Climate change and water resources: evidence and estimate in China

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Climate change impact on water resources is uncertain. This article reviews water resources changes during the past 50 years in China, as well as the modelled results under different scenarios, to figure out a basic framework on the relationship between climate change, water resources and water resources management. China is a rapidly developing country with a large land area and diverse landscape and climate. Due to limited water resources, China is facing water shortage. Studies have shown that climate change has a significant impact on China, especially in north, which faces severe water shortage. The model also shows that in the next 50–100 years an average increase in precipitation is not likely to alleviate water shortage in North China. This is a challenge for water resources management in China. Therefore, all aspects of water resources management, including infrastructure development and non-structural instruments, water saving and new water sources development, etc. should be strengthened to solve the current water problems and prepare to adapt to future changes.

Keywords: China, climate change, evidence and estimate, water resources.

Introduction

THE impact of climate change on water resources is complicated. Water resources are dependent on natural hydrological cycles and human activities through precipitation, runoff and evaporation changes, water resources management, etc.

China has a large land area, diverse landscape and climate. Due to increasing demand for water during the last 30 years and limited water resources, China is facing water shortage. Combined with climate change, many other uncertainties trouble the water resources development and management in China. Therefore, impact of climate change on water resources is still uncertain. From past experience, it is possible to figure out a basic framework on the relationships between climate change, water resources and water resources management.

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Changes in water resources since 50 years

Precipitation change

According to an assessment on water resources and development conducted by the Ministry of Water Resources up to 2006 (Figure 1) between two series of 1956–79 and 1980–2000, the national annual average precipitation did not change significantly, with a marginal 3.7 mm increase in 1980–2000 compared to 1956–79, but there was a remarkable variation in southern and northern China. Since the 1980s, precipitation in northern China has been somewhat less, especially in the Hai, the middle and down reach of the Yellow River basin and Shandong Peninsula. Compared to the 24-year period (1956–79) and the 21-year period (1980–2000), the Hai River basin has 10% less precipitation, the Yellow River basin 6.9% less and the Liao River basin 2.6% less. The precipitation in Shandong Peninsula and Yi–Shu–Si rivers decreased by 16% and 12% respectively. Most regions in southern China, parts of Northwest China and northern part of Northeast China had more precipitation during 1980–2000. The Yangtze River basin increased by 3%; the river basins in Southeast China by 2.6%; the Songhua River basin by 4.6% and river basins in Northwest China increased by 6.5% (Figure 2, Table 1).

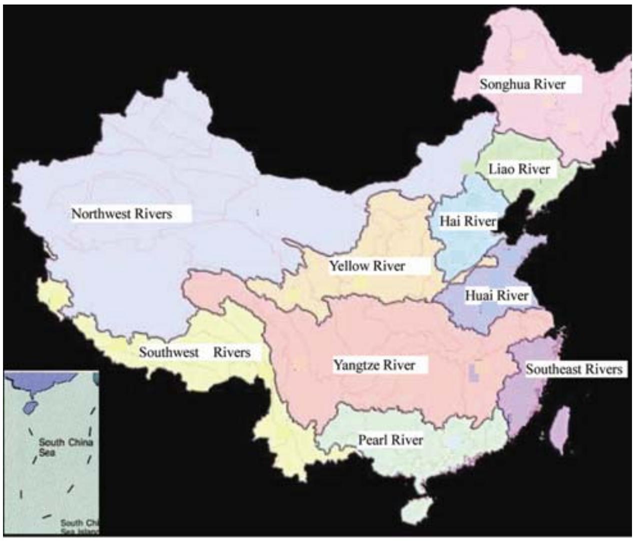

Figure 1. River basins in China.

As for local changes, the precipitation in the Tarim River basin in Northwest China, based on precipitation data during the past 50 years, showed a significant increase in the 1980s and 90s and the average annual precipitation exhibited an increase but of 6.8 mm per decade[1]. This is more or less similar to the national trend.

In Northwest China also, in the Hei river in Gansu Province, precipitation in 1990s increased by 18.5 mm compared to that in 1950s, and 6.5 mm compared to 1960–90. Water resources in the 1990s decreased to 260 million m^3 compared to 1950s, and decreased to 40 million m^3 in the 1990s compared to 1960–90 (ref. 2).

Evaporation change

Comparing the two periods it is evident that except for the Songhua River basin and rivers in Southwest China, the annual average potential evaporation during 1980–2000 was less than that during 1956–79 in other river basins. The annual average potential evaporation of the country decreased by 5.4%.

Other studies also indicate this trend. Shuanhe Shen used the 20 cm diameter evaporation pan data from 472 meteorological stations all over China from 1957 to 2001 and found that the evaporation decreased at 34.12 mm/10a, although there was an increase of average temperature of 0.2°/10a in the average temperature. Among the four seasons, summer has the largest decrease rate of 15.59 mm/10a. An increase occurred only in a few regions, such as the northern part of Northeast China. The maximum decrease occurred in East China, Northwest China and southern Tibet[3]. Other studies indicate that the decrease mainly took place after the mid-1970s (ref. 4).

In northern China, potential evaporation and pan evaporation had the same decreasing tendency during last 50 years. During 1955–2000, the decreasing rate of potential evaporation was 14 mm/10a, although this is much more than the potential evaporation of 69 mm/10a.

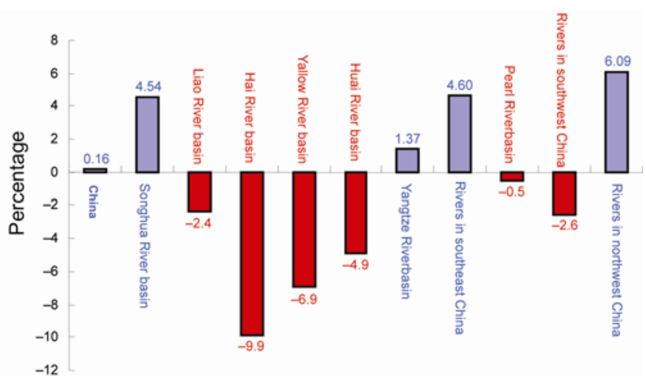

Figure 2. Precipitation comparison between 1956–79 and 1980–2000 in China and different river basins.

A comparison of the evaporation during 1960s with that of 90s showed that evaporation in Northwest China decreased by 475.3 mm, by 253.7 mm in Inner Mongolia Plateau and regions along Great Wall, but a slight increase was noticed in Loess Plateau. A comparison of potential evaporation of the 1960s with that of 90s, according to data from 197 meteorological stations, indicates that potential evaporation decreased by more than 100 mm in Northwest China, and more than 50 mm in Yellow, Huai and Hai river basins. But in some regions in Inner Mongolia and Loess Plateau, there was an increase in potential evaporation by 10–30 mm. The main reasons for the decrease of potential and pan evaporations are the decrease of sunshine percentage and wind speed and increase in air humidity during this period[5].

Water resources change

In the last 20 years, the land cover and climate have changed, therefore water resources evolution mechanism also changed. The Ministry of Water Resources has assessed that precipitation has changed only slightly; surface water resources and total water resources have increased slightly. In southern China, runoff and total water resources increased by 5%; while in northern China, water resources decreased significantly, especially in the Yellow River basin (Figure 3), Hai River basin and Liao River basin. In Hai River basin, a 10% decrease in precipitation resulted in 41% decrease in runoff and 25% decrease in total water resources (Figure 4). In Shandong Peninsula of Huai River basin, 16% decrease in precipitation resulted in 51% decrease in runoff and 34% decrease in total water resources (Table 1, Figure 5).

The decline in water resources in northern China is the result of reduced precipitation and landscape change due to human activities. In general, reduction in precipitation is the main factor although landscape change cannot be ignored resulting in changes in rainfall–runoff relationship. It is estimated that in the Yellow, Huai, Hai and Liao River basins, compared to the recent land cover with that 50 years ago, the area with changes in rainfall–runoff relationship is 35% of the basins, the runoff would decrease by 10–20% under normal precipitation, and by 15–40% in dry year. In these four river basins, the 75% decrease in surface water resources was due to decrease in precipitation, of which 60% was in Yellow River basin and 80% was in Huai and Hai river basins.

Estimate of climate change on water resources in the future

Climate change affected the distribution of water resources in China and significantly impact the spatial and temporal distribution of water resources. It will enlarge the annual and seasonal variations; increase

Table 1. Comparison of water resources between 1980–2000 and 1956–79 in China

	1956–79 (mm)			1980–2000 (mm)			Comparison between 1980–2000 and 1956–79 (%)		
Water resources zones	Precipitation	Surface water resources	Total water resources	Precipitation	Surface water resources	Total water resources	Precipitation	Surface water resources	Total water resources
Songhua River basin	496.6	130.2	150.1	519.4	147.0	168.4	4.6	12.9	12.2
Liao River basin	553.1	138.9	167.6	538.6	124.2	152.9	–2.6	–10.6	–8.8
Hunhe–Taizi rivers	748.0	242.3	282.0	740.6	214.8	251.4	–1.0	–11.3	–10.8
Liao	472.6	64.6	101.7	469.7	61.6	99.9	–0.6	–4.7	–1.8
Hai River basin	559.8	90.5	132.4	501.3	53.3	99.0	–10.4	–41.1	–25.3
North rivers of Hai	506.5	80.1	118.6	458.8	49.6	94.1	–9.4	–38.2	–20.6
South rivers of Hai	579.8	97.5	143.2	511.7	50.4	100.6	–11.7	–48.3	–29.7
Yellow River basin	464.4	83.2	93.6	432.2	71.1	84.9	–7.0	–14.5	–9.3
Hetao–Longmen section	459.7	53.5	63.1	406.8	34.9	50.5	–11.5	–34.7	–19.9
Sanmenxia–Huayuankou section	666.8	156.9	171.3	639.0	112.6	134.1	–4.2	–28.2	–21.7
Huai River basin	859.6	225.1	291.9	815.5	191.9	263.2	–5.1	–14.7	–9.8
Huai River	909.1	237.6	313.9	912.3	239.0	311.4	0.3	0.6	–0.8
Yi–Shu–Si rivers	836.0	215.1	290.9	739.1	154.8	235.7	–11.6	–28.0	–19.0
Shandong Peninsula	732.5	198.6	223.1	613.1	93.7	148.4	–16.3	–52.8	–33.5
Yangtze River basin	1070.5	526.0	531.6	1100.9	573.4	579.1	2.8	9.0	8.9
Taihu lake	1105.1	365.7	433.2	1228.4	502.7	545.9	11.2	37.5	26.0
River basins in Southeast China	1758.1	1066.3	1080.8	1804.6	1108.6	1122.8	2.6	4.0	3.9
Pearl River basin	1544.3	806.9	810.8	1543.7	826.1	828.5	0.0	2.4	2.2
River basins in Southwest China	1097.7	687.5	687.5	1079.0	680.3	680.3	–1.7	–1.0	–1.0
River basins in Northeast China	157.7	34.5	38.6	167.9	35.4	39.4	6.5	2.5	2.2
Northern China	329.8	74.3	88.3	329.0	71.4	86.5	–0.3	–3.9	–2.0
Southern China	1203.6	649.6	654.1	1219.6	679.8	684.2	1.3	4.7	4.6
China	648.4	284.1	294.6	652.1	292.1	303.4	0.6	2.9	3.0

the frequency of hydrological extreme events such as floods and droughts. In particular, climate warming will accelerate the melting of glaciers in western China, and reduce the area and storage of glaciers, which will impact the runoff of rivers mainly supplied from glaciers. Climate warming might increase the drying tendency in North China, and worsen the water supply and demand conflict[6].

Precipitation change

Under the continuing global warming, precipitation distribution will also change. More water in northern China compared to southern China will alleviate the water resources pressure in the north. Due to global warming, precipitation in China is likely to start fluctuating before 2040. Beginning 2015, northern China will have more precipitation compared to south. After 2040, precipitation will significantly increase, with 8–10% increase at the end of the 21st century, demonstrating a rapid increase of precipitation in northern China, whereas it will decrease in the south. This is likely to be the scenario of precipitation under climate warming (more precipitation in middle and high latitudes, and less in subtropical regions)[7].

According to China's National Assessment Report on Climate Change[8], due to double concentration of carbon dioxide in 2070, the annual average precipitation is likely to increase from the results of regional climatic model. Western China covering areas from the western part of North China to Xinjiang will have the highest percentage of precipitation (more than 20% increase). The eastern part of Guangdong Provinces, the western part of Fujian Province and the northeast part of Guangxi Autonomous Region will have more precipitation. In the middle and downstream of the Yangtze River basin, some areas will witness increasing precipitation and some decreasing precipitation. The northern parts of Northeast China show greater increase in precipitation (20% in some areas). But its southern part and the northern part of North China will have decreased precipitation (more than 10%). It should be pointed out that these results, namely, more precipitation in western China and less in some regions in Northeast and North China, are consistent with the change seen in past decades. The annual average precipitation in China is likely to increase by 12%, with 6%, 19%, 6% and 12% in spring, summer, autumn and winter respectively.

Water resources change

Climate change has affected distribution of water resources in China; a decreasing trend in runoff was observed during the past 40 years in the six main river basins, including the Hai, Yellow, Songhua, Yangtze and Pearl rivers.

There is evidence to show an increase in the frequency of hydrological extreme events, such as droughts in North and floods in South. The Hai River basin is most vulnerable to climate change, followed by Huai and Yellow River basins. The arid inland river basins are particularly vulnerable to climate change.

The China National Assessment Report on Climate Change, the Water Information Center of the Ministry of Water Resources based on the population projection of

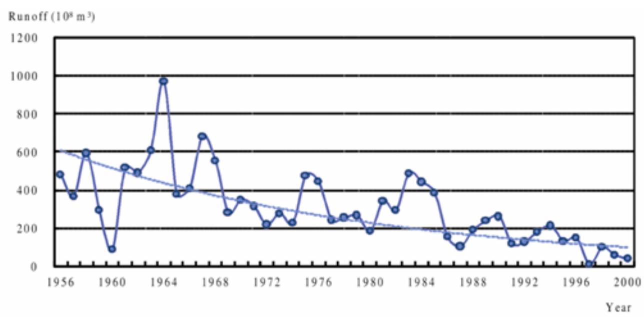

Figure 3. Run-off change during 1956–2000 in Yellow River.

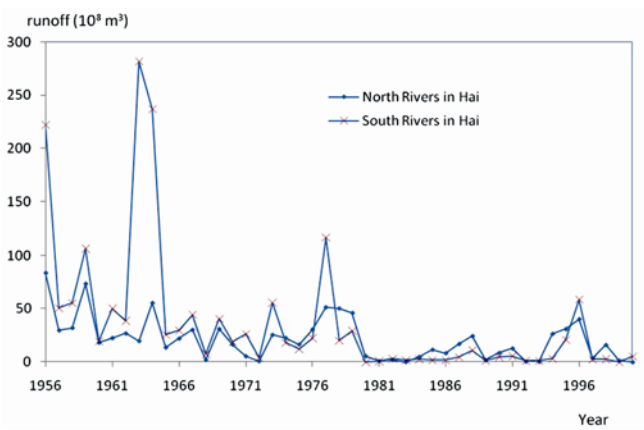

Figure 4. Run-off change during 1956–2000 in Hai River basin.

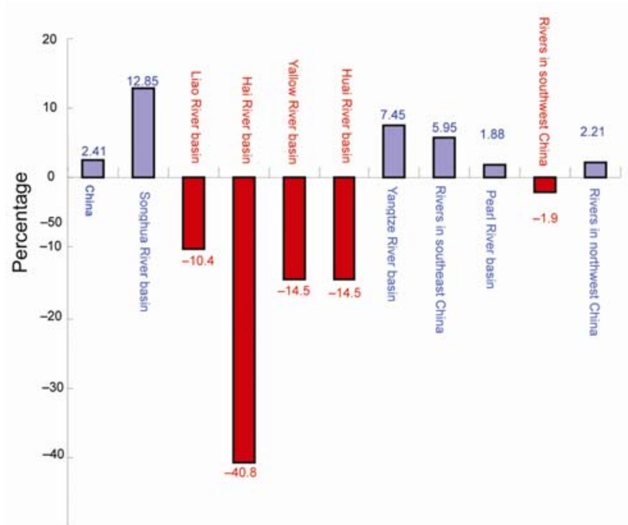

Figure 5. Surface water resources comparison between 1956–79 and 1980–2000 in China and different river basins.

1.62 billion in 2050 and in 2100 – by applying VIC distribution hydrological model and PRECIS 50 km × 50 km SRES A2 and B2 Scenarios – has projected that in future climate change would have a significant impact on water resources. During the next 50–100 years, the mean annual runoff is likely to decrease in some northern provinces and regions, including Ningxia, Gansu, Shaanxi, Shanxi and Hebei; while it would increase remarkably in water-abundant southern provinces and regions, including Hubei, Hunan, Jiangxi, Fujian, Guangxi, Guangdong and Yunnan. This shows that climate change would increase the frequency of flood and drought events; and the situation of water scarcity would tend to continue in northern China, especially in Ningxia and Gansu, where water resources per capita are likely to decrease further. In most provinces, water supply and demand would show general imbalance in the next 50–100 years. Also, the gap between water resource supply and demand might increase in Inner Mongolia, Xinjiang, Gansu and Ningxia.

Given the precipitation changes (0′ ± 25%′ ± 50%) and temperature changes (0°C, ±1°C, ±2°C), the sensitivity analysis indicate that in the Yellow, Hanjiang, Ganjiang, Huai and Hai rivers, the runoff would be more sensitive than temperature, the surface runoff would have a greater impact than the total runoff; the semi-humid areas and the semi-arid areas would be less sensitive compared to the semi-arid and semi-humid areas, with a significant increase from South to North and from mountainous areas to the plains. The most insensitive region would be the arid inland river basins and upper stream of Yellow River basin. The most sensitive regions would be the semi-humid and semi-arid regions, such as Songhua and Liao, Hai and Huai River basins.

According to the China Meteorological Bureau, with the scenario of temperature increasing by 1.9–2.3°C in Northwest China, the glacier area will decrease by 27% compared to the present, and all small glaciers less than 2 km^2 will disappear. With increases in production and increased demand for water, the shortfall in water would be about 20 billion m^3 during 2010–2030 in China[9].

Adaptive management to climate change on water resources

Adapting to uncertainties is a painful process, even worse is to prepare for long-term uncertainties in the future. When one looks at water resources, it is still unclear as to what are the changes that are contributed by climate change from increasing concentration of carbon dioxide, and by the other factors. Given that all the projected scenarios are likely to happen in the future, there is a long way to go and it will depend on so many factors, such as social and economic development which are more intensive than climate change in a short term. Therefore, adapting to climate change on water resources will depend on future events as well as on current understanding and policies. In China, based on current water resources strategies and estimated results of climate change on water resources, the following measure need to be undertaken.

Changing water policy from supply management to demand management

The change from supply to demand management will provide answers to water resources management. Due to climate change impact on water resources, water supply will change resulting in uncertainty. But the demand on water resources is clearly known and could therefore be controlled by humans.

Conducting demand management will change the whole concept and functions of the water sector, including water resource planning, infrastructure development, water resources management, etc. The core of demand management is to increase water-use efficiency and benefits. The focus of demand management in China will be to strengthen water resources allocation, conservation and protection, and regulate industrial structures according to the presently available water resources.

Incorporating climate change into water resources planning

Climate change impact should be incorporated into water resources planning, in order to increase the adaptability of water resources plans which will help analyse water resources reactions under different climate change scenarios covering the extremes.

Strengthening the construction of water infrastructure

Climate change will make water resources circumstances shift to a more unhelpful situation in China, especially in north, with the current shortage of water resources. To adapt to this change, it is necessary to increase the regulation and allocation ability of water resource systems. Therefore, some comprehensive infrastructures need to be built in the river basins and some emergency and backup sources constructed, particularly in the medium and large cities[7]. At the same time, cross-river basin water projects need to be built to transfer water among basins.

Strengthening water resources protection

At present, water pollution is a serious threat to water supply in China. It not only deteriorates water quality, but reduces its availability. It is necessary to protect water resources, to improve protection of drinking water sources and strengthen groundwater sources.

Strengthening non-traditional water resources

Non-traditional water resources include recycled wastewater, desalinated water, saline water, rainwater and floods. To face water shortage in China, utilization of non-traditional water resources will be an important measure to solve the water supply and demand conflict.

Urban rainwater harvesting will increase water use efficiency, reduce urban flood pressure and recharge groundwater. Recycled water is a stable source in urban areas, and could be used as secondary sources to supply to industry, environmental purposes and irrigation[10].

Promoting implementation of integrated river basin water resources management

Integrated river basin water resources management is a useful process. China should implement integrated river basin water resources management at all levels, including water resources planning, institutional reforms and water resources protection.

Adaption in key regions

- The Yellow, Huai and Hai river basins are the political, economic and cultural centres and grain production centre. Water resources would continue to decrease and, therefore, it is necessary to regulate the industrial structure and industrial distribution; to build a water-saving society and increase water use efficiency and effectiveness, change agricultural structure; to promote building of south-to-north water transfer projects in China as well as using of non-traditional water sources.
- Northwest China has a semi-arid and arid climate. Although climate change results in increased precipitation, it will not drastically change the water shortage. At the same time, reduction in glaciers will reduce the stability of runoff. Therefore, it is necessary to allocate water efficiently to guarantee environmental requirements for key areas and drought contingency plans.
- The southeast coastal cities are the economic centres of the region. Due to climate change, the occurrence of hydrological extremes will increase. Therefore, it is necessary to develop a typhoon and flood precautionary system to improve flood control ability; to strengthen water pollution control; and to control groundwater exploitation, to prevent seawater introduction and sea level increase.

Conclusion

It is difficult to define climate change impact on water resources, and even more difficult to estimate the results in China compared to the developed countries, because of China's rapid development not only economically, but also in its land use and natural resources use, etc.

Past experiences have shown that, co-impacted by human activities and climate change, water resources did not shift to a circumstance friendly to human being. The present serious water issues are testimony to all these changes. In the future, although precipitation will increase in the northern part of China, the surface runoff will decrease, which will worsen the water shortage.

It is crucial for China to solve all these problems to realize a sustainable water resources development and at the same time support sustainable social and economic development. Therefore, all aspects of water resources management, including infrastructure development and non-structural instruments, water saving and new water sources development, etc. should be strengthened to solve water-related problems and prepare for adapting to future changes.

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