

A Review of Research on the Impact of Global Climate Change on Hydrology and Water Resources

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Abstract: Climate change has become one of the environmental problems that the scientific community, governments and the public pay attention to. Climate change may have a disastrous impact on the ecosystem and social economy. The impacts of climate change are multi-scale, all-round and multi-level, with both positive and negative impacts, but its negative impacts are more concerned. In recent years, with the gradual deterioration of global climate, it has a great impact on people's production and life, especially on hydrology and water resources. This paper introduces the current situation and progress of research on the impact of global climate change on hydrology and water resources at home and abroad, with emphasis on the current situation and progress of research at home.

Keywords: Global Climate Change; Hydrology and Water Resources; Hydrological Simulation; Hydrological Process.

1. Introduction

In the past century, the global climate has undergone significant changes characterized by global warming. According to the Fourth Assessment Report of the IPCC, since 1750, due to the impact of human activities, the concentration of CO₂, CH₄ and N₂O in the global atmosphere has significantly increased, and the overall impact of human activities on climate has been warming. In the past 100 years, the average surface temperature in China has increased by 0.5 °C to 0.8 °C, and the sea level has risen by 0.1 to 0.2m. Climate change has become one of the common concerns of the scientific community, governments, and the public today. Global warming has had an impact on natural ecosystems in many regions of the world, such as rising sea levels, glacier retreat, and declining lake levels.

In recent years, the gradual deterioration of global climate has had a significant impact on people's production and life, especially on hydrology and water resources. Climate change will inevitably cause changes in the water cycle, leading to the redistribution of water resources in time and space, as well as changes in the total amount of water resources, thereby affecting the ecological environment and socio-economic development. Further research on the impact of climate change on hydrology and water resources can provide scientific basis for the rational development and sustainable utilization of water resources, as well as sustainable economic and social development.

2. Present Foreign and Domestic Research

2.1. Development History of Foreign Research

The research on the impact of climate change began in the late 1970s. It was initiated by the World Meteorological Organization (WMO), the International Science Council (ICSU), the United Nations Environment Programme

(UNEP), the International Association of Hydrological Sciences (IAHS) and other international organizations, and has successively carried out and implemented the World Climate Impact Research Program (WCRP), the Global Energy and Water Cycle Program (GEWEX), etc. [1]. In the mid-1980s, the research on the impact of climate change on water resources attracted great attention in the international hydrological community, and a lot of research work was carried out [2]. In 1988, WMO and UNEP jointly established the Intergovernmental Panel on Climate Change (IPCC), which specializes in scientific assessment of climate change, regularly summarizes the latest achievements, and provides authoritative climate assessment reports [3]. Since the 1990s, research on the impact of climate change on hydrological and water resources has rapidly increased and has attracted more attention. The theme of the Hydrological Science Group of the 20th IUGC Conference in 1991 was to explore the hydrological processes of soil atmosphere interactions; In 1993, the 6th International Association for Meteorology and Atmospheric Physics and the 4th International Association for Water Science (IAMAP-IAHS) Joint Conference was held in Japan, with the themes of climate change, interactions and impacts between the atmosphere and the hydrosphere, and large-scale climate and hydrological simulation technologies; At the 7th International Conference on Hydrology in 2005, the study of hydrological response to climate change became a hot topic of discussion.

Entering the 21st century, climate change has become the main topic of international conferences in various countries. For example, the IAHS conference held in Brazil in 2004 included a discussion topic on the impact of climate change on hydrology and water resources. In 2006, a joint meeting of the Earth Systems science Alliance (ESSP) and the Global Water System Plan (GWSP) was held in Beijing, where the fourth theme discussed the impact of climate change on coastal zones and terrestrial rivers. The scientific issues related to the impact of climate change on hydrology and

water resources were discussed at the Fourth World Water Forum held in Mexico and the IUGG International Conference held in Italy in 2007. In August of the same year, the World Climate Research Programme held a seminar on seasonal prediction in Barcelona, Spain, where the methods and accuracy of seasonal climate prediction were intensively discussed. At the Climate Summit held in Copenhagen, Denmark, in December 2009, the core of the negotiations was whether to adhere to the Convention, the Protocol and the Bali Road Map. Developed countries continued to take the lead in reducing emissions, and how to reflect the principle of "common but differentiated responsibilities" and the principle of fairness. At the meeting, representatives from various countries engaged in intense discussions and negotiations on carbon emissions.

2.2. Domestic Research and Development Process

With the global climate change, China is also facing the problem of water resource shortage. The research on the impact of climate change on hydrology and water resources in China started relatively late. In the "Seventh Five Year Plan" national major project "Research on Climate and Sea Level Change, Trends and Effects in China," the research topic on the impact of climate change on water resources in Northwest and North China was first established. In the "Eighth Five Year Plan" national key project "Impact of climate change on water resources and adaptation strategies", The basin Hydrological model and GCM model are combined to systematically study the impact of Global change on China's hydrology and water resources and their supply and demand; The "Ninth Five Year Plan" science and technology research project "Research on the Impact Assessment Model of Climate Anomaly on China's Water Cycle and Water Resources" focuses on the establishment of climate assessment models; The key project of the "Tenth Five Year Plan", "Impact threshold and comprehensive evaluation of climate change on China's freshwater resources", focuses on the vulnerability of Water resources of China and the impact threshold of climate change.

After entering the 21st century, Chinese researchers have conducted extensive research on the impact of climate change on the distribution of water resources in China, and have achieved certain research results. After analyzing the monthly average temperature and precipitation data observed from 1951 to 2000 at 385 observation stations in China, the researchers of the Institute of Environment and Engineering in Cold and Dry Regions of the Chinese Academy of Sciences preliminarily obtained some characteristics of the change trend of temperature and precipitation in China in the past 50 years. The trend of average temperature changes in China over the past 50 years is consistent with that of global average temperature changes. Especially since the 1970s, the increase in temperature has been significantly higher than the global average. The vast areas of central, northern, and northeastern regions in the northwest region are the regions with the fastest and largest warming rates. The study also found that since the 1970s, there has been no significant trend in the national average precipitation, but regional average precipitation has either increased or decreased significantly.

The research of Chinese scholars mainly focuses on regional research, especially in view of the serious shortage of water resources in North China and the problems of the Yellow River basin. After entering the 21st century, they have

made some research and achieved some research results. Liu Chunzhen and others systematically studied the impact of global climate change on hydrology and water resources and water resources supply and demand in China by using random weather models, basin evapotranspiration (evaporation) models, basin Hydrological model, water resources comprehensive assessment models and Atmospheric circulation models (GCMs) to predict future climate scenarios. Gao Ge and others analyzed the impact of extreme climate events on water resources and the impact of climate change on agricultural drought and flood by using the climate, water resources and other relevant data in North China in the past 50 years. Zhang Guosheng et al. analyzed the relationship between the runoff of the upper reaches of the Yellow River and the precipitation and temperature in the basin over the past 38 years, focusing on the impact of arid climate on the water resources of the Yellow River. The results showed that the water resources in the upper reaches of the Yellow River showed a decreasing trend, which was particularly evident after the 1990s. This trend of change is consistent with the trend of summer precipitation in the upper reaches of the Yellow River, the decrease in precipitation during the flood season is the most direct climatic factor for the decrease in flow in the upper reaches of the Yellow River. Tang Guoping believes that water resource vulnerability refers to changes in the structure of the water resource system, a decrease in the quantity and quality of water resources, as well as changes in water supply, demand, management, and natural disasters such as droughts and floods caused by climate change and human activities. Cao Lijing and others believed that there was a significant positive correlation between the annual average precipitation and the annual average moisture content in North China, and the reduction of atmospheric moisture was one of the main factors that directly led to the reduction of precipitation. In the past 50 years, the total amount of water resources in North China has shown a decreasing trend. The reduction of the total amount of water resources is closely related to the reduction of atmospheric moisture. Climate change of atmospheric moisture has an important impact on water resources in North China. Based on the analytical grid data of NECP/NCAR from 1948 to 2003, the climate change of atmospheric water and its impact on water resources in North China were studied. The results show that the atmospheric water vapor content in North China has a continuous downward trend from the early 1960s to the mid-1980s, and has slightly increased since the mid-1980s, but the range is not large. It has a downward trend since the mid-1990s, and is close to the historical lowest level in the early 21st century; The atmospheric water vapor content in North China is closely related to precipitation and total water resources. The decreasing trend of atmospheric water vapor content is consistent with the change of precipitation and total water resources. Liu Chunzhen pointed out that vulnerability refers to the degree to which climate change may cause damage to the water resource system in a certain watershed area, which depends on the sensitivity and adaptability of the water resource system to climate change. Sensitivity reflects the degree to which climate change affects natural hydrological systems such as precipitation, runoff, evaporation, infiltration, etc. through hydrological cycling phenomena, while adaptability reflects the possible adaptation of water resource systems to climate forcing. Chen Guiya's research results show that under the condition of global warming, the annual runoff of the Jialing River basin

will decrease by 23%~27.9% in 2050 and 28.2%~35.2% in 2100, and the average annual runoff in this year is equivalent to the current drought years with a return period of 7 years and a return period of 12.5 years, respectively. Fan Guangzhou et al. simulated and studied the impact of climate change on water resources in different seasons of the Luanhe River Basin during wet and dry years. The results showed that surface runoff, subsurface runoff, underground runoff, and river runoff in the Luanhe River Basin are mainly affected by changes in precipitation, and are less affected by changes in temperature. Zhang Kai et al. conducted a study on the response of glacier regions in the upper reaches of the Heihe River Basin to climate change, indicating that the glaciers in the mountainous areas of the region are constantly shrinking, and the snow line continues to rise, resulting in strong losses.

3. The Impact of Climate Change on Hydrology and Water Resources

3.1. The Interaction between Climate Change, Human Activities, and Water

Climate, human activities, and water are all interdependent and constrained, whether viewed from a scientific or socio-economic development perspective. It should be pointed out that climate factors are not isolated from human activity factors. The interaction between them can be either positive or negative feedback. In the past 20 years, under the combined influence of climate change, population growth, and socio-economic development, the land water cycle in some regions or basins in China has undergone significant changes. In the Haihe River Basin, groundwater overexploitation, river interruption, and decreasing annual inflow have led to an increase in the vertical component of the water cycle. The consequence not only changes the short-term rainstorm runoff relationship, but also changes the interannual and interdecadal rainfall runoff relationship. The decline of water resources in the Haihe River Basin in the past 50 years highlights the consequences of the interaction between climate, human activities, and water.

With the development of social economy and climate change, the amount of water that humans "toss" into the atmosphere through various means will continue to increase. Under the operation of Atmospheric circulation, some of them condense into rain, and then return to land to participate in the land water cycle. The changes in land water cycle provide feedback to the atmosphere through the exchange of water and energy between land and air. Evaporation and soil water are two mutually constrained and inseparable physical quantities in the terrestrial water cycle. They are both highly sensitive to human activities and play an important feedback role in atmospheric motion. On average, 65% of the global precipitation on land is generated by land evaporation, and 35% is generated by water vapor transport from the ocean [4]. For the atmosphere, soil water plays a low-pass filtering role in prolonging atmospheric predictability [5]. For regional and continental scales, the size of the internal circulation depends on the amount of water vapor that land can transport to the atmosphere and the amount of water that can condense into clouds and rain after entering the atmosphere. Brubaker [6] et al. introduced the concept of hydrological scale to measure the feedback effect of land surface on the atmosphere. The hydrological scale refers to the effective lateral distance between a certain unit of water vapor leaving the land surface in the form of evaporation and returning to the land surface in

the form of precipitation. In tropical regions and over the Qinghai Tibet Plateau, vertical convective activities are prevalent, and the internal circulation is very active. The hydrological scale is small, and small-scale land surface changes can have a feedback effect on the atmosphere. In the middle latitude Westerlies where the water vapor advection is large, the large-scale land surface changes can have feedback effect on the atmosphere. The impact of human activities on the water cycle varies in different climatic regions. In arid and semi-arid regions with high evaporation capacity, the water consumption entering the atmosphere through evaporation is much greater than in humid and semi humid regions. According to the Water resources of China Bulletin in 2001, the consumption of various water uses in the Hai Luan River and inland river basins accounts for 69% of the water, far more than 48% of the Yangtze River and 46% of the Pearl River.

3.2. Research on the Impact of Climate Change on Hydrological Processes

Climate change mainly refers to significant changes in climate factors such as precipitation and temperature. Among them, precipitation, as the main source of runoff, directly affects the runoff of the watershed, while temperature indirectly affects the runoff production and concentration mechanism of the watershed by changing the water surface, soil evaporation, and plant transpiration. At present, domestic and foreign scholars' research on the impact of climate change on hydrological processes is mainly divided into two categories.

One type uses mathematical statistical methods and correlation methods to analyze the evolution characteristics of various climate and hydrological factors, mainly including precipitation, temperature, and runoff. Jin Junliang and others used Mann Kendall non parametric test and Spearman rank test correlation method to analyze the changes in precipitation, temperature, and runoff in the source area of the Yellow River over the past 60 years. The results showed that annual precipitation, daily highest (low) temperature, and daily average temperature all showed an increasing trend, while annual average runoff showed a decreasing trend. Li Jiaxiu et al. used Mann Kendall trend test method and Canonical correlation analysis method to study the temporal and spatial variation characteristics of temperature and precipitation in different climatic regions in Xinjiang. The results show that the temperature and precipitation in Xinjiang have shown an increasing trend in the past 50 years. Some scholars further studied the correlation between runoff changes and climate factors such as precipitation and temperature based on the correlation analysis method. VAS-SILEV I [7] used mathematical statistical methods to analyze the change characteristics of the time series of climate factors in Bulgaria, and carried out a study on the correlation between runoff and climate factors. The results showed that climate factor changes had a significant impact on river runoff, and the change of water resources in the basin was closely related to climate change. Niu Zhirong et al. conducted a study on the impact of climate change on precipitation and surface runoff in the Qingyuan River basin at the source of the Wei River from 1970 to 2016 using the cumulative curve method of distance adjustment and correlation analysis. The results showed that the impact of temperature changes in the basin over the past 50 years on runoff was very significant.

The other is to quantitatively study the contribution rate of

climate change to runoff change through Hydrological model method, Budyko equation method and other methods, and carry out research on future climate change by setting different future climate scenarios. SUN Yu et al [8] explored the spatial variability of the relative contributions of climate change and changes in catchment characteristics to water flow changes in mesoscale watersheds. The results showed that the contribution rate of climate change to the reduction of runoff in the upper reaches of the Han River from 1990 to 2000 was 65%. Jin Junliang et al. simulated the future changes in water resources in the Haihe River Basin based on a variable infiltration capacity model. The results showed that the VIC model has good adaptability in the Haihe River Basin. In the future, the water resources in the Haihe River Basin will show a slight increase trend from 2021 to 2050, but the uncertainty of the estimated results is relatively high. Wang Lei used Mann Kendall trend test and mutation detection methods to analyze the trend and mutation points of runoff changes in the Haihe River Basin from 1956 to 2000. The results showed that annual runoff showed a significant decrease trend, with the mutation point being 1979. Based on the Budyko equation, research found that climate change contributed 40.89% to the decrease in annual runoff.

Overall, climate change is an important driving factor for regional hydrological changes. Under the background of global warming, the average annual precipitation in most regions is increasing, while the average annual runoff is mostly decreasing. Mathematical statistics, correlation analysis, Hydrological model and other methods are the most commonly used tools to diagnose regional hydrological changes in the context of climate change. Uncertainty is the biggest issue in future climate change impact assessment, and it is an important direction and core content for conducting future climate change research.

3.3. Research on the Impact of Climate Change on Extreme Hydrological Events

Studying the changes in extreme hydrological events under the background of global warming has become a hot topic of concern today. Domestic and foreign scholars have conducted research on the impact of climate change on extreme events by county officials. Previous studies have shown that the frequency of extreme precipitation events has increased in several countries such as the United States and Canada [9,10]. Chinese research also suggests that an increase in CO₂ concentration in the atmosphere may lead to an increase in extreme weather in the south [11]. The research on extreme hydrological events mainly includes three aspects: extreme precipitation, extreme floods, and extreme droughts. Wigley calculated and analyzed the change rule and frequency of extreme values of flood and drought based on the historical precipitation records of England and Wales in recent 20 years. Wu Zhiyong et al. used the VIC model and studied the trend of extreme hydrological events in the Heihe River Basin under the influence of climate change based on climate change scenario data. The coupling of multiple statistical downscaling models and Hydrological model is one of the effective ways to predict the changes of hydrological extreme events under climate change scenarios. Muller Wohlfeil et al. used a downscale model to simulate and study extreme climate events and future hydrological processes in the upstream of the Stor basin in northern Germany. Zhang Yong et al. used the regional climate model PRECIS unidirectional nested HadAM3P to analyze the ability of PRECIS to

simulate extreme precipitation events in contemporary China and the possible trends of extreme precipitation events in China during the 1980s under the B2 scenario. At present, most of the research on the impact of climate change on extreme hydrological events is based on statistical analysis of spatiotemporal changes in the frequency and intensity of extreme hydrological events, which is still at the level of qualitative research. Further quantitative research is needed.

4. Summary

It can be seen from the comprehensive analysis of the research status and development trends of the impact of climate change on hydrology and water resources at home and abroad. Relatively speaking, the research started late in China, especially the development of Climate model and Hydrological model. In terms of research content, the analysis of the evolution laws of hydrological factors such as runoff is an earlier and relatively more extensive research topic both domestically and internationally; Secondly, research on the response of groundwater resources to future climate change has been conducted in multiple watersheds, achieving fruitful results. However, in-depth research is still needed in the coupling of land air models, and simulation accuracy needs to be improved; However, there has been relatively little research on the impact of climate change on extreme hydrological events and adaptive strategies for water resources; Most studies only consider climate change, neglecting the impact of human activities, and cannot accurately predict future water resource evolution. Moreover, most studies focus on analyzing changes in runoff, with little research on the impact on groundwater, water environment, and aquatic ecology.

Acknowledgments

Funding: The authors are grateful to the authorities of driving forces (DJNY2022-36) for financial support from Analysis of the evolution of spatial and temporal patterns of arable land in the northern Weibei dry plateau area. for this study.

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