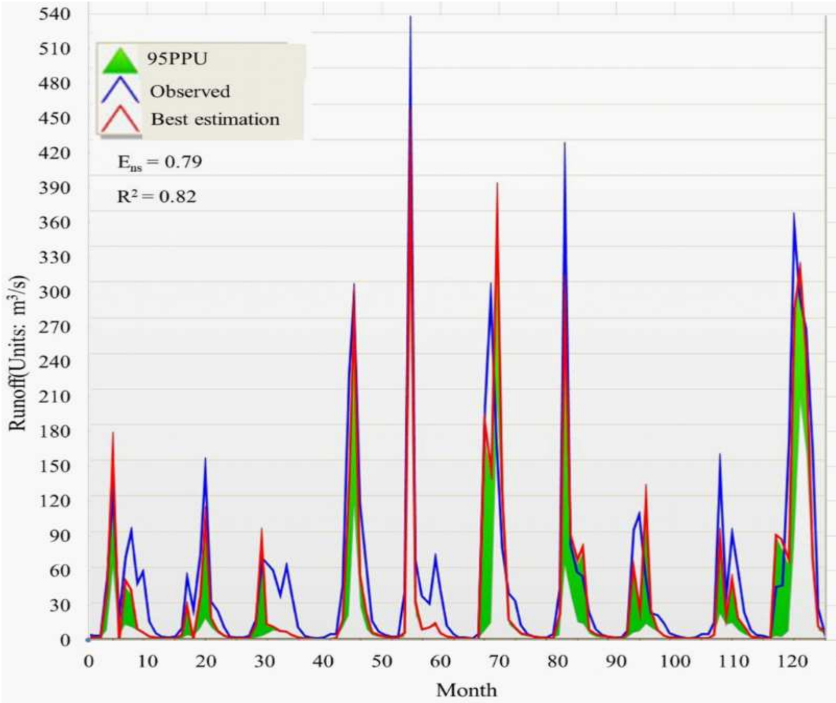


Fig. 2. The SWAT model validation between the observed and simulated discharge in Genhe river basin from 2000–2009

2.1.2 Data Quality Status

The quality control codes of the diurnal extreme data and accumulation data of all elements in the data set were provincial quality control codes in the ground monthly meteorological report data files of the same period. Provincial quality control codes were given by the provincial quality control service in the three-level quality control service system of the ground monthly meteorological report data files. The quality control code of the daily average data was taken from the maximum quality control code of the corresponding timing data in the monthly file. The quality control codes of the extreme data and accumulation data were the quality control results of the hourly data files and daily data files of the automatic stations uploaded in real time, which were automatically marked by the quality control software of the stations. The quality control code of the daily average data was taken from the maximum quality control code of the corresponding timing data in the real-time database. Artificial verification was generally carried out on the detected suspected incorrect data, and corrections were carried out on the data that were clearly wrong after verification.

2.2 Method

2.2.1 Data Processing

We used the tessellation polygon method (Burn et al., 2002) to calculate the meteorological data distributions throughout the river basin. We generated tessellation polygons based on the locations of the three weather stations and the boundaries of the Genhe River basin (Fig. 1). We then used the area of each polygon as a weight and calculated the weighted average precipitation throughout the basin.

2.2.2 Multiple Linear Regression Analysis

The basic task of the multiple regression equation is to calculate the regression coefficient through a series of dependent variables and independent variables and establish a relational model between the dependent variable and the independent variable. According to a large number of studies (Zhao et al., 2008; Dang et al., 2016; Li et al., 2014), meteorological factors such as solar radiation and rainfall have a great impact on evapotranspiration. The relationship between evapotranspiration and meteorological factors can be expressed by linear regression, and the regression coefficient can directly represent the degree of influence of climatic factors on evapotranspiration (Fan et al., 2019). Therefore, multiple linear regression equations were adopted in this paper to describe the dependence relationship between the dependent variable and multiple independent variables. The model was established as follows:

$$Y_i=\beta_0+\beta_1X_{1i}+\beta_2X_{2i}+\beta_3X_{3i}+\beta_4X_{4i}+\beta_5X_{5i}$$

where Y_i is the evapotranspiration, β_0 is the random error term (constant term), including the influence of other variables not included in the model and random error, β_1-β_5 is the independent variable regression coefficient, X_{1i} is the precipitation, X_{2i} is the solar radiation, X_{3i} is the temperature, X_{4i} is the wind speed, and X_{5i} is variation in soil moisture content.

2.2.3 Weighted Comprehensive Analysis of Major Factors

This paper intends to explore the comprehensive influence degree of major factors on evapotranspiration through the weighted comprehensive analysis of meteorological factors. The calculation steps of this method were as follows (Liu et al., 2020).

①Calculate the correlation between evapotranspiration and key factors such as temperature, solar radiation, wind speed and rainfall and their proportions;

②Carry on the normalized processing to each element value;

③Calculate the comprehensive weighted values of the main influencing factors in each period;

④ Calculate the comprehensive influence degree of influence factors on evapotranspiration in each period.

The correlation between evapotranspiration and the major factors is expressed by the correlation coefficient:

$$R_{xy}=\frac{\sum_{i=1}^{n}[(x_i-\bar{x})(y_i-\bar{y})]}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\cdot\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

where R_{xy} is the coefficient of correlation between x and y; X_i is the evapotranspiration in year i, mm; Y_i is the main factor data of the corresponding year; $\bar{X}$ and $\bar{Y}$ are the mean of evapotranspiration and the mean of meteorological data of the corresponding year, respectively; and i is the year variable.

3. Results

3.1 Characteristics of Evapotranspiration during the Freezing-thawing Period in the Genhe River Basin

The monthly average evapotranspiration in the freezing-thawing period in the Genhe River Basin presented a "low-high-low" pattern as a whole, and the variation range was larger than that of the growing season. From April to September, evapotranspiration continued to grow and peaked in September. From September to October, the evapotranspiration decreased continuously and reached a lower value in October.

The monthly average evapotranspiration during the freezing and thawing period was 28.29 mm, and the total evapotranspiration was 113.14 mm, of which 45.84 mm occurred in September, accounting for approximately half of the evapotranspiration during the freezing-thawing periods. Second, the monthly average evapotranspiration in May was 37.48 mm, respectively, accounted for approximately 33% of the freezing-thawing periods. In April and October, the monthly average evapotranspiration, which was 13.91 mm and 15.91 mm, was less (Fig. 3).

The monthly evapotranspiration in the Genhe River Basin fluctuated within the range of 5.08–23.76 mm in April, showing an overall fluctuation. The evapotranspiration in the Genhe River Basin in May was distributed in the range of 19.84–49.06 mm with high evapotranspiration. The evapotranspiration in the Genhe River Basin in September ranged from 29.93 to 53.74 mm and exhibited fluctuations. The evapotranspiration in the Genhe River Basin decreased significantly in October, fluctuating within the range of 6.5 to 31.8 mm (Table 3).

Table 3. Monthly Average Evapotranspiration in the Freezing-thawing Periods in the Genhe River Basin in 1980-2017

Month	The minimum value (mm)	The maximum value (mm)	The average value (mm)
April	5.08	23.76	13.91
May	19.84	49.06	37.48
September	29.93	53.74	45.84
October	6.50	31.80	15.91

3.2 Characteristics of Evapotranspiration during the Growing Season in the Genhe River Basin

Compared with the freezing-thawing periods, the monthly average evapotranspiration in the growing season in the Genhe River Basin showed a small change. From June to August, the evapotranspiration increased and reached its peak in August.

The monthly average evapotranspiration in the growing season in the Genhe River Basin was 67.71 mm, and the total evapotranspiration was 203.13 mm. The monthly average evapotranspiration in July and August was 71.59 mm and 77.12 mm, respectively, accounting for more than one-third of the evapotranspiration in the growing season. The monthly average evapotranspiration in June was the least (54.42 mm) (Fig. 4).

The monthly evapotranspiration in the Genhe River Basin fluctuated within the range of 27.7–72.13 mm in June. The monthly average evapotranspiration in the Genhe River Basin increased significantly in July, with a range of 53.62 mm to 81.83 mm. The monthly average evapotranspiration in the Genhe River Basin was within the range of 61.03–95.51 mm in August, with an increase in evapotranspiration compared with June and July (Table 4).

Table 4. Monthly Average Evapotranspiration in the Growing Season in the Genhe River Basin in 1980–2017

Month	The minimum value (mm)	The maximum value (mm)	The average value (mm)
June	27.70	72.13	54.42
July	53.62	81.83	71.59
August	61.03	95.51	77.12

Fig. 3. Changes in evapotranspiration and meteorological factors in the freezing-thawing periods

Fig. 4. Changes in evapotranspiration and meteorological factors in the growing season

Note: The results in Fig. 3 and Fig. 4 were obtained using the monthly average of 1980 to 2017.

3.3 Interannual Variation in Evapotranspiration in the Genhe River Basin in 1980–2017

From Fig. 5 and Table A1, the following conclusions can be drawn: from 1980 to 2017, the monthly average evapotranspiration showed periodic changes and the average of total evapotranspiration was 317.89 mm. Among them, the highest value of total evapotranspiration appeared in 2014, which was 366.97 mm, and the lowest value appeared in 1987, which was 258.22 mm. At the same time, the five major meteorological factors also showed obvious periodic changes.

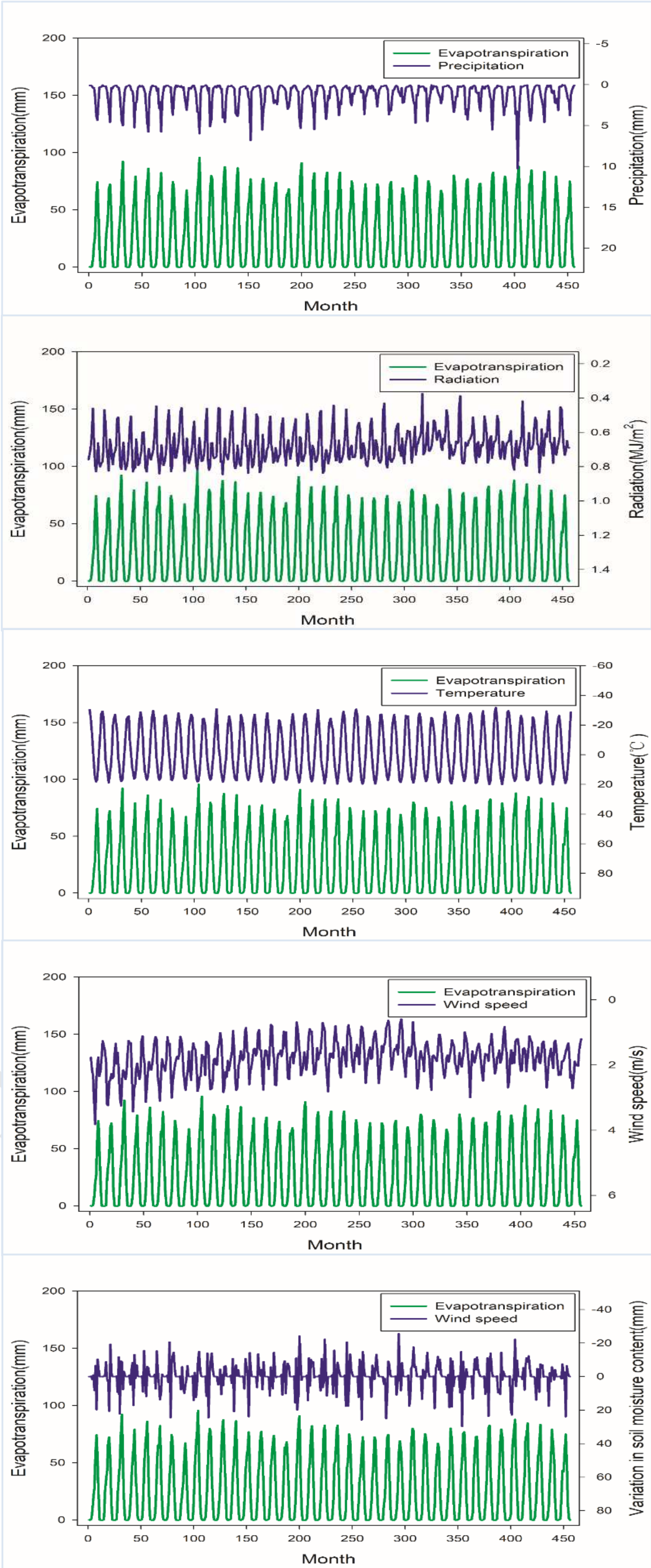


Fig. 5. Changes in the evapotranspiration and meteorological factors from 1980

to 2017

3.4 Mechanism Analysis of Evapotranspiration Change in the Genhe River Basin

3.4.1 Mechanism Analysis of Evapotranspiration during Freezing-thawing periods in the Genhe River Basin

The changes in evapotranspiration during the freezing and thawing periods and the growing seasons were mainly affected by energy conditions (such as temperature, solar radiation, water vapor pressure and wind speed) and the water supply conditions of the underlying surface. A large number of studies have shown that the dominant factors for evapotranspiration are different in different regions and seasons. To determine the relationship between the evapotranspiration and meteorological factors in the Genhe River Basin, multiple regression coefficients of temperature, precipitation, wind speed, variation in soil moisture content and other related factors and evapotranspiration were calculated during the freezing and thawing periods and the growing seasons (Fig. 3 and Fig. 4).

Combining the results of Table 6 and Table 7, we could find that the evapotranspiration changes in the Genhe River Basin during the freezing-thawing periods were mainly affected by three meteorological factors: variation in soil moisture content was negatively correlated with evapotranspiration, and rainfall and temperature were positively correlated with evapotranspiration. The variation in evapotranspiration in April in the Genhe River Basin was mainly caused by solar radiation, which was negatively correlated with evapotranspiration, and temperature, which was positively correlated with evapotranspiration. The variation in evapotranspiration in May in the Genhe River Basin was mainly caused by temperature, which was positively correlated with evapotranspiration. The change in evapotranspiration in September in the Genhe River Basin was mainly caused by rainfall, which was positively correlated with evapotranspiration. The evapotranspiration changes in the Genhe River Basin during October were mainly affected by two meteorological factors: variation in soil moisture content was negatively correlated with evapotranspiration, and temperature was positively correlated with evapotranspiration.

The change in evapotranspiration in the Genhe River Basin was the result of the joint influence of various meteorological elements, and the effects of the meteorological elements on evapotranspiration were different at different scales and periods. Fig. 6 and Fig. 7 show the relationship between evapotranspiration and the weighted values of major factors. As can be seen from Fig. 6, the correlation coefficient of the two was 0.728 in the freezing-thawing period, with a high degree of correlation and good coincidence, indicating that the weighted value of the five influencing factors can well explain the variation in evapotranspiration during the freezing-thawing period. As shown in Fig. 7, in the growing season, the correlation coefficient of the two was 0.352, the correlation was low, and the degree of agreement was general, indicating that the weighted values of the five influencing factors have a weaker interpretation of the changes in evapotranspiration during the growing season.

308 **Table 6.** Multiple regression equations of major elements and evapotranspiration

309 in the freezing-thawing period in the Genhe River Basin

Time	Multiple regression equation	The significance of X_1	The significance of X_2	The significance of X_3	The significance of X_4	The significance of X_5	R^2
Freezing-thawing period	$Y=6.326X_1+22.992X_2+1.910X_3+2.818X_4-0.553X_5-6.167$	0.000**	0.001**	0.000**	0.008**	0.000**	0.910
April	$Y=-0.139X_1-32.57X_2+1.304X_3+5.227X_4-0.059X_5+17.323$	0.915	0.000**	0.000**	0.000**	0.442	0.900
May	$Y=14.622X_1-35.751X_2+1.971X_3+1.716X_4-0.897X_5+14.797$	0.000**	0.069	0.002*	0.431	0.000**	0.721
September	$Y=4.62X_1+22.02X_2-0.145X_3+4.001X_4-0.281X_5+15.83$	0.013**	0.292	0.807	0.156	0.041	0.464
October	$Y=8.468X_1+1.643X_2+1.096X_3+1.861X_4-1.405X_5+4.236$	0.007**	0.937	0.002**	0.435	0.000**	0.650

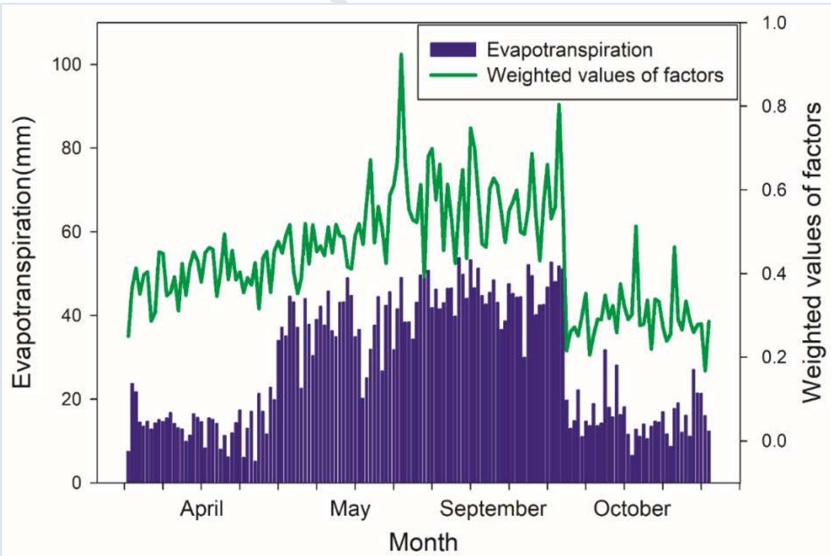
310 **Note:** * indicates significance at the 5% level, and ** indicates significance at the 1% level. Parameter Y is the
311 evapotranspiration; the constant term is the random error term (constant term), including the influence of other
312 variables not included in the model and random error; X_1 is rainfall; X_2 is the solar radiation; X_3 is the temperature;
313 X_4 is the wind speed; and X_5 is variation in soil moisture content.

314 **Table 7.** Correlation among evapotranspiration and major factors

315 in the freezing-thawing periods in the Genhe River Basin

Time	X_1	X_2	X_3	X_4	X_5
Freezing-thawing period	0.555**	0.232**	0.882**	-0.090	-0.545**
April	-0.547**	-0.736**	0.754**	0.317	-0.550**
May	0.243	0.089	0.567**	-0.133	-0.228
September	0.570**	0.528**	-0.144	0.274	0.215
October	-0.183	-0.212	0.382*	0.314	-0.582**

316 **Note:** * indicates significance at the 5% level, and ** indicates significance at the 1% level. Parameter X_1 is
317 rainfall; X_2 is the solar radiation; X_3 is the temperature; X_4 is the wind speed; and X_5 is variation in soil moisture
318 content.



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320 **Fig. 6.** Relationship between evapotranspiration and the weighted values of
321 factors in the freezing-thawing period in the Genhe River Basin

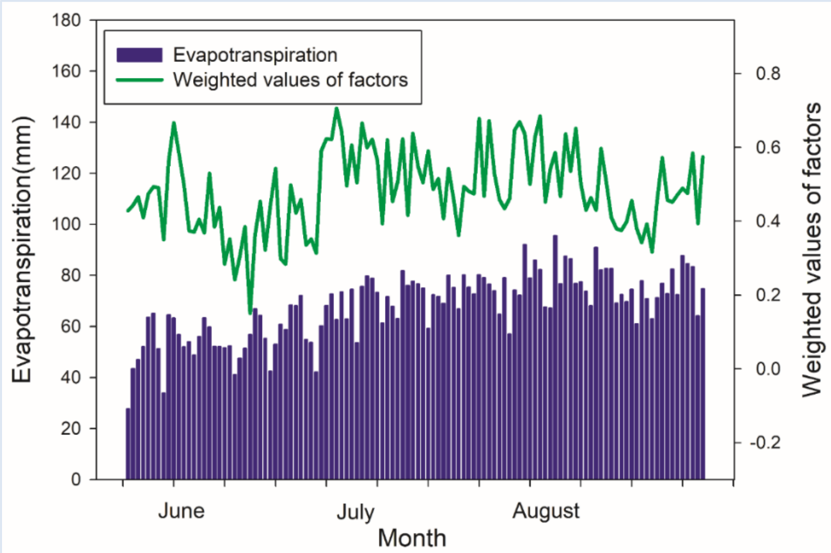

Fig. 7. Relationship between evapotranspiration and the weighted values of factors in the growing season in the Genhe River Basin

3.4.2 Analysis of the Mechanism of Evapotranspiration during the Growing season in the Genhe River Basin

From the scale of the growing season, the overall increase in evapotranspiration was mainly caused by two meteorological factors: solar radiation and rainfall were positively correlated with evapotranspiration. In June, the changes in evapotranspiration in the Genhe River Basin were mainly caused by rainfall, which was positively correlated with evapotranspiration. The change in evapotranspiration in July in the Genhe River Basin was mainly caused by solar radiation, which was positively correlated with evapotranspiration. In August, the changes in evapotranspiration in the Genhe River Basin were mainly caused by rainfall, which was positively correlated with evapotranspiration (Fig. 4).

According to the above analysis, the meteorological element positively correlated with evapotranspiration was mainly temperature. The meteorological elements negatively correlated with evapotranspiration included wind speed and variation in soil moisture content (Table 8 and Table 9).

Table 8. Multiple regression equations for major elements in the evapotranspiration growing season in the Genhe River Basin

Time	Multiple regression equation	The significance of X_1	The significance of X_2	The significance of X_3	The significance of X_4	The significance of X_5	R^2
Growing season	$Y=1.733X_1+101.823X_2+1.553X_3-4.789X_4-0.32X_5-29.397$	0.009**	0.000**	0.000**	0.068	0.000**	0.737
June	$Y=6.8X_1+52.709X_2+2.122X_3-2.923X_4-0.496X_5-22.235$	0.001**	0.139	0.013*	0.425	0.000**	0.713
July	$Y=0.874X_1+65.51X_2+2.933X_3-3.312X_4-0.25X_5-28.908$	0.284	0.015*	0.004**	0.387	0.016*	0.479
August	$Y=3.63X_1+31.564X+1.751X_3+8.694X_4-0.371X_5-3.919$	0.000**	0.181	0.048*	0.060	0.000*	0.706

Note: * indicates significance at the 5% level, and ** indicates significance at the 1% level. Parameter Y is the evapotranspiration; the constant term is the random error term (constant term), including the influence of other variables not included in the model and random error; X_1 is rainfall; X_2 is the solar radiation; X_3 is the temperature; X_4 is the wind speed; and X_5 is variation in soil moisture content.

Table 9. Correlation among evapotranspiration and major factors in the growing season in the Genhe River Basin

Time	X_1	X_2	X_3	X_4	X_5
Growing season	0.501**	0.748**	0.333**	-0.420**	-0.327**
June	0.506**	0.517**	0.110	-0.300	-0.163
July	0.356*	0.365*	0.315	-0.273	-0.250
August	0.576**	0.568**	0.029	0.167	-0.293

Note: * indicates significance at the 5% level, and ** indicates significance at the 1% level. Parameter X_1 is rainfall; X_2 is the solar radiation; X_3 is the temperature; X_4 is the wind speed; and X_5 is variation in soil moisture content.

4. Discussion and Conclusions

In different climatic zones, the factors affecting forest evapotranspiration vary widely. For example, in the tropical, subtropical and most temperate regions, the main factors affecting forest evapotranspiration are precipitation, temperature and solar radiation (Smith et al., 2013; Cristiano et al., 2015). In cold and temperate regions, in addition to precipitation, temperature and solar radiation, the freezing and thawing of permafrost is also an important factor affecting forest evapotranspiration (Park et al., 2008; Tchebakova et al., 2016). The Genhe River Basin has a temperate continental climate. Every year in early November, the temperature begins to fall below zero, and the soil begins to freeze. The soil moisture is almost stopped by the supply of rainfall.

The phreatic aquifer in the soil preserved during the growing season moves towards the soil layer, and the soil moisture gradually reaches saturation or supersaturation and freezes to form tundra. From the beginning of June, the permafrost begins to melt. The soil moisture content begins to increase gradually, reaching a maximum in July and early August, and permafrost melts to 80% to 90% of the maximum thawing depth. In August, the permafrost continues to melt deep, and plants continue to consume water. Therefore, the soil moisture content begins to decline because the deeper the soil is, the larger the gravel size. The large pores make it difficult for the meltwater to rise to supply the upper layer and at the same time, the precipitation easily infiltrates, so the soil water content begins to decline; the main influencing factors of the change in soil moisture content are permafrost and precipitation (You, 2006). From November to March, precipitation (mainly snowfall) is increasing, and the permafrost is thicker. The following spring in April, the temperature during the melt period is high, which is conducive to the rapid melting of the permafrost, and the groundwater level will rise rapidly, which will quickly replenish the water needed for plant germination. The plants turn green, and the transpiration is strengthened. The soil evaporation increases and the evapotranspiration increases. On the other hand, if there is less precipitation in the non-growing season, evapotranspiration is naturally reduced (Wang, 2015).

Since the average temperature during the freezing and thawing period is lower than that during the growing season, the lower temperature has a significant inhibitory effect on evapotranspiration, resulting in a lower total evapotranspiration during the freezing and thawing period; the temperature in summer rises and gradually promotes evapotranspiration (Han et al., 2018; Alexander et al., 2018) so that the evapotranspiration is increasing. During the growing season, temperature and rainfall begin to increase from mid-May, the plants begin to grow green, and the transpiration activity strengthens. The soil moisture is also supplemented by rainfall while supplying plant growth and consumption. The increase in the surface temperature causes the increase in soil evapotranspiration at this time and evapotranspiration increases due to the increase in temperature and rainfall. The Genhe River Basin is controlled by cold high pressure in winter, whose temperature is low, and seasonal freezing-thawing occurs in the soil. The soil freezes from the beginning of November every year until the spring in April and May, and the permafrost gradually melts to form the seasonal frozen layer of water, which becomes an important factor for replenishing soil moisture (Wang, 2015). Therefore, during the freezing-thawing periods, evapotranspiration is highly correlated with soil moisture. Because the process of soil freezing is also the process of increasing soil water content in the surface layer (Guo et al., 2002), the soil moisture in the freezing and thawing period is higher than that in the growing season as a whole. During the freezing period, the soil is in a frozen state, the ground temperature is low, and soil evapotranspiration is also rare (Lei et al., 1999). When the permafrost melts, the soil thaws and water infiltrates into the soil, increasing soil moisture. At the same time, evapotranspiration is enhanced under the influence of temperature and other meteorological factors. At this time, due to the correlation between the land surface and atmospheric feedback, the increase in soil moisture will lead to more evapotranspiration (Heerwaarden et al., 2010). However, the correlation between evapotranspiration and soil moisture in the growing season is not as high as that in the freezing-thawing period. The situation in August is particularly prominent. The soil moisture did not change much with the fluctuation in the evapotranspiration. At this time, other meteorological factors have a greater impact on evapotranspiration, such as rainfall and temperature.

Research has shown that evaporation depends not only on soil and on meteorological characteristics but also on the composition and age of forest stands (Fedorov, 1981; Fedorov et al., 1990). Therefore, it is necessary to increase studies on the corresponding mechanism of vegetation growth phenology and evapotranspiration and comprehensively consider the meteorological characteristics and forest characteristics to explore the influencing mechanism of forest evapotranspiration in future research.

The selection in this paper of the data from only three meteorological stations to study the variation in evapotranspiration in the Genhe River Basin had a certain impact on the results. Therefore, more data from meteorological stations can be added in future research, which is helpful for understanding hydrological cycle characteristics in high-latitude and cold regions. In this paper, factors such as rainfall, variation in soil moisture content, solar radiation, wind speed and temperature were selected to study the mechanism of evapotranspiration. By analysing the relationship between evapotranspiration and water vapor circulation in cold and temperate regions and the influence of evapotranspiration on freezing-thawing permafrost and the growth of vegetation, this paper can provide the scientific basis and guidance for the continuous dynamic monitoring and estimation of evapotranspiration in high-latitude and cold regions. At the same time, this paper provided references for the evaluation of water resources in the alpine region and the study of the impact of climate change (Moses et al., 2018), so as to improve the understanding of the characteristics of evapotranspiration in different periods under the climatic types in this region. It filled in the shortage of research data in high latitude and cold regions' basin.

In this paper, the multiple linear regression analysis method and weighted comprehensive analysis of major factors method were used to explore the variation in evapotranspiration in the freezing-thawing periods and the growing season in the Genhe River Basin and to reveal the change mechanism and influencing factors of evapotranspiration in the Genhe River Basin. The conclusions are as follows:

1. Compared with the freezing-thawing periods, the total evapotranspiration in the growing season was higher. During the freezing-thawing periods, the value of evapotranspiration showed irregular fluctuations, which was mainly caused by changes in temperature. Compared with the freezing-thawing periods, the evapotranspiration trend in the growing season slowed down, and the range of fluctuation decreased, which was related to the stable level of the temperature and solar radiation in the Genhe River Basin in the growing season.
2. The major elements positively correlated with evapotranspiration was mainly temperature; the major factors negatively correlated with evapotranspiration included wind speed and variation in soil moisture content. During the

freezing-thawing periods, the variation in evapotranspiration in May was mainly determined by temperature. In the growing season, precipitation was the main factors affecting evapotranspiration in June.

Author statement

Xinqing Lu: Investigation, Data curation, Software, Writing—original draft preparation, Writing—review and editing, Visualization. **Chuanfu Zang:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing—original draft preparation, Writing—review and editing, Supervision, Project administration. **Tamara Burenina:** Validation, VIsualization, Supervision.

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Table A1. Monthly evapotranspiration in the Genhe River Basin from 1980 to 2017

Year	The minimum value (mm)	The maximum value (mm)	The total amount (mm)
1980	0.00	74.30	259.48
1981	0.00	72.25	304.06
1982	0.00	92.06	337.11
1983	0.00	79.05	311.34
1984	0.00	86.01	339.13
1985	0.00	82.24	327.36
1986	0.00	74.535	301.65
1987	0.00	67.23	258.22
1988	0.01	95.51	357.52
1989	0.00	79.75	328.69
1990	0.00	87.56	358.67
1991	0.00	86.47	337.12
1992	0.00	76.79	310.77
1993	0.00	77.38	331.46
1994	0.00	73.76	320.58
1995	0.00	68.03	311.87
1996	0.00	90.94	335.58
1997	0.00	82.18	320.53
1998	0.00	82.64	331.00
1999	0.00	82.64	335.26
2000	0.00	75.07	308.08
2001	0.00	72.51	270.60
2002	0.00	72.40	295.08
2003	0.00	74.57	295.02
2004	0.00	69.04	280.71
2005	0.00	79.992	330.94

2006	0.00	75.22	310.85
2007	0.00	66.78	280.27
2008	0.00	80.16	306.72
2009	0.00	76.91	334.70
2010	0.00	72.81	311.34
2011	0.00	82.50	325.84
2012	0.00	79.08	332.97
2013	0.00	87.74	362.70
2014	0.00	84.58	366.97
2015	0.00	83.37	330.58
2016	0.00	79.06	313.31
2017	0.00	74.82	305.85

Journal Pre-proof

Highlights

1. The evapotranspiration variability in permafrost region have been analyzed in growing season and freezing and thawing period.
2. The influencing factors of evapotranspiration in a long term have been explored.
3. This study enriches the data of eco-hydrology research in data-deficient areas.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: