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Review on Impact of Climate Change on Water Resources System in the Upper Reaches of Yellow River

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Abstract: Results and progresses of studies on the impact of global warming on the water resources system in the upper reaches of Yellow River in the recent years are introduced based on relevant papers published in various Chinese natural science journals. The studies show that the hydrological and water resources system in the basin is quite particular, because the basin is geographically situated in the Qinghai-Tibetan Plateau, where the average altitude is over 3000 m and the climate is very cold, so it is very sensitive to climate changes, especially to precipitation changes. The surface runoff in the basin increases with precipitation increasing and decreases with temperature rising. The evolutional trend of water cycle in the upper reaches of Yellow River in the 21st century is that the transpiration increases, and the surface runoff decreases with persistent temperature rising. As global temperature rising, the evaporation on land and ocean and the moisture in the atmosphere will generally increase, and the global mean precipitation will also increase, which would seemingly increase the probability of precipitation in the upper reaches of Yellow River. However, the increment in evaporation resulted from temperature rising not only cancels out to a great extent the potential increment of precipitation, but also makes water resources decrease to a certain extent because the range of precipitation increase is very limited. Therefore the future situation of water resources in the upper reaches of Yellow River is still not optimistic. It is necessary to solve the problem of water resources shortage in north and northwest China through various approaches, such as the South-to-North Water Diversion Project, so as to abate and adapt to the unfavorable impact of future climate changes.

Key words: global warming; the upper reaches of Yellow River; water resources

Introduction

A large part of the Yellow River basin is situated in the arid and semi-arid zone in the middle latitudes, where water resources are scarce innately. By way of the biggest water supply source in Northwest China and North China, the runoff in the Yellow River basin only account for 2% of countrywide total river runoff, but the river bears 15% of the irrigation of the countrywide total area of cultivated land and 12% of the water supply of countrywide total population. The upper reaches of Yellow River (It only refers to the catchment ranging from 32° 30′ N to 30° 00′ N, 95° 50′ E to 103° 30′ E, upstream basin of Tangnag within Qinghai Province in the northeast of the Qinghai-Tibetan Plateau) are the major contributor of the runoff in the whole Yellow River basin. The catchment covers 121.9×10^3 km^2, only accounting for 16.2% of the total area of the Yellow River basin (752.4×10^3 km^2), but yields a normal runoff of 24.872×10^9 m^3 per year, accounting for more than 40 % of the total runoff in the Yellow River basin (58×10^9 m^3 per year). Therefore, the upper basin of Tangnag is called the "water tower" of the whole Yellow River basin [1]. The intense response of society and economy in the whole Yellow River basin and the Huanghuai Plain will be incurred once the runoff from the upper Yellow River basin oscillates greatly [2]. The runoff from the upper reaches of Yellow River has been reducing in recent 10 years, and the contradiction between supply and demand on water resources in the Yellow River basin has become more poignant along with global warming. More and more

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scientists has engaged in study on the impact of climate changes on the water resources system of the upper basin, and many momentous results, valuable for reducing the uncertainty of the prediction of water resources changes and accelerating the sustainable utilization of water resources and the sustainable development of society and economy in the Yellow River basin, have been obtained. The results and achievements obtained on study of the impacts of global warming on water resources in the upper reaches of Yellow River are introduced, and based on review of past studies the new approaches on the study of water resources in the upper reaches of Yellow River in the 21st century are explored in this paper. Because the study of the impact of climate change on the water resources system in the upper reaches of Yellow River basin most focused on predicting the future trend of runoff and its impact on water supply based on the changes of temperature, precipitation, evaporation etc. induced by global warming, this paper is going to summarize the study progresses in impacts of global warming on the water resources system in the upper reaches of Yellow River basin from the following aspects.

1 Precipitation

Most of studies were focused on the macroscopic backdrop of precipitation change, that is, physical and the climatic causes of large-scale precipitation decrease in the upper reaches of Yellow River basin were explored under the great background of global warming aiming at the observed fact of the persistent decrease of precipitation in the upper reaches of Yellow River basin in recent more than 10 years [3−4], and many significant achievements have been obtained. Many important facts of the impact of the ocean-atmosphere system on the temporal and spatial distribution of precipitation in China were discovered, and the impacts of the mightiness or feebleness of East Asian winter monsoon and East Asian summer monsoon on precipitation in the Qinghai-Tibetan Plateau and the northwest of China were explored through analyzing the changes of atmospheric element fields induced by sea surface temperature anomalies [5]. The results show that the strong winter monsoon will bring the cold and rainless weather over the large part of northwest of China (including the upper reaches of Yellow River), resulting in largescale droughts over northwest of China, while the strong summer monsoon will bring the summer high temperature weather, which might frequently last up to autumn or winter, in northwest of China, as well as the summer pluvial weather in the southeast and the summer rainless weather in most of the western central of northwest China. Zhang *et al.* [6] analyzed the impact of global warming on the arid climate over the northeast side of the Qinghai-Tibetan Plateau using the sounding data of 500 hPa, 700 hPa, and 850 hPa at the eight representative meteorological stations in northwest China. The result shows that the global warming makes the summer monsoon in northwest of China weakening, i.e. the south component of August winds weakening and the north component strengthening, and the summer climate drying. Under the impact of global warming, precipitation decreases persistently in the major flow-producing basins between Jimai and Maqu in the upper reaches of Yellow River, which is one of the main reasons for the persistent reduction of runoff in the basin in recent ten years. Xie *et al.* [7] analyzed impacts of typhoon activities on the drought on the northeast side of the Qinghai-Tibetan Plateau. The result shows that there is a corresponding relationship of less typhoon activity years with drought circulation patterns and the droughts on the northeast side of the Plateau, and of more typhoon activity years with pluvial circulation patterns and lots of rain on the northeast side of the Plateau. Yang *et al.* [8] thought that the change in precipitation in the upper reaches of Yellow River is periodic, and it is influenced mostly by the laws of motion of celestial bodies, and the change in the intensity of sunspots, subtropical high ridge position, and earth pole oscillating amplitude. Using the five numerical models including the German ECHAM4, the UK's HadCM2, the American GFDLR15, the Canadian CGCM2, and Australian CSIRO, Gao *et al.* [9] calculated and discussed the future trend of precipitation up to the year 2030 in China. The average projection results of the five models under the condition of only considering the greenhouse gas concentration doubling show that future precipitation is going to slightly decrease with a limited reduction range in the area along Tianshan Mountains in northwest of China, but to increase in other areas. After considering the radiative forcing of sulphate aerosols, the precipitation will gradually decrease in Tianshan Mountains and its north peripheral area from northwest to southeast, but slightly increase in the other areas of northwest China.

2 Runoff

Researches on the responses of the river runoff to climate changes might be mainly divided into three aspects, that is, 1) supposing some scenario combinations of climate changes, and then calculating the potential changes of the runoff by using hydrology models in order to analysis the

potential impact of climate changes on water resources in the upper reaches of Yellow River [10]; 2) creating future climate change scenario based on the simulating results of GCMs in order to determine future hydrologic status in terms of hydrology models [2]; 3) establishing statistical models using the statistic correlativity and evolvement laws of long-term hydrologic and meteorological series in order to forecast the impact of climate change on water resources in the upper reaches of Yellow River [11]. Some scientists attempted to explain the runoff changes of the upper basin from the angle of physical mechanisms, such as the statistic correlativity of runoff in the Yellow River basin with El Niño events, Pacific sea surface temperatures, the periodic change of sunspots activity and so on. With regard to the future trend of runoff in the upper reaches of Yellow River, some researchers considered that the runoff will as a whole exhibit a decreasing trend in the future along with global warming [2,10,12]; however, others thought that global warming makes water cycle strengthened, evaporation over oceans and lands increased, and vapour content in the atmosphere increased, leading to the overall increase in precipitation in the future. After analyzing the fact of climatic environment change of Northwest China, Shi *et al.* [13] discovered that the precipitation and runoff in the west and central parts of Northwest China have obviously increased since 1987, and the climate has obviously changed from warm-dry pattern to warm-wet pattern. Besides, some inconspicuous evidence of climate transformation has occurred in parts of Northwest China. Although the east of Northwest China (including the upper reaches of Yellow River) has been in the rainless and the low flow period in recent 10 years, but has probably arrived at the lowest bottom of interdecadal variations, and the climate has a potential trend from warm-dry to warm-wet. However, it is difficult to determine the detail time of the transformation. The above studies indicate that the sensitivity of the runoff in the upper reaches of Yellow River to precipitation is far greater than to temperature, and the runoff increases with precipitation increase and decreases with temperature rise. The runoff will decrease by 3%−7% if temperature rises 1℃ and precipitation is changeless, and the more the precipitation reduces, the more the runoff decreases [14].

3 Temperature

Researches on temperature emphasized more particularly on temperature's response to global warming and its interannual and interdecadal variation characteristics and so on. Research results indicate that the temperature in the Yellow River basin presents a rising trend in naturally annual and decadal variation, and the trend is more obvious after the 1990s. However, the response degree of temperature in the various regions of the basin is different because of their different geographical location [4]. Xu *et al.* [15] analyzed the scenarios of climate change in northwest of China in summer and winter in the 21st century using the simulated results of seven global ocean-atmosphere coupling climate system models (CCC, CCSR, CSIRO, DKRZ, GFDL, HADL, and NCAR) under the conditions of allowing for the impact of greenhouse gas increase only (GG), and the sulphate aerosol and greenhouse gas increases at the same (GS), supplied by the Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC).

The analysis results show that the future trend of climate change in northwest of China is identical with the warming trend of global, east Asian and whole China, and that the rise extent of temperature is higher than the mean for the globe, East Asia and whole China. The analysis results of the linear trends of various seasonal climate change in the future 100 years indicate that the rise extent of temperature in the winter whether in GG or GS case is the largest, being 5−8 ℃/100a, and the temperature rise extent in the Xinjiang area is the largest among those in northwest of China. The minimum and maximum temperatures all will rise markedly because the impacts of human activity in the 21st century, and their linear trends might reach 4−6 ℃/100a. Because there are uncertainties in the regional scale simulations of GCMs, and more study in the above field needs to be done in the future.

4 Evaporation

Researches on evaporations (transpiration) in the upper reaches of Yellow River were relatively lacking in comparison with those on precipitation, runoff and temperature variations, and scientists had some discrepancies in the impacts of global warming on evaporations in the basin. Li *et al.* [14] analyzed the variations of total evaporation, hours of sunshine, air temperature, air saturation deficiency in the basin, with special emphasis on the impacts of above factors on the total evaporation, and results indicate that the total evaporation in the basin presented a rising trend year by year. Because the increases of sunshine hours, air temperature and saturation deficiency and so on accelerated the increasing of total grassland evaporation, while the total evaporation increase and precipitation decrease directly lead to the reduction of runoff and the spread of grassland

desertification in the upper basin. Zhang *et al.* [16] analyzed water cycle in the riverhead area of the Yellow River, and thought that the future change trend of water cycle in the 21st century will be evaporation increasing and runoff decreasing further due to the persistent rise of temperature in northwest of China. Qiu *et al.* [17] analyzed the climatic trend of evaporation of evaporation pans in the whole Yellow River basin in recent 40 years. The analysis result indicates the regional climatic trends of evaporation differed from that for whole Yellow River basin. The climatic trend of evaporation of evaporation pans showed a decline trend in the upper and lower reaches of the River and a very gentle rising trend in the middle reaches. The observation and study on the evaporation should be intensified because the area of the upper reaches of Yellow River is quite far-flung and whose underlying surface statuses have prodigious differences.

5 Epilogue

It can be observed from the above research results that the water resource system is hypersensitive to global warming, and the system is much more sensitive to precipitation changes than to temperature changes. The river runoff increases with precipitation increase, and decreases with temperature rise. The future trend of water cycle in the 21st century will be evaporation increasing and runoff decreasing further along with persistent temperature rise. The global precipitation will present an overall rising trend due to the increase in water vapour in atmosphere as well as the evaporation on ocean and land surfaces brought about by temperature rise. Although the probability of future precipitation increases in the upper reaches of Yellow River, the increment range of precipitation will be limited, and the increment of evaporation caused by temperature rise might cancel out the increment of precipitation, to some extent leading to the reduction of water resources in the upper Yellow River basin. Therefore, water resource status in the basin is not optimistic in the future. Northwest and North China still are the arid and semi-arid areas, and it is necessary to solve water resource problem existing in Northwest and North China through various means including the reasonable utilization and distribution of water resources, the exploitation and utilization of various technologies of water-saving, the enhancement of the water-saving consciousness of local people, and the implementation of the South-to-North Water Diversion Project and so on.

We think that some problems need to be solved although many results have been obtained in the researches on the impact of climate changes on the water resource system in the upper reaches of Yellow River in recent years, such as: 1) the existing studies lack the analysis and discussion on the whole mechanism process of the impacts of climate changes on water cycles, especially on the variation of runoff-producing course brought about by the altering of the basin's underlying surface under the condition of global warming, and changes in the vertical and horizontal movement of moisture in soil and their connection; 2) Most studies focus on the mean variation of the basin's surface runoff and lack the analysis and discussion on the impact of climate change on hydrologic extreme events so that the studies lack the guide meaning to the ordered utilizing of water resources in the basin in the future; 3) the forecast technique of GCMs and the hydrological coupling model has two shortages: first, the problem of precision, that is, the precipitation and the runoff process on land surface have severe sub-grid heterogeneity, and most of GCMs all presume the uniform vegetation and soil in one grid cell of climatic models, so that the hydrological and land surface parameters of the models are oversimplified; and second, the problem of uncertainty, that is, the uncertain factors such as the creation of climate scenarios, the framework of hydrological models and the different space scale conversion between hydrological models and GCMs and so on reduce the reliability of the forecast results because of lacking profound insight to hydrological physical processes and the interior changes within atmosphere system. Presumptive climate scenario method couldn't determine the exact time and scenarios of the precipitation, temperature and runoff changes in the future, bringing about uncertainty of water resource management in the upper reaches of Yellow River in the future.

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