Science & Technology for Sustainable Water in China

A Perspective of the IAC Water Program and Studies in China

XIA Jun [1,2]

[1] Key Laboratory of Water Cycle & Related Land Surface Process, Chinese Academy of Sciences, Beijing 100101, China

[2] State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China

Abstract Water is a big issue in the world. As we enter the 21st century, a global water crisis threatens the security, stability and environmental sustainability of all nations, particularly those in the developing world. The Inter-Academy Council (IAC) proposed to undertake a study of the current and emerging challenges and opportunities for sustainable water resources management at its 2009 Board meeting. This paper gives a perspective of the IAC Water Program, and the case studies conducted by China Working Group of the IAC Water Program on three key issues, namely climate change & water adaptive management, agricultural water & ecology, and urban water & environment. The purpose is to show the role of science & technology for sustainable water in China. These studies are the 1st phase of the IAC Water Program in China. Perspectives of new challenges and opportunities on this Program for the water future in the world and China are also given in the paper.

Prof. Jun Xia is Director of Center for Water Resources Research, Chinese Academy of Sciences (CAS), and Leading Professor of Hydrology & Water Resources, Wuhan University. He has had ample experience on leading water research, managing and consulting jobs in China and international activities since 1987. He also severs as, among others, President of International Water Resources Association (IWRA), Board Governor of World Water Council (WWC), Co-Chair of the InterAcademy Council for Water Programme (IAC-WP) and the member of Scientific Steering Committee for Global Water System Project (GWSP-SSC) .

E-mail: xiaj@igsnrr.ac.cn

1. Background of IAC water program

As humanity enters the 21st century, it is faced with an increasingly warming world that threatens human survival. Chief amongst the threats brought about by global warming is its negative effects on water resources. Even without factoring in global warming, there are already serious problems of water resources worldwide. The World Water Commission for the 21st Century warns that: 1.4 billion people live without clean drinking water; 2.3 billion people lack adequate sanitation; 7 million people die yearly from diseases linked to water; half the world's rivers and lakes are seriously polluted and many rivers do not reach the sea for much of the year because of upstream withdrawals; food shortages (caused by drought) create millions of environmental refugees; nearly 450 million people in 29 countries face water shortage problems; 20% more water is needed than is available to feed the additional 3 billion people who will be alive by 2025; and by 2050, 2.5 billion people would face water stress. Amongst the major water problems in the world are: the general misconception that the amount of available water is infinite and renewable, over-emphasis on a single approach of supply management, large-scale destruction of water catchments, water pollution, loss of water through high rates of non-revenue water (NRW) in developing countries, water wastage due to public apathy, ineffective privatization of the water industry, low water tariffs due to government subsidies, and climate change.

Water resources management, both from sciences and the humanities, is confronted with current and emerging new challenges as nations and the world face serious problems of water availability due to global climate change. Water, via the hydrological cycle, imposes itself upon all natural spheres — atmosphere, hydrosphere, lithosphere, biosphere, and most of all anthroposphere. Within human society, water is a cross-cutting issue that cuts across almost all aspects of life. Human society is exerting increasing pressures on the water system via water demand. Hence, notwithstanding the importance of science in discovering new water technologies, it is imperative that human society finds a deeper understanding of how human pressures are altering the water cycle and affecting the quality and quantity of water available to humans and the environment. International organizations such as the IAC, governments and other agencies need

Prof. LU Yongxiang, Co-chair of the IAC, having talks with Dr. John P. Campbell, Executive Director of the IAC.

accurate information to make decisions on such issues as: water and wastewater management, water supply and demand management, integrated water resources management (IWRM), innovative water treatment, desalination, reverse osmosis (RO) treatment, groundwater management, allowable water use and the issue of virtual water in an increasingly complex world interlinked by globalization. Furthermore, human society is ever evolving and changing along with economic growth, land use transform, and population patterns change. All these topics cannot be solved by science alone. Neither can they be completely addressed by social science and the humanities. A portion of the water problems is the result of natural causes, and a portion due to human causes. Hence, water problems cannot be addressed separately by science or the humanities. They need to be addressed by both and this requires integrated studies linking various disciplines. Such integration necessitates cutting-edge research modalities for identifying problems, acquiring data, converting raw data into information, and synthesizing findings. An effective response to a globalizing and warming world requires revisiting the agenda for water and hydrologic science, revamping ways in which water science is done, and integrating social sciences and humanities with water science towards sustainable global water resources.

The IAC recognizes the significance and complexities of existing and emerging water issues and the resulting need to expand and adjust its water science research efforts with stronger emphasis on global/climate change driven

International Workshop on Water Vulnerability & Adaptive Governance under Climate Change & Development is held in Beijing in September 2010.

considerations. In recognition of the changing needs and emerging innovations in water science to address water issues, the IAC Water Program (IAC-WP) committee met in Beijing on 21–22 November 2009, and unanimously decided to propose a new study that will examine the current and emerging challenges and opportunities in sustainable water resources management, including: (1) a review of the current status of water issues & problems at the global, regional and local levels; (2) a review of current status of the science of water resources management and its linkages to other fields of sciences (*e.g.* geosciences, biosciences, high & new technologies on space observation & waster water treatment including sea water sanitization *etc*.) and social sciences and the humanities; and (3) the identification of promising new opportunities to advance the science of water resources management for a better understanding of the water cycle that can be used to improve water resources availability (quantity and quality), its management and conservation towards sustainable global water resources.

With the support of the Chinese Academy of Sciences (CAS), particularly from its former president Prof. LU Yongxian, who is also Co-Chair of the IAC, China Working Group of IAC for water program was formed in 2009. Three key workshops on the IAC water program were organized in Beijing on 21–22 November, 2009, and on 17–18 September, 2010; and in Xi'an from 19 to 24 October, 2011. The case studies in China for the IAC Water Program focus on three key water issues, namely, (1) climate change & water adaptive management, (2) agricultural water & ecology, and (3) urban water & environment. It is important to define a proper niche for the IAC Water study, avoiding an overlap with other ongoing initiatives. The intention is to add value of science & technology to the knowledge about water by looking sufficiently into the future. The major studies will focus on the following aspects:

(1) *For the review of the challenges of sustainable water resources management for the world at both the global and regional scales*, the key question is "What are the challenges?" These include challenges of quantity and quality, space-time variability (too much and too little), droughts and floods, increasing competition for water, agricultural water, and drinking water. Other key challenges include urban water, eco-water, water disasters, water governance and management issues, and the interplay between water and energy. These challenges all occur over the global and regional scales.

(2) *For understanding the causes of, and the science behind, water problems, including the impacts of climate change and human activities*, a deeper and more comprehensive understanding of natural variability versus anthropogenic activities, water economics and human behaviors, uncertainties in modeling of hydrologic processes, the linkage between natural and social sciences, human activities and water shortage, and interaction and feedback of ecosystem demand and water resources are examined.

(3) *For the identification of adaptation and mitigation*

measures and capacity to environmental impact, we need to identify adaptation measures (*e.g.* using less water), mitigation measures (*e.g.* increase source and decrease demand), and adaptation capacity, amongst others.

(4) *For the innovation and promising new opportunities to solve the water crisis and ensure sustainable water resources to the world*, the identification and evaluation of technical innovations (*e.g.* water treatment technology, seawater desalination, membrane technology), economic innovations (*e.g.* water marketing, virtual water), and management innovations (*e.g.* changing human behaviors, using water tariffs) will be examined.

By the case studies in different regions and on different water issues in China, the following intellectual merits would be get: Addressing complex issues presented by global climate change, ecosystem protection, water resource sustainability, and new water demands; Understanding how human pressures are altering the water cycle and affecting the quality and quantity of water available to humans and the environment; Providing accurate information for decision-makers on allowable water use and waste management in an evolving economy as climate, land use, and population patterns change; and Identifying promising new technology and disseminating scientific knowledge for sustainable water resources management.

The primary focus of this study will be the IAC Water Program with the outputs disseminated to all IAC countries, but given the global importance of water issues, the report should also serve the academic/educational community, other agencies with programs in water resources, World Water Council, professional societies, and other entities with missions related to Earth sciences and water resources. This study also could serves the academic/educational community, the United Nations and other international and national agencies with programs in hydrology and water resources, professional societies, and other entities with missions related to global changes and water resources.

In this special issue of the *Bulletin of the Chinese Academy of Sciences* (*BCAS*), the total 14 papers are collected from over 30 contributions in the past three regional IAC Water Workshops in China since 2009. These studies were carried out by an *ad hoc*, interdisciplinary special working group of approximately more than 30 volunteer experts from different institutes of CAS and universities in China, such as the State Key Laboratory of Water Resources & Hydropower Engineering Sciences in China. It is hopeful China Working Group can learn more from other countries on water sustainable use by science & technology support, and also these Chinese experiences would be beneficial to others.

2. China's water issue and challenges

China is a developing country with a variety of climate & other stresses from its population and economic development, and its water resources become the most important issue associated with regional and national sustainability. Although the total annual runoff in China amounts to 2,712 billion m^3, it has to feed about one fifth of the world population by 6.4% of the world land area and 7.2% of the world cultivated land. By the end of 2000, the water resources in terms of per capita availability was only 2,200 m^3, being one fourth of the world average, and the available water per unit area of cultivated land accounts for only 80% of the world mean.

The situation is aggravated by the uneven regional distribution of water resources between the south and the north of the country. For the four southern regions, including the whole Yangtze River Basin, there are 36.5% of the country's territory, 36% of its cultivated area and 54.4% of its population, whereas they have as many as 81% of the country's total water resources with 4,170 m^3 per capita, about 1.6 times of the country's average value, and 61,950 m^3 per ha, being 2.2 times of the average. As a most outstanding one, however, the water resources per capita in the Haihe-Luanhe Basins are merely 430 m^3, being 17% of the country's value, and 3,760 m^3 per ha, constituting 13% of the country.

Droughts frequently afflict China especially the Northern China Plain where water stress on irrigated crops results in significant reduction in agricultural production. The historical data shows that within the 1 million km^2 area of east China, there were 53 serious drought events in the past 510 years. This represents an average recurrence interval of 10 years. However, if a smaller area of 500,000 km^2 is considered, 323 serious drought events occurred in the period of 510 years. This indicates an average


By curtsey of Xia Jun

There is an acute shortage of water in Beijing. The photo shows a scene of the Miyun Reservoir, one of the main water sources of China's capital.

recurrence interval of 0.66, in other words two events in every three years. From 1949 to 1990 the average drought affected farmland of the country is estimated at 165,000 km^2, approximately 16% of the cultivated land. It is estimated that significant losses of agricultural production occur in 50% of the drought affected land.

The water shortage is becoming more acute as the demand from principal water users grows. Agriculture is the major user of water resources. In China, 50% of the cultivated land is irrigable and the other 50% is rain-fed. In order to meet the increasing demand of the population growth, further development of irrigation seems indispensable. The increase of water demand requires enormous capital investment, technology transfer and management improvement. The water use in irrigated field still remains at a low level, and the irrigation efficiency over the whole nation is estimated at about 40%. The limited water resources have not been efficiently used due to technical, economic as well as managerial reasons.

The over abstraction of surface water and the depletion of groundwater continue to pose considerable constraints for sustainable development in China. This is particularly the case for the Haihe River Basin where surface water has been diverted and groundwater over-exploited for irrigation since the 1970s. Overdraft of groundwater in shallow aquifers has brought about the drastic reduction of surface runoff, and the trend of dryness in this area is significant. As a result of surface runoff reduction, the rivers are turning to be intermittent even for median sized basins in these areas.

The competition for water resources between different areas has been increasingly acute for the water scarcity regions. In order to bring the maximum benefit of the limited water resources, it is indispensable to have a rational allocation of water. The water allocation in the Yellow River is an example in this regard, which was approved on the basis of overall study of water resources and water demand of riparian provinces, providing the basis for coordination and development planning of riparian provinces in their water use.

Water quality has been deteriorating since the 1980s in many rivers across China. Based on a nationwide investigation in 2000, the water quality of 58.7% river reaches were severely polluted, falling into the category IV or V according to national criteria, meaning their water was badly polluted.

In China, especially in the Hai River Basin, surface water has been diverted and groundwater has been comprehensively used for irrigation since the 1970s. The overdraft of groundwater in shallow aquifers has brought about the drastic reduction of surface runoff, and the trend of dryness in this area is significant.

The overdraft of groundwater has brought about significant impact not only on the reduction of surface runoff but also on the sustainable water supply to the cities especially in China's Northern Plain.

New challenges in the 21st century in sustainable water resources in China will focus on: (a) Understanding water cycle process under a changing environment, *i.e.* climate change and human activities; (b) Quantifying water security linked with social-economic & environment issues to support the sustainable management of water resources.

3. The ability and potentiality of technology for water issue in China

The solution to water issue lies in an integrated (legal, institutional, economic and science and technology) approach of water management. The Water Law of the People's Republic of China, which was adopted at the Twenty Fourth Meeting of the Standing Committee of the Sixth National People's Congress on January 21, 1988, is China's first basic law on water since 1949. It marked the beginning of a new period of development, utilization,

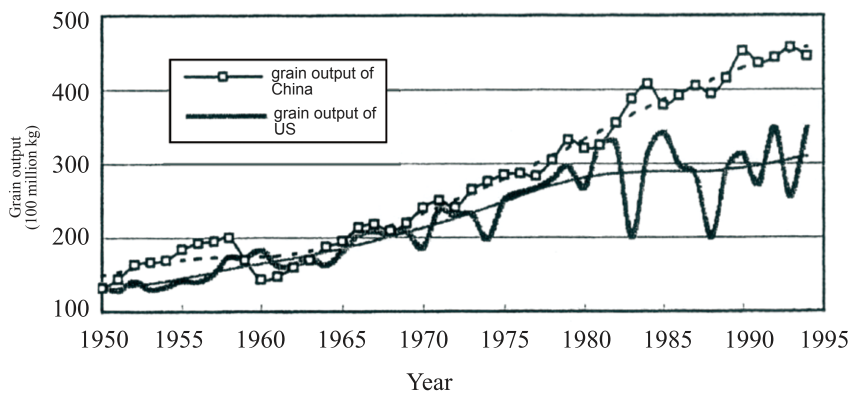

Figure 1 The grain output difference between China and US.

protection and management of water resources as well as control of water disasters in the country. In 1993, the State Council issued a government regulation entitled "Measure for Enforcement of the Water Drawing Permit System", which was formulated in accordance with the "Water Law" for the enhancement of water resources management, efficient water use and promoting rational development and utilization of water resources.

The water drawing permission system is an important means for the state to enhance the management of water resources and is also a basic measure for water management. The water drawing permission applies to the withdrawal of groundwater directly from the aquifers or surface water from rivers and lakes. Therefore, "primary water drawing" of "direct water drawing" must get the permission from relevant authorities.

Water saving as a national policy is emphasized in the Water Law and specific provisions in water saving for different users, and water metering is adopted as the basic system to ensure the implementation of water saving policy. For agriculture water use, Article 50 of the Water Law states that "people's governments at all levels shall promote water saving methods and water saving techniques in irrigation, and take necessary measures of seepage control for agricultural storage and delivery projects to raise efficiency of agricultural water use."

Science and technology play an important role in the development of all water sectors. Statistics shows that irrigation is the major factor affecting China's agriculture yields over the past century.

The figure shows the different trends of grain output between China and US, in which the grain output of China steady grows under the different climate conditions within the recent half century.

In view of the different safe water supply needs in rural areas, many researches and projects have made development and improvement on the water recycle and water purification, for instance, the removal of fluorine by bone char, chlorine dioxide generator and brackish water treatment technology and equipment, which were applied in many areas and reached good effect.

China is also facing big challenges as how to wisely manage its limit water resources under the great stress from social-economic development and environmental protection. Science & technology can play a key role in understanding the causes of and the science behind water problems for water quality management, including the impacts of climate change and human activities. Moreover, China is shifting to a new water strategy based on the principles of "three red lines" control, namely the control of total water use, the control of lower water use efficiency and the control of total waste water load. This new water policy is also significantly influencing China policy on water quality management. External assessment of China's water problems, and recommendations for policy solutions, often fail to recognize that interrelated physical, institutional, historical-cultural, and ideologically grounded contradictions in the water sphere. They are distinctive to China, and challenge Chinese policy makers in unique ways. Thus, good water governance will challenge traditional China water policy, meaning the process in which government and society get organized to use water resources sustainably to meet the needs within a legal and ethical framework in accordance with the water availability at any given time with equity and dignity. The new water policy, which is based on "three red lines" control on total water use, and strives to increase water use efficiency and reduce waste water into rivers, will significantly change China's water policy in a new phase. The new challenges for this strategy are how to implement these "three red lines" control. They need good water accounting and water governance systems to indicate if total water use could be controlled within a maximum limit, if water uses efficiency could be increased relative to traditional ways, and how to really control waste water. Thus, China will confront these challenges to find good solutions to the implementation of the new water policy. Three key issues will benefit these solutions, *i.e.*, appropriating governance & enforcing relevant regulations, sharing the understanding of IWRM & setting up the suitable tools to help decision makers, and elaborating & disseminating methods and means for water systems efficient operations. Bilateral and multilateral efforts to ameliorate China's water problems may be successful in achieving these objectives in the several water sectors.

4. Opportunities & challenges for solutions to China's water problems

The water resources safety problem in China is remarkably important, particularly for northern China. As the growing population, agricultural–industrial and urban economic development, the inconsistency of supply and demand of water resources becomes serious (Qian & Zhang, 2001; Xia and Chen, 2001; Xia *et al*., 2009).

by courtesy of Xia Jun

Water monitoring is conducted at the Ganzi section of the Yalongjiang River, a waterhead of the Western Route Project of the South-to-North Water Transfer.

In line with global change, China's climate has witnessed significant change in the last 50 years. These changes include increased average temperatures, rising sea-levels, glacier retreat, reduced annual precipitation in north and northeast China and significant increases in southern and northwestern China. Extreme weather and climatic events are projected to become more frequent in the future and water resource scarcity will continue across the country. Coastal and delta areas will face greater flood and storm risks from sea level rise and typhoon generation (Liu, 2001; Xia, 2008; Zhang & Wang, 2005). These problems are associated with rapid economic development, which has led to excessive exploitation of water resources and reduction of runoff. The result is that water security, such as in north China, is severely threatened. Water security problems in China have received considerable attention from the Chinese government, and there has been notable progress (Qian & Zhang, 2001; Chen, 1994; Chen & Xia, 1999; Xia & Zhang, 2007).

To solve water problems, the China Water Resources Master Plan (CWRMP) was initiated in 2002 by the Chinese Ministry of Water Resources (MWR). Main tasks of this plan include (a) Researching basic situation of water under the climate change conditions; (b) Building basic information platform of national water resources, and (c) Indicating the strategic planning for future 20 years. Also, MWR is processing the new water strategy based on three red lines control since 2008, namely (1) the control of total water use by Total Water Resources Allocation (TWRA); (2) the control of lower water use efficiency by Water Demand Management (WDM), and (3) the control of total waste water load by Water Quality Management (WQM). However, the question is how to implement and realize these three red line controls in China? Thus, Sciences & technologies for sustainable water future in China will play a key role.

It should be pointed out that several organizations, including the Chinese Academy of Sciences, the National Natural Sciences Foundation of China and the Chinese Ministry of Sciences & Technology and other founding bodies, supported a series of key projects or program for water sciences & water resources studies since the 1980s. On the other hand, the gap between scientific research and solutions of complex water problem still needs to be filled as quickly as possible, particularly on agriculture water, urban water, eco-water, and their integrated water resources management to climate change and human activities. These are still big tasks in the 21st century for sustainable water future in the world.

Prof. XIA Jun delivers opening remarks at the XIVth IWRA World Water Congress held in 2011 in Brazil.

5. Concluding remarks

Based on Chinese experience over the past four decades, the rapid economic development does not necessarily lead to the crease of its total water use. Agriculture water use (irrigation) supported the increase of total grain output from 320 million tons in 1980 to 460 million tons (44%) in 2000. Irrigation plays a major role in the growth of China's grain output and the improvement of its irrigation system, and the enhancement of its irrigation efficiency is the core factors. Integrated management of agriculture water is being promoted in the agriculture sector in which science and technology in irrigation is indispensable and widely used in different regions of China. Development and application of irrigation technologies have to take fully into account the local conditions including climatic, geographic, economic factors as well as the indigenous practices, even farmer's behavior. So technology application should be region specific: water diversion and storage irrigation in the middle and south part of China, rain water irrigation (rain-fed agriculture) in its north and northwest, ground water irrigation in the north China plain. Restructuring of plantation in agriculture (changing the three crops of rice into two crops, and growing drought plants instead of rice) is necessary and also a useful measure for water saving without affecting economic benefit. That means the agriculture growth should take fully into account the availability of local water resources.

Adequate and clean drinking water supply is indispensable for human life. Difficult access to drinking water is one of the big issues in rural areas especially in mountainous and remote areas as well as in pasture region of China. In dealing with drinking water supply in these areas, simple and cheap technologic measures deem necessary. Small water cellar in peasant's courtyard and rain water collected from the roof etc are used in rural areas in north and northwest of China. However, water quality is a big issue. During the rapid urbanization process in recent decades, farmers in some areas will migrate to new communities. The provision of a public water supply system is expected to mitigate the problem.

On the basis of preliminary studies, climate change will lead to temperature increase over Chinese territory, sea water level rise along the coastal areas, glacier retreat and the decrease of annual rainfall in the north and the northeast and increase of rainfall in the south and the northwest. Most possibly climate change will bring about significant impact on regional water resources distribution and allocation, which could produce negative impact on large water projects like South-North water transfer, river basin flood protection system as well as food security. The water cycle will be impacted by climate and human activities, so developing a new generation of large-scale distributed simulation system for the water cycle is necessary, incorporating the land-atmosphere two-way coupling simulation, and providing an efficient method to differentiate the impact on various hydrological elements (temperature, precipitation, evaporation *etc*.) by establishing a mechanism of interactions among climate change, human activities and hydrological cycle. The impact of climate change on economic and social development should be seriously considered. However, certain case studies in China show that it could also have positive impact. Climate change might be conducive to the environment for some regions under study. In conclusion, facing the potential impact due to climate change, appropriate policies should be formulated and adaptable measures be implemented in different regions of the country.

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