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Current Situation and Future Security of Agricultural Water Resources in North China

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Abstract: North China is one of the major breadbaskets in China and is critical in ensuring food security of the nation. It sustained 18% of national total arable land, and 23% of national total grain crop output using only 6% of national total water resources. However, such impressive accomplishments were achieved at huge costs incurred in resources, environment, and ecosystem. We first presented accomplishments, current situations, and main challenges facing agriculture and water use in North China. Then, using an integrated framework in agricultural water management widely adopted by international water research communities, we reviewed the trajectory of agricultural development and its associated water withdrawal, water use efficiencies, and productivities in North China from 1998 to 2015, from which some major experiences and lessons were derived. We then tentatively proposed policy and strategy pathways to ensure food security in North China in the future.

Keywords: food security; agricultural water use; water use efficiency; crop water productivity.

1 Agricultural achievements and problems present in North China

1.1 Agricultural achievements by North China under situations of water shortage

North China (NC) enjoys superior conditions in politics, economics, science and technology, and geographic locations in China. Its prosperity is of significance to nationwide political, economic, and societal stability. NC comprises two municipalities under direct jurisdiction of the central government (i.e. Beijing and Tianjin) and three provinces (i.e. Hebei, Shandong, and Henan), representing 24% of the national total population and 17.9% of national total arable lands. NC is also endowed with favorable light and heat resources and fertile arable land conditions that are key to crop and livestock outputs in the nation. It accounts for nearly a quarter of the national gross agricultural output values. Its agriculture is characterized by crop and livestock production; its crop output value accounts for 58% of the national total and livestock productions make up 32% of the national total. In 2014, NC produced 1.397×10^8 t of grains, accounting for 23% of the national total. Of all crop outputs, grains accounted for 60%, followed by vegetables and fruits, 34%. Wheat and corn predominated grain output, with wheat representing 51% and corn 40%. NC is the most important wheat production region in the country, with 48.3% and 56.2% of the national sowing acreage and outputs, respectively. Per unit area yield of wheat is 6.1 $\text{t}\cdot\text{ha}^{-1}$, which is

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fairly above the national average of 5.2 t·ha^{-1}.

However, it should be kept in mind that such impressive achievements of the NC crop and livestock sectors are obtained despite poor water resources. The total internally renewable water resources (IRWR) of NC represent merely 6% of the national total. Adding to this, its per capita water resources and disproportionate fit between water and land is far below the national average. For example, per capita IRWR for the Haihe River Basin, one of the two major river basins within the geographic extent of NC, is only 250 m^3, just 12.5% of the national average. Caught between both a drying climate and growing industrialization and urbanization, agricultural water withdrawal (AWW) in NC fell considerably by 24.4% from 5.603×10^{10} m^3 in 1998 to 4.234×10^{10} m^3 in 2015. Meanwhile, the share of AWW in NC's total water withdrawal (TWW) declined from 72.2% in 1998 to 61.7% in 2015 [1]. Even with decreased AWW, crop outputs and per unit area yield steadily increased due to better crop and water management practices adopted in NC in recent years. For major breadbasket provinces in China and in NC as well (Hebei, Henan, Shandong), the total grain output increased by 5.85×10^7 t. Great improvements on per unit area yield mostly contributed to an increase in the total output of crops. Wheat yield increased by 3.01 t·ha^{-1}, an 120% improvement; corn yield increased by 2.69 t·ha^{-1}, a 90% improvement. Water consumption did not increase concurrently with higher crop outputs, which may be owing to the improved infrastructure and technology in crop production.

Such intensified agricultural production also brings about enormous negative eco-environment effects albeit NC had contributed immensely to ensuring food security for the nation through high crop and livestock production. Of particular importance is the ever-spreading drawdown cones and land subsistence due to over-tapped groundwater (GW), which severely threatens sustainable irrigation in NC [2]. To address this problem, General Secretary of the Communist Party of China (CPC), and President of People's Republic of China, Xi Jinping proposed an illuminated water control idea, which prioritized water saving and equilibrate locations. His plan also included clauses about governing in a systematic manner and using a system in which both top-down and bottom-up forces are exerted to push on the problem. The particular strategy was to set upper limits of cropland acreage, manufacturing outputs, and development goals in accordance with the availability of water resources for a specific region. Putting the above principles into practices in recent years has achieved obvious results. Especially after the adoption of water saving and GW tapping restriction policies in 2014, water and crop governance has been developing five categories of projects, which embrace water saving, water diverting, water storing, water regulating, and water managing. The detailed practices include water conservation centered on water saving irrigation, adequate water diversion from off-NC basins, water-adapted and water-limited cropping system shifts, ground water tapping restrictions, dual control on GW tables and volumes, and improved regulation and legal system. Systematic water governance encompassing water source and farmers' field, engineering projects and agronomic practices, construction, operation, and maintenance has been taking shape. Preliminary outcomes from implementing the abovementioned practices show that over-tapped GW has been basically contained. However, with the integrated regional development of Beijing–Tianjin–Hebei and urbanization, agriculture will release more water of its own. These different sources of water demand lead to concerns on how to best manage water while also taking the environment and ecosystem into account. This question is a great challenge for NC.

1.2 Major problems facing water-limited agricultural development in North China

Six major problems are bottlenecking agricultural development in NC under water limited conditions.

First, agriculture in NC is still far from following a water-adapted mode. The scale of agriculture in NC far surpasses the carrying capacity of water resources of its own, leading to extensive drawdown cones and land subsistence in the region. The continued decline of GW resources has not been reversed despite over thirty years of water saving irrigation technologies in the North China Plain (NCP). Results from water saving lag far behind increased water use. A weird phenomenon of 'the more we save water, the less water we have' has been taking place. Diversity of crops has been continuing to decline, while demand for water demanding crops such as vegetables and fruits continues to grow. Hence, agriculture is far from being water-adapted in NCP.

Second, NC has an inappropriate cropping structure, with ever increasing and disproportionate vegetable and fruit growing. Such production patterns with intensified water consumption per unit area, high water and fertilizer input, and high crop outputs have resulted in lower quality outputs, lower crop prices, and lower resource use efficiencies, as well as more negative environmental externalities. The share of grain crops in the total crop sowing acreage in NC continually fell from 78.9% in 1981 to 66.3% in 2014. Of all crops grown in NCP, shares of vegetables and fruits with higher water requirements have increased by 11.1% and 4.1% respectively. Vegetable

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outputs of NC represent 37% of the national total, and fruits 29% of the national total. Vegetables are second only to grain crops with respect to consumed irrigated water. High water consumption by vegetables is ascribed not only to the more rotations of vegetable crops but also to inappropriate irrigation practices and schedules, which lead to more rooting zone percolation, higher nutrient leaching, and consequential environmental risks.

Third, a compensation mechanism for water saving practices has not taken form. Water saving projects have yet to play positive roles due to insufficient driving forces in extending water saving technologies, and unsound extension service systems for agricultural water savings combined with lower performance standards for water saving projects. Even though society as a whole benefits from water saving practices, farmers are the only stakeholders that need to comply with these practices. The economic benefits derived from lower irrigation are much lower than the ecological benefits enjoyed by the society as a whole. This is due to low pricing for watering staple crops. Meanwhile, farmers have to invest considerable money in installing and operating water saving equipment, thus pushing their production costs upward. Hence, adopting agricultural water saving techniques is not a priority for farmers. Moreover, a sensible compensation mechanism that reflects the principle of the “more water we save, the more money we earn” has not yet been well placed, thereby affecting the positivity and activity of farmers’ water saving practices.

Fourth, a well-established water use monitoring and measuring system is in its infancy and currently does not effectively monitor regional AWW and GW over-tapping. This consequently affects the effective control of regional crop water use and per unit area water consumption. An accurate and precise monitoring and measuring system is one of the most important prerequisites of moving forward water saving practice and its accompanying compensation mechanisms. As of 2015, over 95% of irrigated areas under surface water irrigation have not installed field water metrics. For the irrigated area under GW irrigation, no tight water withdrawal permits are in place, causing disorderly tapping of GW and difficult management of GW withdrawal.

Fifth, water saving policies and practices released by different water and crop administrations are insufficiently coordinated. Engineering-oriented and agronomic-oriented water saving technologies are ill matched with each other. A standardized water saving technology that can be applied on a large scale is still badly needed in NCP. Crop and water management in NCP is currently under direction and directives from different government organs that are insufficient in coordinating mechanisms among them. A particular patch of farmland can even receive conflicting and contradictory guidelines, with one office saying that water adapted cropping system has to be practiced, and the other one saying that the farmer must increase cropland acreage, leading to higher water consumption.

Sixth, the subsidy policies in the over tapped area of GW have invested enormous amounts of money, but the real effects are limited, and the policies do not seem sustainable.

Based on the abovementioned facts and figures, it can be safely concluded that water is the largest limiting factor that may constrain sustainable agriculture in NCP. Therefore, the objectives of the research are 1) to systematically analyze the current water resource situation, agricultural water use and its efficiencies in the past 18 years (1998–2015); and 2) to project the future developing trajectory of agriculture water use under the grand background of internationalized and green agricultural development.

2 Current situation of agricultural water and land resource use in North China

2.1 Water resource changes in North China from 1998–2015

The mean annual precipitation in five province-level administrations of NC as a whole from 1998–2015 decreased by varying degrees compared to multiple-year values averaged from 1956–2000 (Fig. 1). Of the five provinces and province-level municipalities, Beijing, Hebei, Tianjin, and Henan’s levels fell by 15.6%, 9.6%, 5.2%, and 1.9%, respectively. Shandong was the only province in which rainfall increased (0.3%). NC’s level as a whole decreased by 3.9%. If analyzed using multiple-year hydrological frequencies, water-rich and normal years have occurred more frequently in recent years from 2011–2015, showing a bit of a wetting trend. Whether such trend will continue or not depends on the scope and magnitude of climate change. However, some research indicates that NC will enter into a time period of relatively rich precipitation in the next 30 years [3].

Even though there was only a slight decrease in precipitation, both surface water and ground water from precipitation decreased with remarkable rates due to great changes in land covers and land uses arising from rapid economic growth and urbanization. Consequently, the surface IRWR in five provinces and municipalities decreased enormously (Fig. 2), of which Beijing’s level fell by 54.4% and Hebei’s by 52.7%. Tianjin, Henan, and

Shandong, and NC as a whole's level decreased by 21.8%, 13.8%, and 6.7%, and 16.7%, respectively. As a major grain production province, a decrease of 52.7% of surface IRWR would definitely exert a negative impact on TWW for all water use sectors and agricultural water use, in particular.

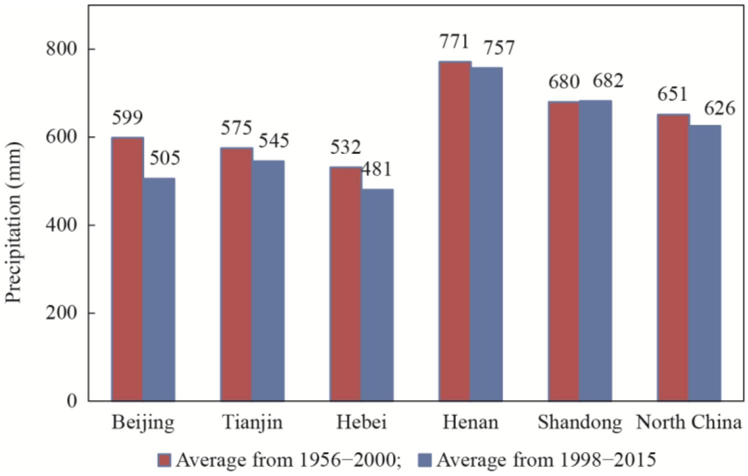

Fig. 1. Mean annual precipitation averaged from 1998–2015 in NC compared to multiple-year (1956–2000) averages.

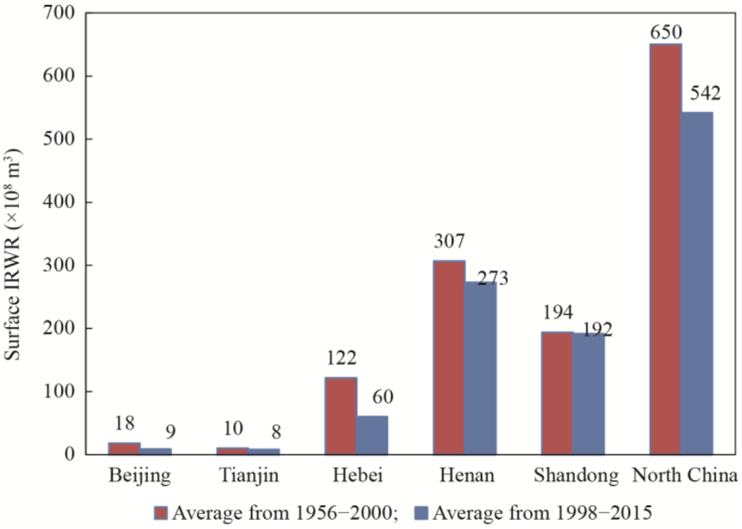

Fig. 2. Mean annual IRWR from 1998 to 2015 compared to multiple-year averages (1956–2000).

The GW arising from precipitation also declined for 18 years, from 5.89×10^{10} m^3 to 4.45×10^{10} m^3, dropping drastically by 24.4%. The share of ground water in NC compared to the national total of GW dropped from 6.27% to 5.71% (Fig. 3).

Overall, total IRWR in NC declined from 1.212×10^{11} m^3 to 6.303×10^{10} m^3, an approximately 48% reduction (Fig. 4). The aforementioned results indicate that the IRWR in NC drops by half even with a relatively abundant precipitation in recent years, which might be mainly ascribed to enormous alterations of land covers and land use in the last twenty years since the turn of 21st century. AWW was thereby severely restricted by the declining IRWR.

In the meantime, population growth also intensified water tensions in the region. The per capita IRWR in NC declined from 450 m^3/cap in 1998, to 207 m^3 /cap in 2015, falling remarkably by 54.0% (Fig. 5).

The per capita IRWR based on hydrological years was as follows: 1) 478 m^3/cap in water-rich years (1998 and 2003); 2) 373 m^3/cap in relatively water-rich years (2000, 2004, 2005, 2007, 2010); 3) 302 m^3/cap in normal water years (2008, 2009, 2011, 2012); 4) 214 m^3/cap in relatively water-poor years (2001, 2006, 2013, 2014, 2015); and 5) 189 m^3 /cap in water-poor years (1999 and 2002). Despite huge gaps among different hydrological years, the overall per capita IRWR in the region remains fairly low.

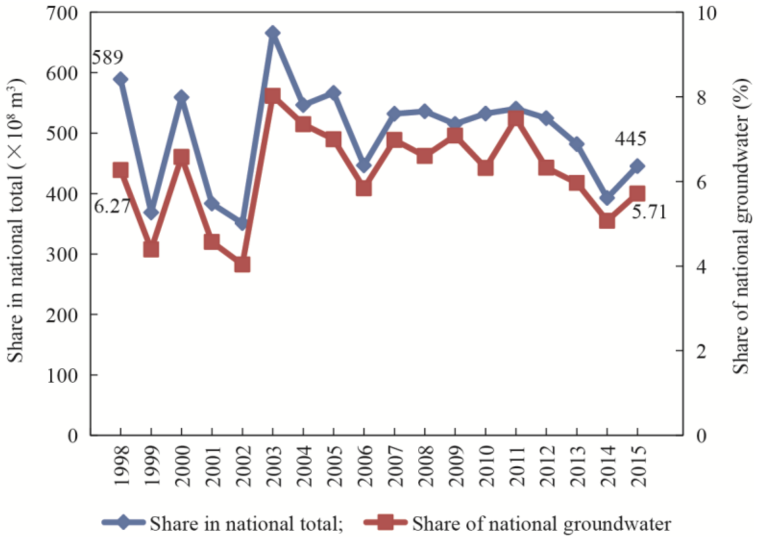

Fig. 3. Changes in groundwater in North China and its share of the national total (1998−2015).

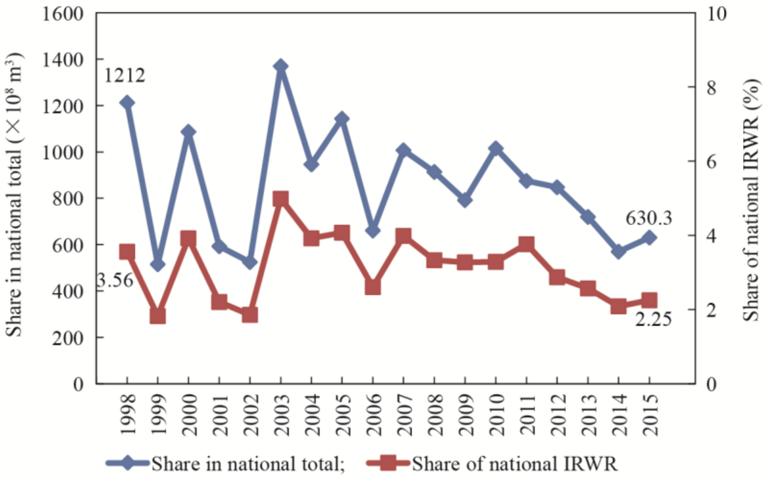

Fig. 4. Changes in IRWR in North China and its share of the national total (1998−2015).

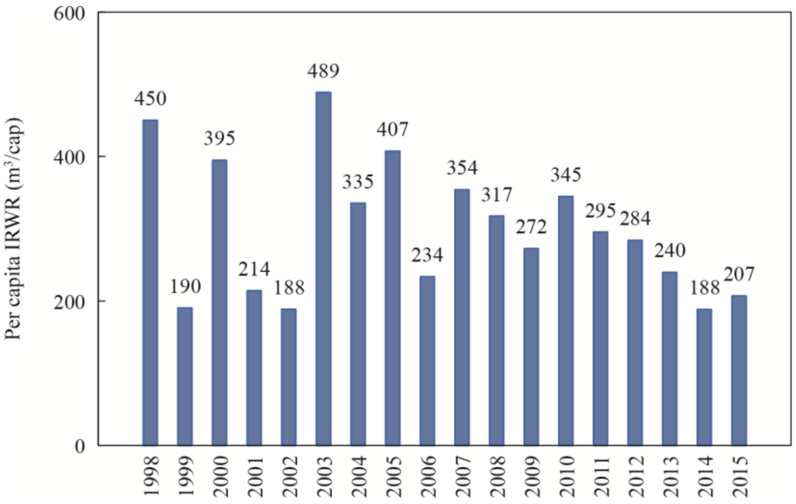

Fig. 5. Changes in per capita IRWR in North China (1998−2015).

The IRWR appropriated by per unit area of arable land in the region as grouped by hydrological years was as follows: 1) 5 585 m^3/hm^2 in water rich years; 2) 4 558 m^3/hm^2 in relatively water-rich years; 3) 3 746 m^3/hm^2 in water-normal years; 4) 2 771 m^3/hm^2 in relatively water-poor years; and 5) 2 234 m^3/hm^2 in water poor years (Fig. 6). The IRWR shared by per unit area of arable land also exhibited a huge gap, with that in water-rich years being 2.5 times that of water-poor years, and that in relatively water-rich years being 1.6 fold that in relatively water-poor years. Hence, 3 746 m^3/hm^2 in water-normal years is representative of the IRWR share by arable land in the region.

In sum, the overall water situation in NC is severe, and the regional AWW and match between water and land will further strain if squeezed by a fast dropping IRWR, rapid economic development, and population growth.

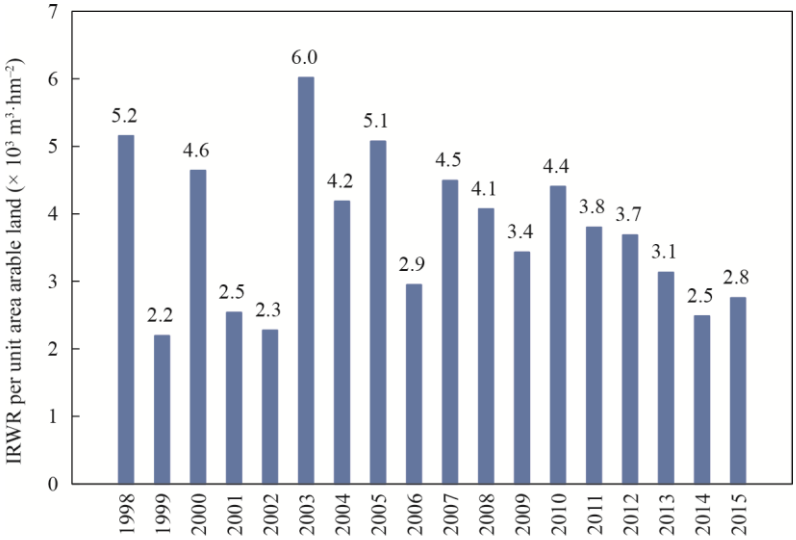

Fig. 6. Changes in IRWR per unit area arable land in North China (1998−2015).

2.2 Broadly-defined available water for agricultural use in North China

Agricultural water use and management span across a continuum from purely rain fed to purely irrigated crop production, with varying degrees of mixing of green (i.e., rainfall) and blue (i.e., irrigation) water lying in-between. To address such continuum from green to blue water, a comprehensive agricultural water analytical framework, which is based on the paradigm shift in water resource management widely adopted by global water research and policy communities in recent years, is proposed and applied in this research. The framework defines a series of inter-related concepts associated with “broadly-defined available water for agricultural use”, or BAWA [4−6]. BAWA consists of two components, cropland precipitation and cropland irrigation, with the former referring to the “green” effective precipitation falling upon croplands and the latter to the “blue” irrigated water received by croplands.

Blue water is defined as the water that enters various types of surface and sub-surface water bodies (i.e., streams and river channels, lakes and ponds, reservoirs, underground aquifers, snow and ice caps) on earth during precipitation (i.e., rainfall and snowfall). It is visible as “blue” to the human eye, so it is termed as blue water. Blue water coincides with the conventional assessment of renewable water resources, or IRWR in general, and irrigated water in agriculture in particular. Green water is defined as water that enters soil to support the growth of green vegetation upon precipitation. Such soil moisture is lost through either soil evaporation or plant transpiration. The water is directly used by green plants, so it is termed green water. Water that is held by the field capacity of the soil profile is also referred to as “green water storage”, and water that is evaporated and transpired is referred to as “green water flow”. Both blue and green water jointly contribute to biomass and yield formation of crops. However, the traditional agricultural water management focused more on blue water parts while ignoring, if not totally neglecting green water parts within cropland. Hence, in the new generation of agricultural water management, both blue and green water components should be considered. The BAWA proposed herein includes both cropland precipitation and irrigation.

Moreover, BAWA also contains a series of inter-related concept groups. The depletion rate of blue water is the ratio of evapotranspired water to delivered irrigated water on croplands, while the depletion rate of green water is the ratio of evapotranspired water to effective precipitation on croplands. The contribution rate of blue water is defined as the evapotranspired blue water that is consumed in biomass/yield formation divided by total consumed evapotranspiration, and similarly, the contribution rate of green water is defined as the evapotranspired green water that is consumed in biomass/yield formation divided by total consumed evapotranspiration. Crop water productivity is defined as crop outputs divided by evapotranspiration consumed in crop yield formation.

Proceeding from the above concepts, the following results were calculated. In the period of 1998–2014, the maximum BAWA in the NC region occurred in the water-rich year of 2003, as 1.927×10^{11} m^3; the minimum BAWA was 1.041×10^{11} m^3 in the water-poor year of 2002. Of the BAWA, the maximum cropland irrigation occurred as 5.27×10^{10} m^3 in the water-poor year of 1999, and the minimum irrigation was 3.54×10^{10} m^3 in the relatively water-poor year of 2014. The maximum cropland precipitation occurred as 1.523×10^{11} m^3 in the water-rich year of 2003, and the minimum was 1.041×10^{11} m^3 in the water-poor year of 2002. The eighteen-year average (1998–2015) of BAWA was 1.647×10^{11} m^3, of which the average cropland precipitation was 1.224×10^{11} m^3 and the average cropland irrigation was 4.23×10^{10} m^3 (Fig. 7). The BAWA averaged over different hydrological years was as follows: 1) 1.816×10^{11} m^3 in water-rich years; 2) 1.699×10^{11} m^3 in relatively water-rich years; 3) 1.657×10^{11} m^3 in water-normal years; 4) 1.557×10^{11} m^3 in relatively water-poor years; 5) 1.555×10^{11} m^3 in water-poor years.

The relative share of green and blue water in BAWA swung back and forth between 20% to 80%. The maximum share of green water in BAWA was 79.1% in the water-rich year of 2003, and the maximum share of blue water was 33.2% in the water-poor year of 1999. The minimum share of green water in BAWA was 66.8% in the water-poor year of 1999, and the minimum share of blue water was 20.9% in the water-rich year of 2003 (Fig. 8). The above results obviously show that the 'rise and fall' of the relative share of blue and green water in BAWA coincided exactly with each other.

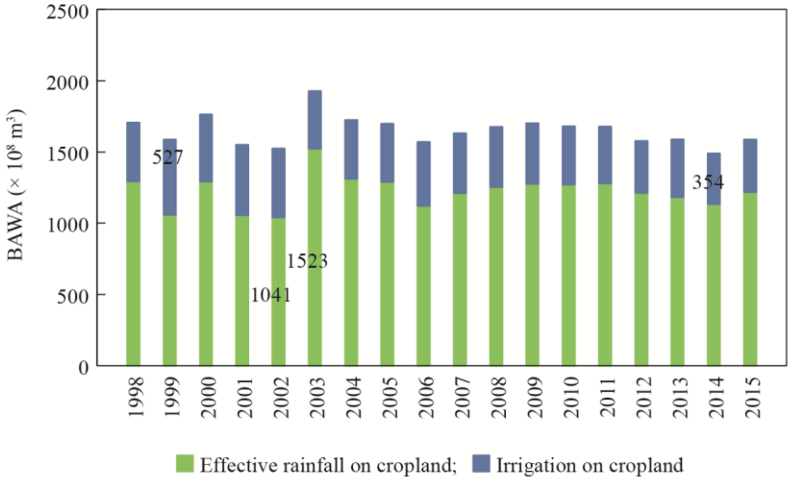

Fig. 7. Changes in BAWA and its components in North China (1998−2015).

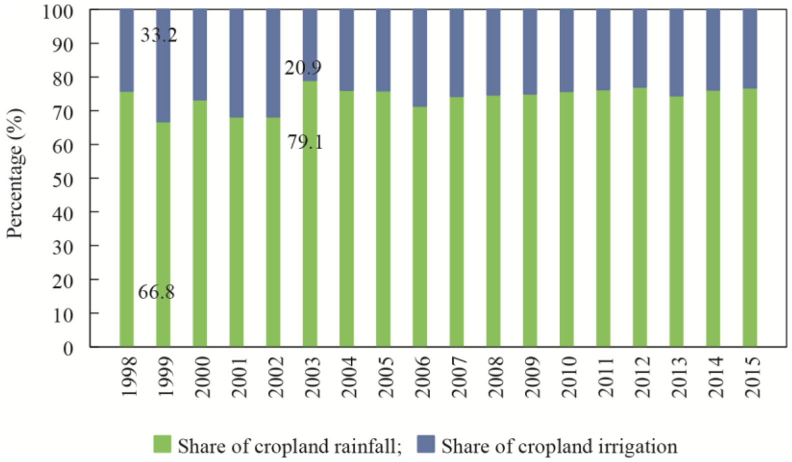

Fig. 8. Changes in relative share of green and blue water in cropland in North China.

2.3 Past and present agricultural water withdrawals in North China

AWW in NC declined from 5.603×10^{10} m^3 in 1998 to 4.234×10^{10} m^3 in 2015, dropping by 24.4%. In the meantime, the share of AWW in the TWW fell from 72.2% in 1998 to 61.7% in 2015. The share of NC's AWW compared to the national total AWW declined from 14.9% in 1998 to 11.0% in 2015. Of all AWW, irrigated blue water represented the majority, ranging from 90% to 95%. Of particular attention is that the share of irrigated water in AWW had been constantly declining in the 18 years studied. Due to data paucity in irrigated water in water resource bulletins, we adopted the cropland area under irrigation as a proxy variable to generalize past and present situations of cropland irrigation.

Total irrigation area in NC increased from 1.523×10^7 hm^2 in 1998 to 1.602×10^7 hm^2 in 2015, with an increasing rate of 5.1%. The share of arable land equipped with irrigation in total arable land area increased from 45.0% in 1998 to 55.7% in 2015.

The amount of arable land acreage that was irrigated in NC increased from 1.436×10^7 hm^2 in 1998 to 1.507×10^7 hm^2 in 2015, with the corresponding shares in total area of arable land increasing from 61.1% to 65.8%. The share of irrigated arable land in total irrigated area slightly declined, from 94.2% in 1998 to 92.7% in 2015. Within irrigated land, the share of irrigated arable land slightly declined and the share of irrigated woodland increased.

Against the backdrop of both increasing area and the share of irrigated arable land compared to total arable land, and the slightly decreasing share of irrigated arable land compared to total irrigated land, the irrigation withdrawal in NC continuously dropped, from 4.512×10^{10} m^3 in 1998 to 3.942×10^{10} m^3 in 2015. The irrigation withdrawals for arable land averaged over different hydrological years were: 1) 4.39×10^{10} m^3 in water-rich years; 2) 4.19×10^{10} m^3 in relatively water-rich years; 3) 4.2×10^{10} m^3 in water-normal years; 4) 4.67×10^{10} m^3 in relatively water-poor years; 5) 5.23×10^{10} m^3 in water-poor years. Therefore, the falling level of irrigated withdrawal might be ascribed to two factors: 1) only two relatively water-poor years occurred since 2003, with the remaining years being water-normal and relatively water-rich, and 2) there was wider adoption of water saving practices.

2.4 Contribution rate of green and blue water to grain production in North China

We also calculated the contribution rate of blue and green water in four major grain crops combined in NC, i.e., rice, corn, wheat, and soybean. Green water contributed to an average of 65.5% of NC's grain outputs, ranging from 60.9% to 69.3%; and blue water contributed to an average of 34.5%, ranging from 30.7% to 39.1%. If grouped by hydrological years, blue water contributed 34.0% and green water 66.0% on average in water-rich years. In relatively water-rich years, blue water contributed 33.0% and green water 67.0%. In water-normal years, blue water contributed 33.2% and green water 66.8%. In relatively water-poor years, blue water contributed 35.4% and green water 64.6%. In water-poor years, blue water contributed 39.0% and green water 61.0%. In sum, the relative contributions of blue and green water on grain outputs in NC generally coincided with the respective hydrological years; however, the blue water contribution rate in water-rich years did not decrease significantly compared to that of water-normal years. Such phenomenon demonstrated that upon the ease of water tensions in water-rich years, water withdrawal would increase, contrary to common perceptions. This finding is consistent with similar research conclusions that more water saving might lead to higher water usage [7−9].

2.5 Grain crop water consumption and productivity in North China

Grain crop water consumption refers primarily to the actual evapotranspiration that would be consumed in the formation of biomass or economic yield of major grain crops combined (i.e., rice, corn, wheat, and soybean). Crop water productivity (CWP) herein is thus defined as the economic yield per unit volume of actual evapotranspiration. CWP of grain crops in this research is the total output of four major grains divided by total evapotranspiration consumed by the four grain crops. Four major grain crops combined has always represented over 90% of total grain outputs in the nation in general, and in NC in particular, so, both water consumption and CWP of the four grain crops could be an approximate proxy for all grain crops.

A longstanding point of view holds that water saving agriculture will definitely cut down water consumption and thus save a great deal of water when there is a sufficient crop supply. However, opposite to common perception, increased crop outputs will definitely bring about increased water consumption when there is already a high baseline of crop outputs. The results of this research also proved this point. China's national grain outputs from 2004 to 2015 achieved a historic successive-twelve-year increase, with accompanying yield gains in the four major grains and a corresponding increase in water consumption in spite of a slower rate of increase in water

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consumption than that of grain outputs. This again demonstrated the concurrent gains in CWP of grain crops.

In analyzing CWP of the four grains in NC, we excluded the time series of 1998–2003 since these years experienced a continuous dropping of grain outputs in the nation in general and in NC in particular. Hence, only the time series of 2004–2015 was included in the analysis. In the period of 2004–2015, CWP of four grain crops combined increased enormously from 1.275 kg/m^3 to 1.801 kg/m^3, remarkably increasing by 41.3%. Gains in CWP may be associated with diverse factors, of which the most important one might be the gains in per unit area grain outputs, or yield. From 2004 to 2015, yield levels of the four grains combined in NC jumped from 4.95 t /hm^2 to 5.98 t /hm^2, increasing considerably by 20.7%. Crop yield displayed an obvious correlation with CWP in NC over the course of 2004–2015 (Fig. 9).

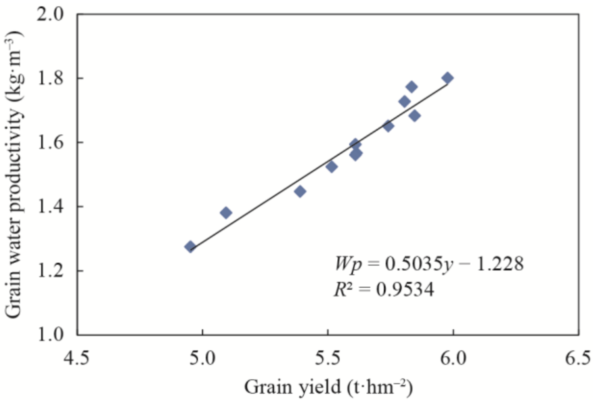

Fig. 9. Per unit area grain yield and water productivity in North China.

The match between land and water in NC was highly disproportionate. The share of NC's arable land is merely 16.96% of the national total; however, NC's share of the national total IRWR is only 2.25%. The share of irrigation withdrawal of NC compared to the national total was 10.74%. Three provinces presented the most severe situations, i.e., Hebei, Henan, and Shandong. Hebei cultivated 4.38% of national total arable land by using only 0.49% of the national total IRWR. As for Henan, the corresponding values were 6.00% and 1.03%, and Shandong were 5.64% and 0.60%, respectively. Such situation held for NC from 1998 to 2015. The highly disproportionate use of land and water resources can hardly be reversed under the current situation of rapid economic and societal development in NC and also is a major challenge to NC's food security.

3 Recommended strategies and policy suggestions

Based on the above presentation of figures and facts on the NC water and food situations, several strategies and suggestions have been proposed.

First, deepening the reform of supply-side policies necessitates the relocation of the most water-short provinces, especially for Heilonggang in Hebei as a grain and vegetable productions base. In the meantime, the ecological function of winter wheat that is widely grown in NC should be fully understood. It is not appropriate to cut down the sowing area of winter wheat in the short run, until a proper strategy is utilized to set up an upper limit for winter wheat outputs based on the water availability of NC. Mixed irrigated and rain-fed wheat production has to be encouraged in the future. Developing high-quality wheat with more profitable revenues for farmers is also a viable alternative. The vegetable cultivation with high levels of consumed water should be modestly cut down. NC as a whole should firmly establish a water-adapted agricultural development model.

Second, decreasing multiple-cropping systems or developing mixed irrigated and rain-fed cropping patterns is imminent in most water-short sub-regions. Seventy-three counties in NC have been displaying severe over-tapping of deep GW aquifers, of which 51 are in Hebei, 4 in Tianjin, 12 in Shandong, and 6 in Henan, covering an extensive arable land area of 4.88×10^4 km^2. The current cropping system of "two-harvests-per-year" has to be switched to "one-harvest-per-year". NC enjoys a unique position in nationwide wheat production and supply. Wheat coverage in the wind-prevailed winter and spring seasons in NC is an ideal and desirable break from soil erosions from wind. Therefore, a rain-fed winter wheat followed by a mixed irrigated summer corn will be a proper solution. In this system, the annual water consumption for wheat plus corn will be kept within the ranges of 550–600 mm. The GW table dropping in these regions is expected to be halted. Under this scenario, the grain outputs of these regions would decrease by 2.2×10^{10} kg, a 15.7% decrease in NC and 3.6% in nationwide.

Third, decreasing intensified use of irrigated water in water-short sub-regions is necessary. Decreasing growing acreage and the number of harvests per year may result in more non-productive soil evaporation and consequently yield loss. Hence, the water saving effects of this practice is not as obvious as that of cutting down per unit area irrigated water. Related research results also showed that decreasing per unit area irrigated water would result in less yield loss for winter wheat and the water saving effect of the practice is superior to that of cutting down irrigated acreage. For a total of 117 counties (i.e., 6 in Beijing, 9 in Tianjin, 50 in Hebei, 25 in Shandong, 27 in Henan, arable land area of 7.13×10^4 km^2) with over-tapping problems due to shallow GW aquifers, the current "two harvests per year" of "winter wheat and summer corn" could be maintained; however, the amount of irrigation has to be reduced. Sowing of winter wheat has to be carried out under sufficient soil moisture. One time irrigation is needed in the jointing stage in water-normal or water-rich years, and an additional irrigation is needed in the flowering stage in water-poor years. In such systems, the yield of summer corn will be maintained, and water consumption of wheat will decrease by 70–90 mm. Under such scenario, the total wheat outputs in NC would drop by 8.6×10^9 kg, a 6.1% reduction in grain outputs of NC. The equilibrium between the recharging and tapping of shallow GW aquifers could thus be achieved.

Fourth, the full potential of grain production in water-rich sub-regions of NC should be exploited. Grain loss in water-poor sub-regions of NC can be made up for by grain gains in water-rich sub-regions in Yellow River and the Huaihe River Basins in the region. The 110 water rich counties (i.e., 49 in Jiangsu, 16 in Shandong, 45 in Henan, with total arable land of 1.128×10^5 km^2) should devote efforts to further push forward the yield of wheat and corn through technological renovation, and modestly expand the cropping acreage of wheat and corn. The strategy can fully compensate for the loss in grain outputs in water-poor sub-regions.

Fifth, the scale of vegetable production in NC should be modestly reduced. Given the current situation of vegetable supply surpassing demand in NC, vegetable growth acreage can be cut down by 10%–15%, which will have little impact on the regional vegetable market supply. In the meantime, vegetable farmers' revenues and profits would not be affected under the condition of stable prices and better quality. A reduction of 7×10^6–8×10^6 mu (1 mu equals to 666.67 m^2) of vegetable acreage will reduce irrigated water consumption by 2.5×10^9 m^3–3.0×10^9 m^3, an apparent contribution to the cutting down of GW tapping in NC.

In sum, under the multiple squeezes of industrialization, urbanization, and ecosystem conservation in NC over the past 18 years, grain production in the region has still achieved a remarkable record, which may be attributed in large extent to elevated irrigation efficiency, improved per unit area yield, and continued enhancement of CWP. However, climate change in the future may further complicate the NC water situations, while simultaneously AWW has to meet requirements of the national and regional "redline for water withdrawal." Moreover, further gains in grain outputs necessitate higher water consumption. Hence, the traditional agricultural production and operation mode of "high-input intensification" has to be shifted to that of "sustainable intensification." Optimizing the match between land and water resources, reinforcing monitoring on over tapping of GW, developing water-adapted agriculture, and adopting synergic strategies of engineering, agronomic, and institutional water saving practices, are all viable and feasible solutions to realizing a win-win strategy of water use and food security in North China.

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