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# Water resources research to support a sustainable China

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**ABSTRACT**
Water resources are the basis for the sustainable development of China. However, the country is currently facing alarming water-related problems associated with its fast economic development and climate change. This editorial introduces briefly the status of its water resources research at the national level and the researcher level. It also introduces the research reported in this thematic issue to highlight its role in addressing flood and water-scarcity issues, improving water management in inland plains and supporting the sustainable development of the country. Finally, some further recommendations for improving water resources research in China are offered.

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## Introduction

It is well recognized that water resources are indispensable for human survival, social development and economic growth. Of all global freshwater resources, only 29.9% is groundwater and only 0.26% is concentrated in lakes, reservoirs and river systems (Shiklomanov, 2000). The greater portion is in the form of ice and permanent snow cover and therefore excluded from human use. With the use of the available, albeit limited, freshwater resources, the global population has increased to 7.5 billion people, with considerable economic growth. However, climatic changes, population growth and excessive economic development will lead to a number of water-related problems in the long term (Vörösmarty, Green, Salisbury, & Lammers, 2000). Water pollution, water scarcity and many other water-related problems have emerged in nearly every corner of the world, which has attracted considerable attention from the public and from professionals (Wu & Sun, 2016).

Water problems are especially serious in arid and semi-arid developing countries, many of which are distributed along the routes of the New Silk Road (Li, Qian, Howard, & Wu, 2015). These Silk Road countries have a long history of water shortages and water resources mismanagement, and the situation may become even worse due to climatic changes and increasing human activities (Howard & Howard, 2016). One of these countries, China, is facing increased water stress, which is a global concern due to the developing connections of China with the rest of the world, both economically and environmentally (Jiang, 2009). Water

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resources problems are common throughout China, which makes it essential that the Chinese economy develops with utmost caution, fully acknowledging the fragile environment and the need for sound scientific research and reliable data (Li, Qian, & Zhou, 2017b). For two decades, the Western Development Programme, initiated in 2000, has brought much needed investment to the arid and semi-arid regions of western China. Unfortunately, these dry western areas are highly sensitive to human activity and climate change, raising concerns about the sustainability of water supplies and the risk of soil and water quality degradation (Li, 2016; Li, Tian, Xue, & Wu, 2017a; Wu et al., 2017). Eastern and northern China, for example the North China Plain and the Su-Xi-Chang Region, are also seeing water resource overexploitation and degraded water quality, leading to seawater intrusion, ground subsidence and ground fissures (Cao, Han, & Moser, 2013; Guo et al., 2015; Kang, Wang, & Du, 2017; Peng, Qiao, Leng, Wang, & Xue, 2016b; Peng, Sun, Wang, & Sun, 2016a). The situation in southern China is also not encouraging. Climate change and economic development have caused frequent drought and water contamination in some areas in southern China, threatening the sustainability of water resources (Wan, Zhou, Guo, Cui, & Liu, 2016; Wei, Yang, Li, & Wang, 2015; Yang, Chan, & Scheffran, 2018).

Facing these problems, the country and its scholars have already taken action to protect water quality and quantity and to mitigate the water crisis caused by climate change and human activities. At the national level, the government has issued several regulations and guidelines since 2010 and set up a series of policy goals and priorities to protect national water quality, such as the National Groundwater Pollution Prevention and Control Plan and the revised Technical Guidelines for Environmental Impact Assessment: Groundwater Environment (Li et al., 2017a). The central government has also implemented the Strictest Water Resources Management System since 2009 to achieve sustainable use of water resources (Zuo, Jin, Ma, & Cui, 2014). This is regarded as a strategic move to balance the interests of different water users. Water pricing is an efficient and effective socio-economic tool to manage and allocate water resources (Mamitimin, Feike, Seifert, & Doluschitz, 2015), but it has some drawbacks and is heavily affected by external social and economic factors (Shen & Wu, 2017). The Chinese water pricing framework is being gradually transformed to a water taxation framework to better balance demand and supply. Hebei was the first pilot province of this transformation, starting in 2016, and this was expanded to another nine provinces and autonomous regions at the end of 2017 (http://www.chinatax.gov.cn/n810341/n810755/c2928033/content.html). In addition to these policy-oriented actions, China has implemented engineering megaprojects to balance the need for water resources among different regions and different sectors, of which the South-to-North Water Diversion Project and the Three Gorges Dam project are the best known. These megaprojects have indeed alleviated the water crisis to some degree, though researchers have varying opinions on their environmental and ecological consequences (Sternberg, 2016; Xiong et al., 2017).

Researchers have also carried out various water resources studies, which have enhanced the ability of the country to adapt to climate change and tackle the water crisis. Wang and Jia (2016) presented a dualistic water cycle theory to highlight the important role of human activities in the regional water cycle. This provides a solid theoretical foundation for tackling water resources problems in China. More studies, however, focus on two major water issues: water pollution and water scarcity. Regarding water pollution, Hou, Li, and Nathanail (2018) report that nearly 80% of groundwater monitoring wells in 17 northern provinces have poor or very poor quality water, which is unsuitable for domestic uses. This has made groundwater remediation an emerging market, with over one million contaminated sites to be remediated (Hou et al., 2018). Zhou et al. (2014) summarized the main water environment problems in China and identified a trend: 'Water pollution in China has spread from point source to non-point source, from fresh water to coastal water, and from surface water to groundwater.' Regarding water scarcity, Jiang (2009) summarized its contributing factors and pointed to future challenges in tackling it. The two most important contributing factors are the natural characteristics of water resources (which are controlled by climate conditions) and the increasing demand for water due to urbanization and population growth; and both of these are almost impossible to adjust. China's water scarcity can only be alleviated cost-effectively by improving water resources management. Liu et al. (2013) provided an overview of the achievements and challenges of the massive water conservation projects aiming at addressing water scarcity issues. To ease the water scarcity induced by climate change, Wang et al. (2012) sought the best water resources management strategy for adaptation to droughts by analyzing the records of historical droughts and their impacts. These studies provide just a glance at the status of water resources research in China, but they show that this research indeed supports its sustainable development. Still, we are a long way from true sustainability.

In view of the alarming water-related problems and the current status of water resources research, this thematic issue has been compiled to reflect interesting current research on water resources in China in the context of climate change and anthropogenic activity and to further boost interest and effort in this field to safeguard sustainable development. The issue includes five papers, whose topics range from flash flood early warning and flood regime modelling to sustainable water resources management in inland plains and the world-famous South-to-North Water Diversion Project. All these topics are important for the sustainable development of China, and the results from these studies can potentially support national policy making. In fact, some of these results have already been applied in practice.

## Water resources research to support a sustainable China

China is a large country, and its water resources are unevenly distributed. The water resources in southern China are abundant (accounting for over 80% of the national total), while 60% of the farmland areas are in northern China, with only 19% of the water resources (Liu & Speed, 2009). This uneven distribution of water resources has constrained the economic development and the use of land resources. The serious water crisis in northern China prompted the implementation of the South-to-North Water Diversion Project. The Middle Route of this project has been operational since 2008 and is providing freshwater to some large cities in northern China (Gao & Yu, 2018). However, this project is highly susceptible to water pollution, as pointed out by Lei, Zheng, Shang, and Wang (2018). The authors therefore propose an emergency regulation technical framework, which consists of four sub-models corresponding to four steps of emergency regulation: source identification, simulation/warning, emergency regulation, and evaluation of emergency measures. This framework has been successfully applied in the project and is therefore worth promoting in similar projects. There is an even larger water diversion project planned for western China, which will transfer an estimated 60 billion $m^3$ of water per year from the Qinghai-Tibet Plateau to arid north-west China (http://www.xinhuanet.com/politics/2017-12/05/c_129757481.htm).

This project will completely change the environmental and ecological conditions in arid north-western China. The emergency regulation technical framework proposed by Lei et al. (2018) can be further modified and improved to guide the design and operation of the new western water diversion project by taking into account the special geological and structural conditions.

Arid north-west China covers 47% of the total territory of China, but has only 7% of the total water resources (Chen & Xia, 1999). This area contains some important crop production plains and oases, which demand large quantities of irrigation water. But poor water resources management in these irrigated areas has caused various environmental problems, such as groundwater pollution, soil pollution, land desertification and soil salinization, threatening agricultural production and food security (Li, Qian, Howard, Wu, & Lyu, 2014; Li et al., 2016a). In all major plains in north-west China (Yinchuan Plain, Guanzhong Plain, Hetao Plain, Qaidam Basin, Hexi Corridor and Tarim Basin), soil salinization and land desertification have been reported (Li, Wu, & Qian, 2016b; Wang, Wu, & Jia, 2016; Wu, Li, Qian, & Fang, 2014a), and these are generally caused by inadequate water management. In these areas, soil salinization is usually caused by high groundwater levels and intense groundwater evaporation. Therefore, lowering the groundwater level is an effective short-term method of soil salinization control in these areas. Li, Qian, and Wu (2018a) suggest the conjunctive use of surface water and groundwater to alleviate soil salinization in the Yinchuan Plain, where large volumes of Yellow River water are diverted for irrigation each year. For the cities of this plain, they have determined the optimal proportion at which groundwater should be exploited for irrigation. However, this technique is effective only in the short term and represents a rather small step in soil salinization control. For long-term benefits, water resources in the agricultural plain must be used sustainably, and therefore scientific research must be strongly encouraged and steadily supported (Li et al., 2018a).

The development of a sustainable water resources management plan is complex. Chen, Wu, Qian, and Li (2016) pointed out the challenges of sustainable groundwater management in the Yinchuan Plain, where confined groundwater is heavily abstracted for domestic and industrial purposes. Groundwater depletion, groundwater quality deterioration and environmental degradation such as soil salinization, as discussed by Li et al. (2018a), are the major problems caused by inadequate groundwater resources management. Local governments are fully aware of these problems and have already been trying to address them, albeit under a fragmented management framework, with responsibilities divided between three different local departments. This fragmentation makes it difficult to handle complex responsibilities, leading to overlapping and conflicting work (Chen et al., 2016). A similar situation can be found in other provinces of China, because these divided responsibilities stem from the central government. Unless the management framework imposed by the central government is improved, this challenge will remain. Chen et al. (2016) offered several recommendations for sustainable groundwater management in the Yinchuan Plain, which ranged from enhancing cooperation and encouraging public participation to integrating monitoring networks and strengthening scientific support. Some of these recommendations, shared by Li et al. (2018a), are useful for local water resources management. We will emphasize and elaborate on some of these later so that international professionals and decision makers can gain more insights from them.

Global climate change has produced great uncertainty in hydrological processes and associated research (Refsgaard et al., 2016; Zhu, Zhang, Ma, Gao, & Xu, 2016). The impacts on hydrological processes are mainly caused by temperature increases and precipitation variations, generating increased stream flows and extreme weather events (Arreguín-Cortés & López-Pérez, 2013; Azari, Moradi, Saghafian, & Faramarzi, 2016; Wu, Qian, Li, & Song, 2014b). Flash floods are regarded as a result of climatic changes and poor drainage infrastructure and have been frequently reported in China in recent years, causing casualties and enormous economic losses. For example, the 21 July 2012 flash flood in Beijing caused 79 deaths and economic losses of nearly 10 billion yuan (http://www.weather.com.cn/zt/kpzt/696656.shtml), and the 18 July 2007 flash flood in Jinan caused at least 34 deaths and 171 injuries (http://www.weather.com.cn/zt/kpzt/372771.shtml). The severity of flash floods, especially urban floods, prompted the government to create the Sponge City Programme to address urban flooding and waterlogging (Dai, van Rijswick, Driessen, & Keessen, 2017). But to get the best results from the Sponge City Programme, it is necessary to understand the flood regime and to establish a flash flood early warning system. Li, Lei, Shang, & Qin (2018b) describe the long-term and real-time flash flood early warning systems in China. Long-term early warnings can help governments to identify high-risk areas and thus to develop adequate disaster control plans. Real-time early warnings are helpful in determining the likelihood of a flash flood disaster (Li et al., 2018b). But both of these systems are based on the understanding of the flood regimes, using statistical analysis and modelling approaches as major tools. Wang, Lei, Liao, and Shang (2018), in a case study of the Second Songhua River Basin, analyze the changes in flood regimes using EasyDHM, a distributed hydrological model. Based on the changes of various environmental elements, various distributed hydrological models have been developed, seeking optimum simulation results. For example, Guzha and Hardy (2010) applied the TOPNET model to predict watershed streamflow based on meteorological data. Garg et al. (2017) used a three-soil-layer VIC (VIC-3L) hydrological model to study the impact of land-cover change on the hydrological regime. But none of these hydrological models is perfect, mainly because the model parameters have large uncertainties, which are caused by factors such as sparse data and uncertain human activities. As stated by Wang et al. (2018), 'To satisfy the precision required for flood forecasting, future work is needed to correlate basin storage capacity, including the status of soil water, groundwater, and reservoir storages, with water consumption for industrial, agricultural, and residential purposes.' There is still a long way to go in hydrological modelling research.

## Further recommendations for water resources research in China

The five articles in this special issue reflect very relevant topics in China. However, to develop a sustainable China, hydrologists, water resources managers and water resources educators will have to work hard. As mentioned, Chen et al. (2016) and Li et al. (2018a) have already offered some suggestions to promote water resources research in local regions. Here, we emphasize and elaborate on some of these suggestions to guide water resources research throughout China and benefit the entire hydrological community.

### *Expanding professional collaboration to citizen science*

It has been recognized that collaboration between professionals within a discipline or from different disciplines can facilitate the development of disciplines. However, this is only a narrow collaboration, which may not be very successful in a Big Data era (Kelling et al., 2015).

In this era, collaboration indeed should be encouraged between professionals, organizations and governments, as suggested by Li et al. (2015, 2018a), Chen et al. (2016) and Hartley (2017). However, it should also be expanded to a broader scope, for example, collaboration between professionals and non-expert communities (citizen scientists). Citizen science has been defined by Buytaert et al. (2014) as the voluntary participation of non-experts with professional scientists in research design, data collection and interpretation. This is a promising research tool or research field that can greatly aid water professionals; it has already been successfully used in environmental monitoring, forest monitoring and biological data collection (Conrad & Hilchey, 2011; Daume, Albert, & von Gadow, 2014; Everett & Geoghegan, 2016) and is recommended by a number of scholars (De Reyna & Simoes, 2016; Freitag, 2016). In hydrological studies, both modelling research and mechanism interpretation require large amounts of reliable data, and citizen science can be a good solution to the crisis of sparse monitoring and data shortage. To our knowledge, no citizen science has yet been incorporated in Chinese water resources research. Researchers and officials should consider this seriously and encourage it, to accelerate and improve water resources research in China.

### *Supporting more young water scientists*

Water resources research needs constant development, and thus requires 'new blood' to participate. The central and local governments should constantly support young water scientists and students to help them complete their researches and studies. The next generations are the hope of our future (Li, Howard, & Currell, 2017c), so governments and agencies should financially support the younger generations of water professionals. Young non-professionals should also be supported, so that citizen science can be implemented successfully and constantly. Education resources and training opportunities are required throughout China to ensure that a sufficient number of young people are involved in water science research and study, but this may be hindered by China's new Double First Class University Plan. This plan aims to create world-class universities and disciplines by the end of 2050 (http://en.people.cn/n3/2017/0921/c90000-9272101.html). In this plan, 'first-class disciplines' will develop faster because they receive more investment from the government, while unsponsored disciplines may be disadvantaged. Hydrology and water-resources-related disciplines in China are not generally considered first-class disciplines, except in some universities with hydrology as their top discipline. This will limit the number of young water scholars and constrain the development of water resources research in China. Sufficient investment should therefore also be dedicated to the non-first-class disciplines, including hydrology and water resources.

### *Linking research to policy making*

It is widely acknowledged that scientific research is fundamental to ensure the sustainable development of a nation (Li et al., 2015). In their recent articles, Chen et al. (2016) and Li et al. (2018a) advise local governments to enhance scientific research to achieve the sustainable development of water resources. We generally agree with these authors. However, we would like to emphasize that such efforts should be closely linked with policy making. As Cookson (2005) stated, 'Most academics like the idea of evidence-based policy making (EBP), just as most journalists like the idea of public service broadcasting.' Scientists should provide evidence and knowledge to support sound decision making. Thus, we encourage the water scientists of China to put more thought into the relationship between their research and policy making, as this is the only way their research can support the sustainable development of China.

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