Bulgarian Chemical Communications, Special Edition H, (pp. 209 – 213) 2017

The factor analysis of climatic change on water resource: a case study in Haihe river basin of Hebei province

A.J. Shao, L.Y. Zhao, S.W. Wang

Hebei GEO University, Shijiazhuang, China

Received May 25, 2017; Revised July 20, 2017

Hebei is a province of north China. According to the data of climate and runoff from 68 weather stations and 105 hydrologic stations in Hebei province between 1956 and 2000, the change of climatic essential factors and runoff are analyzed. Since the 1960s, the average annual temperature in Hebei province has been increasing gradually. Compared with the 1960s, the average temperature in the 1990s has risen 0.9℃. From the age, the average annual evaporation in Hebei province has appeared a tendency of decline. And it descends 62 mm every ten years on average. The average year's precipitation has gradually diminished year by year. The precipitation in the 1990s has decreased 60 mm compared with the 1950s. The average year's runoff of the whole province, which declines 19.4×108 m3 every ten years on average, emerging a gradually decreasing trend from the 1950s to the 1990s, is 120.2×108 m3. With the decrease of the precipitation and the rise of the temperature, the runoff declines. The models of climatic essential factors and the runoff established by utilizing the multiple regression analysis are logarithmic non-linear functions. Obviously, the impact of precipitation variety on the runoff is more than the effect of the temperature or the evaporation change on the runoff by the sensitivity analysis. According to the prediction of the future climatic change with regard to the runoff, the whole province runoff will alter from 114.36 to 138.24×108 m3 in 2030. Similarly, the runoff will vary from 106.8 to 137.8×108 m3 in 2050.

Keywords: climatic change, runoff, water resources, sensitivity, analysis, prediction

INTRODUCTION

Hebei, a province of north China, is a severely resource-based water-deficient area. The amount of water resources per capita or acre of the whole province is respectively 1/7 and 1/9 of the national average, far below internationally recognized severe water shortage cordon. The mean annual runoff of the whole province is 120.8×108 m3, which is 58.5% of the total amount of water resources. The surface runoff takes an important position in the constitution of water resources.

The change of water resources is closely connected with climatic conditions, and climate change has a direct influence on runoff. Internationally the research into climate change impacts on runoff is carried out based on hydrologic model of basin and water resources assessment model [1]. The commonly used hydrological models such as SLURP model, HBV model, macroPDM model and so on, have already gradually developed and applied to the research of the prediction of climate change impacts on water resources [2]. For the moment, domestic and overseas scholars are doing research based on distributed hydrologic model coupled between GIS/RS and climatic model. And they have made certain progress. The distributed hydrologic model has already not only become important means of currently multi-target hydrologic investigation oriented, but also is the trend or direction of the development of modern hydrologic model[3-6]. However, there are not so many models on influence of climatic factor for the runoff in a large scale, furthermore, the complexity and uncertainty of climate factors make all the GCM climatic models should be enhanced further.

This article mainly studies the effects of changes of meteorological factors on surface runoff. According to the data of climate and assessment of surface water resources from 68 weather stations and 105 hydrological stations in Hebei province from 1956 to 2000, the change of climatic factors and runoff are analyzed. Because of the nonlinear relations between runoff and climatic elements, we establish a logarithmic non-linear statistical model by multiple regression analysis, referring to documents written by domestic and overseas scholars [7-11]. We take meteorological elements such as precipitation, evaporation and temperature into consideration. Then, we carry on sensitivity analysis of the effects of changes of climatic elements on runoff using different climatic situations, and we predict surface runoff according to future climate change.

* To whom all correspondence should be sent:
E-mail: shaoaijun@sohu.com

CHARACTERISTICS OF CLIMATE CHANGE

Temperature

Temperature is one of the significant meteorological elements. A great deal of domestic and international researches indicates that, in the last hundred years, the earth weather system is undergoing a marked change, the center of which is global warming. The temperature in China has gone up by 0.4 to 0.5˚C, so the recent twenty years is the warmest periods of the 20th century. The lowest of mean annual temperature in Hebei province is 9.8˚C in 1960s, rising gradually later. The highest temperature is 10.7˚C in 1990s, which is 0.9˚C higher than that in 1960s. And the temperature rises 0.3℃ during every decade [12, 13] (Table 1). According to the age, the mean annual temperature in Hebei province, going up 0.3 to 0.4℃ during every decade, is on the rise in general. The temperature rises by a large margin, above 1℃ in most areas of the Eastern Hebei Plains, Yanshan hilly areas, parts of the Northern Hebei Plateaus and local regions of Taihang Mountains Plains.

Table 1 The average temperature in every ten years in the 20th century in Hebei province (˚C).

	1950s	1960s	1970s	1980s	1990s
Mountain area	7.8	8.6	8.7	8.8	9.3
Plain area	11.9	12.2	12.2	12.3	12.9
Whole province	9.9	9.8	9.9	10.1	10.7

Evaporation

Evaporation is not only one of the important segments of water circulation, but also the major meteorological element. On the basis of observed data by 20 cm caliber evaporation pan, the maximum of mean annual evaporation in Hebei province is 1881 mm in 1960s, then falling gradually later. According to the age, the mean annual evaporation in Hebei province, diminishing 62 mm during every decade, shown a declined trend totally. The evaporation falls by a large margin, over 220 mm among western of the Eastern Hebei Plains, middle of Taihang Mountains and eastern of Taihang Mountains Plains. People may think that climate warming may increase evaporation from terrestrial water surface, but the result is opposite. According to the research, there is an obviously positive interrelationship between the main cause for evaporation decline and the decrease in average wind velocity [14] (Table 2).

Table 2 The average evaporation in every ten years in the 20th century in Hebei province (mm)

	1950s	1960s	1970s	1980s	1990s
Mountain area	1739	1798	1771	1674	1648
Plain area	1996	2048	1932	1764	1707
Whole province	1860	1881	1816	1705	1695

Precipitation

Atmospheric precipitation, the important segments of water circulation and one of the most significant meteorological element, is the main source of forming surface runoff. In a word, the general tendency is that the precipitation in Hebei province has become gradually less by age. Besides, the range of reduction of the mountainous regions is more than that of the plain areas [15] (Table 3).

Table 3 The average precipitation in every ten years in the 20th century in Hebei province (mm)

	1950s	1960s	1970s	1980s	1990s
Mountain area	590	545	541	510	522
Plain area	560	582	551	526	507
Whole province	576	561	545	517	516

IMPACT OF CLIMATE CHANGE ON SURFACE RUNOFF

Surface runoff is expressed by river runoff. According to a series of hydro-meteorological data from 1956 to 2000, the maximum of the surface runoff of the whole province is 294×108 m^3(in 1959), besides the minimum is 45.3×108 m^3 (in 1999) and the extremum ratio is 6.5. The variation for overyear is rather big.

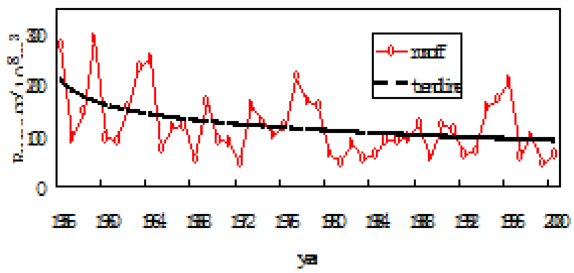

Fig 1. The runoff and the trend line

The runoff fluctuates a lot during 1950s, 1960s and 1970s, especially in 1956, 1959 and 1963. On the contrary, it fluctuates a little in 1980s. The range of change in runoff increases in 1990s particularly in 1996, which is related to the great floods in 1996.

The general tendency is that the runoff has become less by age (Figure 1).

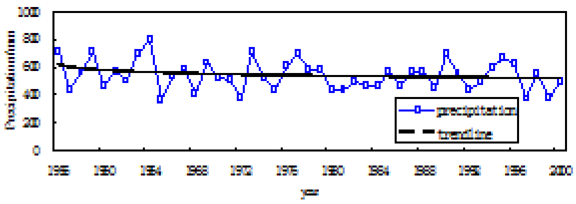

Fig 2. The precipitation and the trendline

The maximum of the annual precipitation of the whole province is 795.2 mm (in 1964), and the minimum is 366.3 mm (in 1965). The whole tendency is that the precipitation is dropping year by year (Figure 2). The tendency of runoff is in accordance with that of precipitation, and the change of runoff is obviously under the control of precipitation. That is to say, the runoff increases with the rise of precipitation, and it decreases with the reducing of precipitation. The peak or crest value of precipitation curve is in accordance with that of runoff curve completely. The maximum of the annual evaporation of the whole province is 2104.4 mm (in 1972), and the minimum is 1465.2 mm(in 1956).

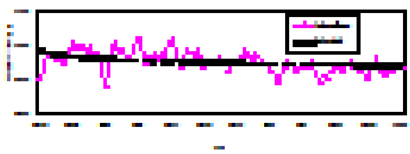

Fig 3. The evaporation and the trendline

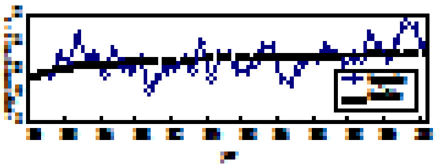

Fig 4. The temperature and the trendline.

The general tendency is that the evaporation has become less year by year, which is in accordance with the tendency of runoff (Figure 3). The maximum of the temperature of the whole province is 11.6℃ (in 1998), and the minimum is 7.9℃ (in 1956). The whole tendency is that the temperature has been rising year by year, which is opposite to the tendency of runoff. That is to say, the runoff decreases with the rise of temperature (Figure 4).

The tendency of surface runoff of the whole province nearly keeps in step with that of precipitation, and it decreases with the reducing of precipitation. The tendency of surface runoff is opposite to that of temperature, and it decreases with the rise of temperature. In accordance with the hydro-meteorological observed data of the whole province from 1956 to 2000, we establish a statistical model, which indicates the relationship among the surface runoff y ($10^8 m^3$/a), precipitation x1 (mm/a), temperature x2 (˚C /a) and evaporation x3 (mm/a), by statistical software—Eviews. The statistical model is as follows:

Model one: $$\ln y = -10.2 + 2.14 \ln x_1 - 0.74 \ln x_2 \qquad (1)$$

Model two: $$\ln y = -26.5 + 2.45 \ln x_1 + 1.05 \ln x_3 \qquad (2)$$

Through statistical examination, we can see that in the Model One, the calculated value F=69.4, the value referred to table F_α=3.21(α=0.05), it is markedly interrelated because of $F > F_\alpha$. In the Model Two, the calculated value F=76.1, the value referred to table F_α=3.21(α=0.05), it is also markedly interrelated owing to $F > F_\alpha$. Consequently, we can carry out the related forecast using the model established.

From the model mentioned above, we can see that precipitation is in positive correlation with runoff, and it is in negative correlation with temperature, namely, runoff increases with the rise of precipitation and it decreases with the rise of temperature. In addition, according to the observed data, a positive correlation is found between evaporation and runoff, and both of them show a downward tendency with the passage of time.

From the model mentioned above, according to the change of meteorological factor, we can analyze the change in runoff. The method is known as sensitivity analysis of change in climatic elements on runoff. Precipitation ranges from –20% to +20%, which is the same as evaporation, and the temperature ranges from 0 to +3℃We can obtain the response of runoff to different kinds of changes in climatic elements by calculation (Table 4).

From Table 4 we can see that the temperature rises and the runoff decreases at constant precipitation. Both the precipitation and the runoff rise at constant temperature. The less the precipitation is, the higher the temperature is and the less the runoff is. The response to runoff is more distinct during high or low flow year. Obviously, the impact of precipitation on runoff is more than the effect of change in temperature or evaporation on runoff. At present, the decreasing precipitation is one of the major causes for the reducing of runoff.

Table 4. The response of the runoff to the climatic changes

Changes in precipitation		-20%	-10%	0	+10%	+20%
Changes in temperature	0˚C	-38%	-20.1%	0	22.6%	47.7%
	+1˚C	-42.6%	-24.7%	-4.6%	18%	43.1%
	+2˚C	-46.7%	-28.8%	-8.7%	13.9%	39%
	+3˚C	-50.4%	-32.5%	-12.4%	10.2%	35.3%
Changes in evaporation	-20%	-65.5%	-44.9%	-20.9%	5.4%	35.4%
	-10%	-55.5%	-34.5%	-10.5%	15.8%	45.8%
	0	-45%	-24%	0	26.3%	56.3%
	+10%	-34.5%	-13.5%	10.5%	36.8%	66.8%
	+20%	-24%	-3%	21%	47.3%	77.3%

IMPACT OF FUTURE CLIMATE CHANGE on SURFACE RUNOFF

Prediction of Future Climate Change in Hebei Province

The United Nations Intergovernmental Panel on Climate Change (IPCC), which is jointly established by World Meteorological Organization (WMO) and the UN Environment Programme (UNEP) in 1988, is an intergovernmental organization.

The third assessment by IPCC shows that the global average surface temperature has been rising continually since 1861. The added value of the 20th century is 0.6±0.2˚C. In accordance with the prediction using the global weather patterns of IPCC opened in 2002 by Chinese academics, they make tendency forecast for climate change of the 20th century in Mainland China. Besides, they present the change of average annual temperature and annual precipitation in 2030 and 2050 in Hebei province according to analog results of regional weather patterns provided by National Climate Center. These will serve as a basis. They predict the surface runoff in 2030 and 2050 in Hebei province on the basis of the statistical assessment model of impacts of climate change on surface runoff in Hebei province in recent 50 years.

The prediction of future climate change shows that, in 2030, the average annual temperature of Hebei province will rise over 1˚C, as compared with 1.3 to 1.4˚C in the northern part of Zhangjiakou, Chengde, Qinhuangdao and the northeastern part of Tangshan, 1.2 to 1.3˚C in the southern part of Zhangjiakou, Langfang and the southwestern part of Tangshan, and 1.1 to 1.2˚C in the south-central part of the region. In addition, the annual precipitation will be widespread increase. The annual precipitation will go up 3% to 5% in the northern part of Zhangjiakou, Chengde, and part of the city of Langfang, as compared with 9% to 13% on the east coast of Tangshan, in part of Qinhuangdao, Cangzhou, the southern part of Shijiazhuang, Xingtai and Handan, and 5% to 9% in other regions. In 2050, the average annual temperature of Hebei province will still be rising continuously.

Prediction of Surface Runoff in Hebei Province in 2030 and 2050

According to the statistical assessment model of impacts of climate change on surface runoff in Hebei in recent 50 years, the multivariate statistical method mentioned above reflects the response of runoff to climate change, namely, the sensitivity of climate change towards the effect of runoff. Runoff is the most sensitivity to climate change in variables of water resources. Combining with the prediction of future climate change provided by National Climate Center, this section makes a prediction for change in water resources under the circumstance of future climate change in Hebei province in the aspect of runoff on the basis of these models, which is used as a reference in plan for utilization of water resources in Hebei province in the future.

Table 5 and 6 are the response of surface runoff in Hebei province on climate condition predicted in 2030 and 2050 respectively. The temperature in Hebei province in 2030 is on the high side, ranging from 1.1 to 1.4˚C, and the annual precipitation will rise ranging from 4% to 12%.

The established mathematical models indicate the relationship of climatic condition by runoff, temperature and precipitation in the past 50 years. It also reflects the response of surface runoff in Hebei to changes in climatic element without analyzing the effects of artificial factors, such as reservoir filling cutoff of mountainous areas, the groundwater over-extracted in plain regions, the lowering of the groundwater table and so on. Therefore, the prediction based on these mathematical models has a great deal of uncertainty. The conclusion we may have would be preliminary, and it can only reflect the impacts of changes in temperature and precipitation on surface runoff in the present circumstances.

Table. 5. The prediction of the runoff in Hebei province in 2030 ($10^8 m^3$).

Changes in precipitation		+4%	+6%	+8%	+10%	+12%
Changes in	+1.1˚C	117.24	122.4	127.56	132.84	138.24

temperature	+1.2˚C	116.28	121.44	126.6	131.88	137.28
	+1.3˚C	115.2	120.36	125.52	130.8	136.2
	+1.4˚C	114.36	119.52	124.56	129.96	135.36

Table 6. The prediction of the runoff in Hebei province in 2050 (108m^3).

Changes in precipitation		+4%	+6%	+8%	+10%	+12%	+14%
	+1.7˚C	111.3	116.5	121.6	126.9	132.3	137.8
	+1.8˚C	110.	115.5	120.7	126	131.4	136.9
Changes	+1.9˚C	109.4	114.6	119.7	125.0	130.4	135.9
in temperature	+2.0˚C	10^8.6	113.4	118.9	124.2	129.6	135.1
	+2.1˚C	107.6	112.8	117.9	123.2	128.6	134.1
	+2.2˚C	106.8	111.9	117.1	122.4	127.8	133.3

CONCLUSION

(1)According to the analysis of the data of climate and assessment of surface water resources from 68 weather stations and 105 hydrological stations in Hebei province in recent 50 years — from 1956 to 2000, the lowest of the average annual temperature in Hebei is in 1960s, rising gradually later. And the highest is in 1990s, 0.9˚C increase over that of 1960s. The average annual temperature rises 0.3 to 0.4℃ during every decade. According to the age, the mean annual evaporation in Hebei province, diminishing 62mm during every decade, shown a declined trend on the whole. The general tendency is that the precipitation of the whole province has become gradually less by age. The average annual precipitation of the whole province in 1990s decreases 60mm comparing to that in 1950s. There is 15mm decline during every decade. Besides, the range of reduction of the mountainous regions is more than that of the plain areas.

(2) The average annual surface runoff of the whole province is 120.2×10^8 m^3, and the mountainous areas is 102×10^8 m^3, as compared with 18.2×10^8 m^3 of the plain regions. The mean annual runoff has shown a trend of decrease since from 1950s to 1990s. The mean annual runoff declines 19.4×10^8 m^3 during every decade. One of the major causes for the decrease is the general reduction of precipitation. The large amount of precipitation in 1996 is the chief reason for runoff rising a bit in 1990s. Runoff decreases with the reduction of precipitation and it increases with the decline of temperature. Their relationship is nonlinear logarithm. The sensitivity analysis shows that the impact of precipitation on runoff is more than the effect of change in temperature or evaporation on runoff.

(3) On the basis of the prediction of future climate change of surface runoff in Hebei, the surface runoff of the whole province in 2030 ranges from 114.36 to 138.24×10^8 m^3, as compared with ranging from 106.8 to 137.8×10^8 m^3 in 2050. The factors that influence change in runoff are complicated, including both climatic and artificial elements. Hence, the conclusion we may have would be preliminary, and it can only reflect the impacts of changes in climatic factors on runoff in the present circumstances.

REFERENCES

1. Working Group of IPCC, Technical Guidelines for Assessing Climate Change Impacts and Adapting [R], 1994.
2. C. Lingfei, W. Hongya, *Resources Science*, **26**(6), 62 (2004).
3. R.A. Freeze, R.L. Harlan, *Journal of Hydrology*, **9**, 237 (1969).
4. K.J. Beven, M.J. Kirkby, *Hydrological Sciences Bulletin*, **24**(1), 43 (1979).
5. B. Storm, K.H. Jensen, *Nordic Hydrology*, **15**, 283 (1984).
6. D. Yang, S. Herath, K. MMusiake, *Hydrological Processes*, **11**, 2085 (2001).
7. Liu Changming, Fu Guobin. Some analyses of climate change impacts on hydrological regimes in China [A]. ZHANG Yi (chief editor). Climate Changes and Their Impacts [C]. Beijing: Meteorology Press, 1993.
8. Xu C, Chen Y, Yang Y, Hao X，Shen Y. *Journal of Geographical Sciences*, **20**(4), 599 (2010).
9. X. Zhang, Cao, Guo. *International Journal of Sediment Research*, **25**(3), 283 (2010).
10. H. Wang, Y. Chen, W. Li, H. Deng. Chinese Geographical Science, **23**(3), 286 (2013).
11. Y.Songcai, *Quaternary Sciences*, **22**(2), 148 (2002).
12. L. Xuefeng, R.Xin, L.Yuanhua, *Scientia Meteorologica Sinica*, **25**(6), 638 (2005).
13. L. Yuanhua, C. Shaojing, *Chinese Journal of Agrometeorology*, **26**(4), 224 (2005).
14. A. Yuegai, L.Yuanhua, *Journal of Arid Land Resources and Environment*, 19(4), 159 (2005).
15. S. Aijun, H. Chunsheng, *China Rural Water and Hydropower*, **10**, 38 (2002).