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# Climate change and water resources: Case study of Eastern Monsoon Region of China

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**Abstract**

This paper addresses the impact of climate change on the water cycle and resource changes in the Eastern Monsoon Region of China (EMRC). It also represents a summary of the achievements made by the National Key Basic Research and Development Program (2010CB428400), where the major research focuses are detection and attribution, extreme floods and droughts, and adaptation of water resources management. Preliminary conclusions can be summarized into four points: 1) Water cycling and water resource changes in the EMRC are rather complicated as the region is impacted by natural changes relating to the strong monsoon influence and also by climate change impacts caused by $CO_2$ emissions due to anthropogenic forcing; 2) the rate of natural variability contributing to the influence on precipitation accounts for about 70%, and the rate from anthropogenic forcing accounts for 30% on average in the EMRC. However, with future scenarios of increasing $CO_2$ emissions, the contribution rate from anthropogenic forcing will increase and water resources management will experience greater issues related to the climate change impact; 3) Extreme floods and droughts in the EMRC will be an increasing trend, based on IPCC-AR5 scenarios; 4) Along with rising temperatures of 1 °C in North China, the agricultural water consumption will increase to about 4% of total water consumption. Therefore, climate change is making a significant impact and will be a risk to the EMRC, which covers almost all of the eight major river basins, such as the Yangtze River, Yellow River, Huaihe River, Haihe River, and Pearl River, and to the South-to-North Water Diversion Project (middle line). To ensure water security, it is urgently necessary to take adaptive countermeasures and reduce the vulnerability of water resources and associated risks.

*Keywords:* Climate change; Water cycle; Water resources; Vulnerability; Adaptation

## 1. Introduction

It is important to determine the impact of climate change on water resources to enable sustainable global water utilization (GTTWFH, 2013; IPCC, 2007a, 2007b, 2014a, 2014b; Pahl-Wostl et al., 2005). Considerable changes have occurred in the water cycle due to the integrated influence of climate change and human activities; such changes ultimately alter water resource distribution and the environmental evolution of

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soil and water (Chahine, 1992; Oki and Kanae, 2006). In China, precipitation is distributed extremely unevenly, both spatially and temporally, particularly in the Eastern Monsoon Region of China (EMRC). This area has the highest population density and has experienced the fastest speed of economic development in China; therefore, water shortages, drought, flooding, and eco-environmental problems are very prominent (Xia, 2012).

According to natural geographical regionalization in China (Xia and Chen, 2001), the country can be divided into three natural geo-regions: the EMRC, the Arid and Semi-arid Region in Western China (ASRWC), and the Tibetan Plateau Region in China. However, from the perspective of climatology, there is another terminology, namely the East Asian Monsoon Region, which is usually considered to be an area east of 100°E whose cover is larger than EMRC (Tao and Chen, 1987; Zhang et al., 1996; Wang et al., 2004). EMRC focuses on more on natural geography aspect in China, i.e., one of three natural geo-regions in China. EMRC is the largest of the three natural geo-regions and is home to 95% of the population. It occupies 46% the total land area of China and covers an area east of Great Khingan, south of the Inner Mongolia Plateau, and east of the Qinghai-Tibetan Plateau. As such, it has considerable socioeconomic importance, is very sensitive to climate change, and is also largely affected by serious water problems. The EMRC covers almost eight of the major river basins in China, such as the Yangtze River, Yellow River, Huaihe River, Haihe River, and Pearl River, which are focal areas for national water resource evaluation and planning, as well as regions covered by the South-to-North Water Diversion Project in China (Xia, 2012; Xia and Chen, 2001). Under the background of global warming, available water resources in northern China are decreasing, water consumption is increasing, and extreme hydrological events are occurring more frequently (Xia, 2012; Duan and Phillips, 2010). Such problems increase the vulnerability of water resources and will ultimately influence their allocation in China, thereby reducing the benefit of large water transfer and flooding control projects. It is thus necessary to explore four key scientific issues:

How has the climate and water cycle changed historically?
What will the changes be in the future?
What is the mechanism of change?
How should we adapt to these changes?

These questions are the research focus of the National Key Basic Research and Development Program with respect to, "The impact of climate change on terrestrial water cycle, regional water resources security and the adaptation strategy for Eastern Monsoon Region of China" (2010CB428400), and are the most prolific water science issues relating to the Earth's system. Under guidance from the project leader, the research team has been working for the past five years to obtain new ideas and knowledge, and applied to Ministry of Water Resources in China and other sections; these are briefly summarized in this paper.

## 2. New advances in understanding climate change and water resources in EMRC

The impact of climate change on the water cycle is a very complex and nonlinear inter-related process. Under the impact of nature climate change and anthropogenic forcing, the spatiotemporal distribution, intensity, and total amount of precipitation (and parameters such as movement of the rain belt, temperature, humidity, wind speed, and evaporation) will largely deviate in the long-term and will result in changes in global and regional water cycles. In addition, certain human activities such as land use and cover change, agricultural activities, deforestation, urbanization, water resource utilization, and ecological environment change also cause changes in evaporation, infiltration, runoff generation and concentration, and ultimately influence the water cycle. In general, none of these above-mentioned processes occur in isolation, and although they are both interdependent they impose mutual restraints on each other. In addition, they have their own particular characteristics. In the past five years, the research team has obtained new knowledge and technological advances, and these are described as follows.

(1) A gridded dataset has been developed in China; this provides quality control for correlations based on observations from high density meteorological stations (Liu and Xia, 2011). This fruitful gridded dataset provides a scientific basis for understanding the characteristics of regional water circulation in the EMRC under climate change. Furthermore, variability in hydrological and meteorological variables have been identified based on the new observations, and changes in the water balance between different time periods have been clarified. For example, based on new observations of both meteorological and hydrological stations in the EMRC, changes relating to hydrological cycling and water resources have been evaluated within China for the periods 1960–1985 and 1986–2013 (some of these results are presented in Table 1). In addition, Zhang (2015) has provided an overview of observed summer climate change over the EMRC during the past half century, and this study is extremely helpful for understanding the climate change aspect within the EMRC.

(2) A new two-layered Land-Atmosphere Coupling Model and land data assimilation system have been developed. Based on the developed model, the contribution of natural climate change and anthropogenic forcing to the water cycle of EMRC have been identified. This includes an evaluation of the attribution rate of climate change impact to precipitation and runoff, and also the impact on the South-to-North Water Diversion Project (middle route) and on the feedback involved between regional climate and groundwater exploitation (Liu and Xia, 2011; Zhang et al., 2015; Yu et al., 2014; Duan and Phillips, 2010). Research on the attribution aspect has shown that hydrological change in China is due to

Table 1
Comparison of water cycle budget and its changes in water-vapor, precipitation, and runoff in China between 1960–1985 and 1986–2013 ($10^3$ BCM).

| Period | Input water vapor | Regional net water vapor | Output water vapor | Precipitation | Evaporation | Surface water resources | Groundwater resources |
|---|---|---|---|---|---|---|---|
| 1960–1985 | 16.3 | 4.2 | 12.2 | 2.99 | 3.9 | 2.29 | 1.19 |
| 1986–2013 | 14.4 | 3.3 | 11.1 | 3.03 | 4.19 | 2.28 | 1.44 |
| Δ | −1.9 | −0.9 | −1.1 | 0.04 | 0.29 | −0.01 | 0.25 |

both natural climate variation and greenhouse gas emissions, in which the contribution of natural variability to precipitation accounts for about 70% and anthropogenic forcing accounts for 30% on average in the EMRC (Zhang et al., 2015). With future scenarios of increasing $CO_2$ emissions, the contribution rate from anthropogenic forcing will be increased. Therefore, water resources management will face increasing risks associated with climate change.

(3) Climate change projections face various uncertainties, for example from greenhouse gas emission scenarios, internal variability of the climate system, and representation of the climate processes. To cope with future climate change, a workable and practical new approach has been developed using a probability distribution; this quantitatively describes uncertainties from different GCMs and the model-self, and assesses climate change projections contained in IPCC AR5 for continental China (Liu and Xia, 2011). The results show that under climate change the frequency and intensity of extreme hydrological events (floods and droughts) and the number of intensive precipitation events are projected to increase in 2020–2040. In addition, the frequency of extreme drought events have increased over the past 63 years in the EMRC, and this frequency is projected to continuously increase (with fluctuations) over the next 30–50 years, which will exacerbate problems of water supply, demand, and resource vulnerability in northern China.

(4) A new approach for non-stationary extreme flood frequency analysis related to climate change has been developed based on the climate change index method combined with hydrological frequency calculations (Wu et al., 2015). This method has been applied to the Huaihe River Basin, and results have shown that the 20-year return flood in Wang Jia Ba, one of the major hydrologic stations on the Huaihe River, will increase by 23%–30% in 2020–2050, relative to 1970–2000. This will certainly result in a larger risk of flood inundation and will also increase the amount of time required to divert large floods. Again, such results show that it is crucial to consider the impact of climate change in relation to flood control in China.

(5) Vulnerability and adaptation are priority issues for water management in relation to climate change (Yu et al., 2014). A new theory and method for quantifying water resource vulnerability has been developed (based on the multivariate index system and functional approach) in relation to climate change, the socioeconomic impact of change, adaptive processes to change, and risk (Xia, 2010; Xia et al., 2014). The approach is used to establish an internal relationship between vulnerability and adaptability, and to provide a scientific basis for the adaptive management of water resources to climate change. Results show that approximately 90% of the EMRC, which account for 95% of the total population and nearly half of the China's land area, exists under the condition of moderate and severe water resource vulnerability. Furthermore, China will face more challenges relating to water resources security issues, especially in northern China.

Under the impact of climate change, there will be a continual increase for water in the EMRC in the future. In North China, the consumption of water for agriculture will increase by about 25 mm with an increase in air temperature of 1 °C. Under the impact of climate change, water demand in the Yangtze River Basin will increase by 31.3 billion $m^3$ by the 2030s, which will exacerbate water resource vulnerability in the middle and lower reaches of the Hanjiang River Basin and add extra pressure to the ability of the South-to-North Water Diversion Project (the middle route) to supply water. In the near future, there will be a significant expanse of EMRC regions that experience moderate and severe water resource vulnerability conditions, especially in southern China and the Yangtze River Basin.

The operation of the South-to-North Water Diversion Project (middle route) is projected to be largely affected by climate change. It has been observed that streamflow into the Danjiangkou Reservoir in the upper reaches of the Hanjiang River has continuously decreased since the 1980s (a decrease of about 21.5% between 1990 and 2012 compared to between 1954 and 1989). This area has experienced a long dry period, although streamflow has shown a slight increase since 2000. Under the impact of future climate change, forecast results show that runoff of the Haihe River will firstly decrease and then increase slightly until 2040. However, runoff in the upper reach of the Hanjiang River will still decrease with a risk on water supply to North China.

The water resource vulnerability condition will increase in the Hanjiang River Basin under future operation of the water transfer project and the impact of climate change; this indicates the need for urgent adaptive water resource countermeasures.

There will be a considerable change in the encounter probability of flood and drought within water transfer and water-receiving areas. From observations of hydrological data, the probability of concurrent drought in the Hanjiang and Haihe River Basins is increasing (from 9% in 1956−1989 to 30% in 1990−2011) and is highly likely to increase during 2020−2050. This will challenge the success of the water diversion project, which is a strategic attempt to resolve the water crisis on the North China Plain. However, the current planning and design of water resources, and the operation scheme of the water division project have yet not considered the impact of climate change. We therefore stress the need for urgency in preparing adaptive measures to ensure the project's long-term sustainable operation.

(6) Countermeasures and suggestions for adaptive water management in the EMRC have been proposed to deal with climate change. These include: the immediate promotion of adaptive management in relation to planning and construction of water resources at a national level; carrying out capacity-building of a water resources adaptation decision-making system to deal with climate change as soon as possible; and actively implementing innovation-driven basic scientific research under the impact of climate change, and national water security development strategies under a changing environment.

The Three Red Lines policy has been introduced by the Chinese government to set limits on future water use, water efficiency, and quality. The policy states that by 2030, the total national water consumption will be controlled in 700 billion $m^3$; water use efficiency will be close to the largest in the world, and water consumption per CN¥ 10,000 of value-added by industry will be reduced to less than 40 $m^3$, and irrigation water use efficiency will increase to more than 0.6; and water quality standards will be improved by 95% or more.

These results show the significant benefits of adaptive water management, i.e., even under the worst climate change scenario, water resource vulnerability in the EMRC can be reduced by 21.3% and the degree of sustainable development can be increased by 18.4%, if adjustments and countermeasures are used to adapt water resources (Xia, 2012).

## 3. Concluding remarks

Global climate change and water resources are extremely important issues that are currently being researched internationally, as they are crucially important for human sustainable development. China is a developing country, but it has the largest global population and the most severe water stress. Therefore, research on the impact of climate change on water resources in China are extremely important to prepare adaptive management. With the support of China's 973 Project, and through cooperation with research and production teams, this study integrates long-term hydrological and meteorological observations and scientific research into four issues that are of greatest concern in relation to China's needs. The results and understanding include:

(1) Major changes in the land−water cycle in the EMRC relate to the co-action of greenhouse gas emissions and natural variability; the contribution of natural variability on changes in precipitation accounts for about 70% whereas anthropogenic forcing accounts for about 30% of regional average changes.

(2) With future increasing $CO_2$ emissions, there will probably be an increase in extreme flood and drought. In addition, together with a rising temperature of 1 °C in North China, the agricultural water consumption will increase to about 4% of total water consumption.

(3) With increasing future $CO_2$ emissions, climate change will become an important driving factor of water cycle change. Therefore, existing water resource planning, design, and management of water division projects will be at high risk because of limited considerations of the impact of climate change. Even under the worst climate change scenario, water resource vulnerability in EMRC can be reduced by 21.3% and the degree of sustainable development can be increased by 18.4% if adaptive management and countermeasures are implemented for dealing with climate change to ensure water security in China. Under the changing environment, it is thus crucial to modify existing water resource planning and management standards in major water conservancy projects.

It is understood that due to the complexity and uncertainty of the impact of climate change and highly intense human activities on the water resources in the EMRC, certain issues need to be further explored to provide more accurate results and suggestions for management. These include studies of evapotranspiration mechanisms; the impact of inter-decadal natural variability, global warming, and human activities on water resources; and standards for flood control under climate change.

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