Runoff prediction under different climate scenarios in the source region of the Yellow River

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Abstract

Climate change has great effect on water resources in the source region of the Yellow River, which affects agricultural productivity, industrial water supply and wildlife management in the whole river basin. The hydrologic characteristics of precipitation, temperature and runoff in the source region of the Yellow River are analyzed using the long-term observed data from 1961 to 2010. The trend of runoff is predicted by the multivariate linear regression method under different climate scenarios. Reasons for the changing runoff are explored from the climate change and human activities perspective.
Keywords: the source region of the Yellow River, runoff, climate change.

1 Introduction

Climate change has great effect on water resources, which affects agricultural productivity and industrial water supply. The 100-year linear trend (1906-2005) of the global surface average temperature is 0.74[0.56 to 0.92]°C, and the linear warming trend over the 50 years from 1956 to 2005 (0.13[0.10 to 0.16]°C per decade) is nearly twice that for the 100 years from 1906 to 2005 (Parry *et al.* [1]). Global warming could intensify the hydrological cycle, which will redistribute the water resources at spatial and temporal scales. Besides, melting glaciers will increase flood risk during the rainy season, and strongly reduce dry-season water supplies.The future water resources status will depend on the effect of climate change and human activities. It is a great challenge to evaluate these

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impacts due to many reasons, such as population growth, economic development, improvement of technologies and water management policy.

The source region of the Yellow River occupies 16.2% of the whole basin area and contributes about 35% of the total water yield in the Yellow River basin (Chen and Liu [2]). There are no large dams or irrigation projects in this area, and human activities can be ignored because of less population, so the runoff could be thought as a kind of natural response to climate change. The temperature in this area has increased obviously from the 1980s, especially during the last ten years. The runoff has been decreasing continually since the end of the 1980s, which greatly affected the agriculture, flooding and the ecological environment in this area. This obvious change causes lots of attention. This study analyzes the hydrologic changing characteristics using the up-to-date data and predicts the runoff in the source region of the Yellow River under different climate scenarios, which give us a guideline to manage the water resources efficiently in this river basin and a better understanding how climate change affects the water resources.

2 Study area and data

The source region of the Yellow River is located in the northeast Qinghai-Tibet Plateau between 32º12'-35º48'N and 95º50'-103º28'E, and includes the region above the Tangnaihai Hydrologic Station. The area is 12.2×10^4 km^2 and has great elevation difference from 2546m in the east to 6282m in the west. It is called the 'water tower' of the Yellow River. Around 80% of the region is covered by grassland. Eling and Zhaling are the two largest lakes in the west region, covered 610 km^2 and 550 km^2, respectively (Hu *et al.* [3]).

The daily precipitation and temperature data from 1961 to 2010 are used in this study, which are collected from ten meteorological stations including Xinghai, Tongde, Zeku, Henan, Maduo, Dari, Jiuzhi, Maqu, Ruoergai and Hongyuan.

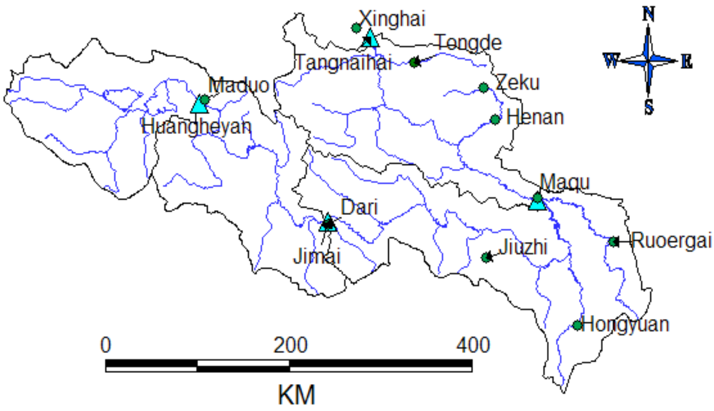

Figure 1: The location of hydro-climatic stations and river network in the source region of the Yellow River.

Daily streamflow data from four hydrologic stations located in the mainstream, including Huangheyan, Jimai, Maqu and Tangnaihai, are used to analyse the runoff change. Tables 1 and 2 show the summary characteristics of hydro-climatic stations in the study area. The precipitation and temperature for this area are calculated by arithmetic average method.

Table 1: Summary of characteristics of ten meteorological stations.

Station	Altitude (m)	Longitude (ºE)	Latitude (ºN)	Annual Precipitation (mm/a)	Annual Temperature (°C)
Xinghai	3323	99.98	35.58	365.3	1.44
Tongde	3289	100.39	35.16	411.2	0.67
Zeku	3663	101.28	35.02	418.1	-2.16
Henan	3500	101.36	34.44	583.9	0.31
Maduo	4272	98.13	34.55	318.5	-3.63
Dari	3967	99.65	33.75	551.8	-0.78
Jiuzhi	3629	101.48	33.43	744.7	0.71
Maqu	3471	102.08	34.00	589.2	1.58
Ruoergai	3440	102.97	33.58	649.7	1.20
Hongyuan	3492	102.55	32.80	747.1	1.52

Table 2: Streamflow characteristics of four hydrologic stations.

Station	Altitude (m)	Longitude (ºE)	Latitude (ºN)	Mean Discharge (m^3/s)	Record Length
Huangheyan	4221	98.17	34.88	20.2	1956-2009
Jimai	3969	99.65	33.77	129.3	1958-2009
Maqu	3471	102.08	33.97	455.2	1959-2009
Tangnaihai	2546	100.15	35.50	631.5	1956-2009

3 Hydrologic characteristics

3.1 Temperature

The temperature continued to rise from 1960s and especially had a strong increasing trend during the last ten years, and it has the maximum value of 1.71°C in 2010 (see Figure 2). The temperature change in the source region of the Yellow River has the same trend with the whole Qinghai-Tibet Plateau area (Hao and Wang [4]). Figure 3 shows monthly temperature variation using the data from 1961 to 2010. The maximum value is 10.42°C in July and the minimum value is -11.84°C in January. The temperature is lower than zero centigrade degree around half period every year.

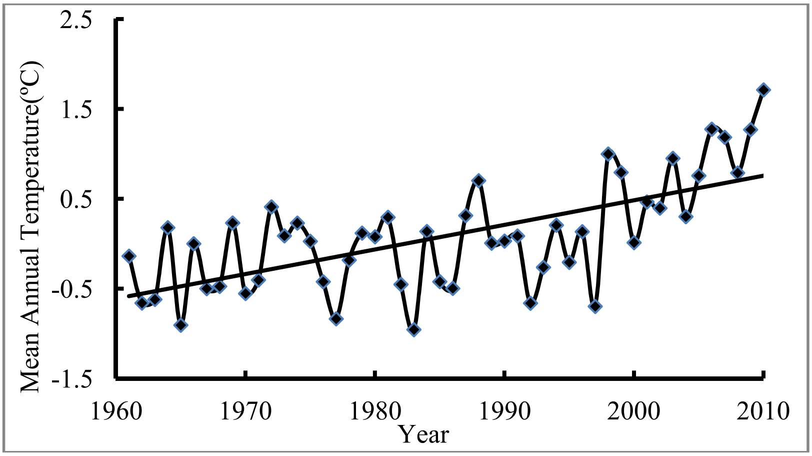

Figure 2: The mean annual temperature in the study area.

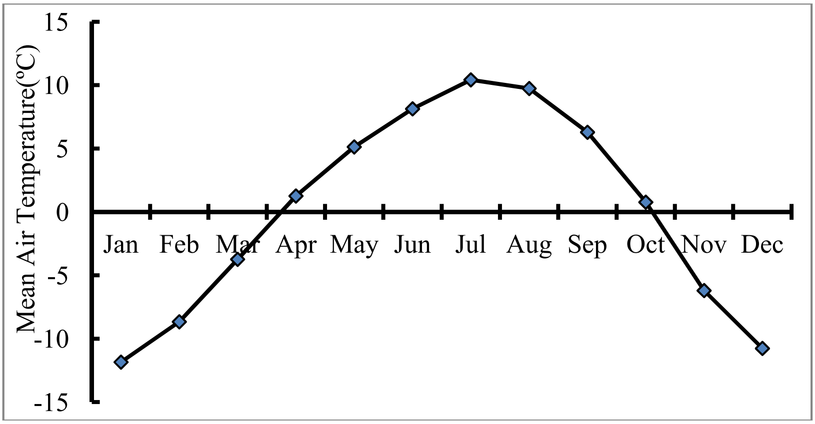

Figure 3: The mean air temperature in the study area from 1961 to 2010.

3.2 Precipitation

During the period of 1961-2010, the mean annual precipitation has a slight downward trend in the source region of the Yellow River (see Figure 4). The basin average precipitation from 1961 to 2009 is 541.7mm. The maximum value is 691.5mm in 1967, and the minimum value is 417.4mm in 2002. The precipitation has a great decreasing trend in the 1990s. The basin average precipitation has decreased by 28.2mm in the 2000s compared with the 1960s, and the decreasing rate was 5.64mm/10 years. The monthly precipitation varies during the year (see Figure 5). It is 108.64mm in July but only 2.15mm in January. The less precipitation will reduce the runoff in this area.

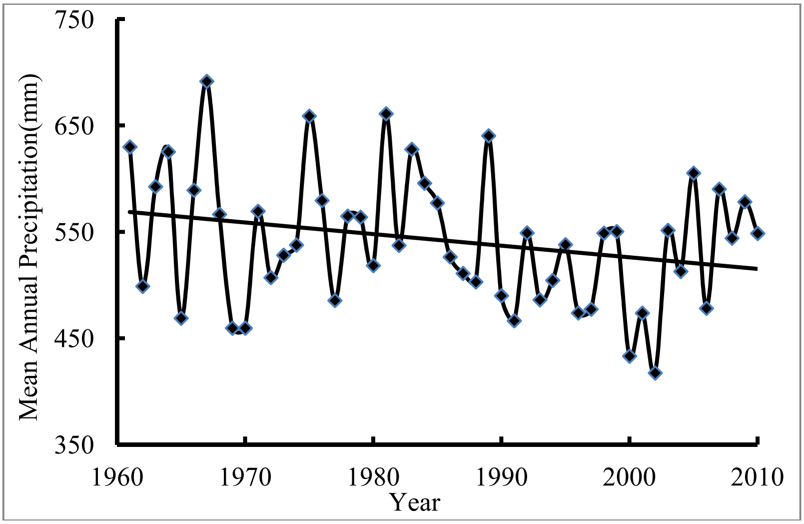

Figure 4: The mean annual precipitation in the study area.

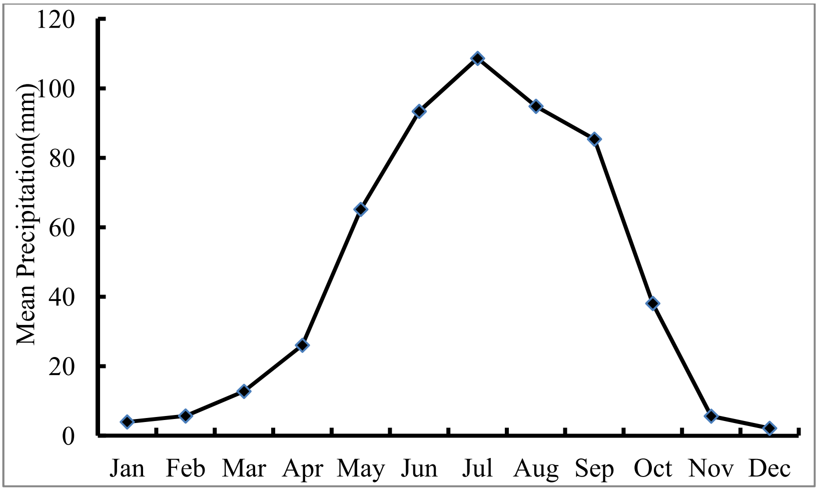

Figure 5: The monthly precipitation in the study area from 1961 to 2010.

3.3 Runoff

The runoff didn't change a lot in the 1960s and 1970s for every station in this area. It reached the peak in the 1980s. The discharge in every hydrologic station decreased significantly in the 1990s (see Figure 6). The runoff is mainly concentrated during the flood season (June-October), which is corresponding to the precipitation. The data from Tangnaihai and Maqu hydrologic station showed the same trend both in decadal mean discharge and in annual discharge (see Figure 7). The decadal mean discharge at Tangnaihai hydrologic station had decreased 210m^3/s in the 2000s compared with the 1980s, and it decreased by 27.5%. The runoff is mainly influenced by the climate factors rather than human activities due to the less population in this area.

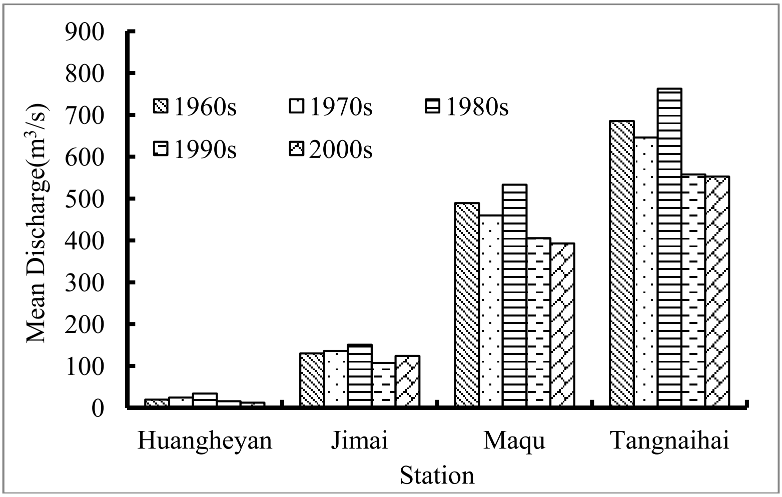

Figure 6: The decadal mean discharge at four hydrologic stations.

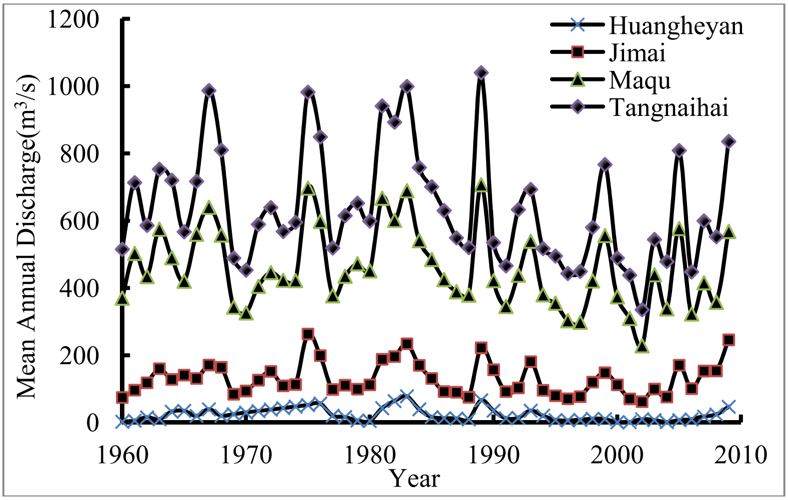

Figure 7: The mean annual discharge at four hydrologic stations.

4 The response of runoff to climate change

4.1 The future climate scenarios

Increased concentration of greenhouse gases changed the component of atmosphere, causing change in temperature and precipitation and other hydrologic variables (Houghton *et al.* [5]). The present and future climate scenarios simulated by global atmospheric general circulation models (GCMs) has been published by the IPCC data center. Such climate models are becoming increasingly sophisticated, but they do include uncertainty due to the limited understanding of climate system and computing power (Trenberth [6]). Besides, we cannot make use of the climate model output directly for hydrological prediction because of the scale difference.

The future temperature in the source region of the Yellow River will increase about 1.5°C in the 21^{st} century simulated by various climate models (Parry *et al.* [1]). We need to provide the future climate scenarios as the input for the runoff prediction. In this paper, we use the suppositional climate scenarios. The temperature scenario has 5 kinds of change based on the basin average value from 1961 to 2009, which increases by +0.3°C, +0.6°C, +0.9°C, +1.2°C and +1.5°C. The precipitation scenario has 7 kinds of change based on the basin average value from 1961 to 2009, which is changed by -15%, -10%,-5%, 0%, 5%, 10%, 15%. There are 35 kinds of combined suppositional scenarios.

4.2 Runoff prediction

The hydrologic cycle is quite complex. The runoff can be predicted by the statistical method under the climate scenarios. We build up the multivariate linear regression formula based on the long-term data series from 1961 to 2009, including precipitation, temperature and runoff depth in the source region of the Yellow River. The formula is as follows:

$$R(P, T) = -154+0.59P-12.17T \tag{1}$$

R, P and T represent runoff depth, basin average precipitation and average temperature, respectively. Table 3 shows the regression statistics results.

Table 3: The regression statistics results.

Regression Statistics			
Multiple R	R Square	Adjusted R Square	Standard Error
0.86	0.75	0.73	22.71

The results from table 4 show that the increasing runoff is corresponding to the increasing of precipitation and decreasing of temperature. Generally, the climate in the source region of the Yellow River is considered to be the “warm-aridness" scenario, which means the temperature will increase and the precipitation will be the opposite way. The runoff depth will reduce by 65.83mm under the most 'warm-aridness' scenario.

Table 4: The response of runoff to different climate scenarios.

ΔP \ ΔT	+0.3	+0.6	+0.9	+1.2	+1.5
-15%	-51.22	-54.87	-58.52	-62.18	-65.83
-10%	-35.17	-38.82	-42.47	-46.12	-49.78
-5%	-19.12	-22.77	-26.42	-30.07	-33.72
0	-3.06	-6.72	-10.37	-14.02	-17.67
5%	12.99	9.34	5.68	2.03	-1.62
10%	29.04	25.39	21.74	18.08	14.43
15%	45.09	41.44	37.79	34.14	30.48

5 Conclusions

This paper analyzed the hydrologic characteristics using the up-to-date data from 1961 to 2010 and predicted the runoff by multivariate linear regression method under different climate scenarios. The conclusions are as following:

(1) The precipitation change varies at different stations because of the temporal and spatial difference, and it has a slight downward trend for the last 50 years in the whole area.

(2) The temperature had increased, especially during the last ten years. This change in the source region of the Yellow River, even in the whole Qinghai-Tibet Plateau, is corresponding to global warming.

(3) The runoff reached the maximum value in every hydrologic station in the 1980s, and since then it reduced gradually because of the rising temperature and decreasing precipitation. The decadal mean discharge in every station did not show the same changing trend, and probably due to the mechanism for generating the runoff. The runoff distribution within the year is unbalanced. This situation will easily cause drought and flood. We should pay more attention to the monthly change.

(4) The runoff is predicted under different suppositional climate scenarios. The rising temperature will increase glacier and snow melt, and affect the runoff volume. The runoff is more sensitive to the precipitation change. It could reduce 40% of the average value under the most "warm-aridness" scenarios.

Acknowledgements

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