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An Overview of Policies in Managing Groundwater Over-pumping in the North China Plain

Introduction

The agricultural sector increasingly relies on groundwater abstraction for irrigation in many regions of the world. Expansion of irrigated agriculture and groundwater use, on one side, contributes to increased food production and food security; on the other side, leads to over-pumping of groundwater resources, which has become a common challenge in key agricultural production areas across the world, threatening the sustainability of production. Over-pumping of aquifers causes ecological and environmental degradation of vegetation, wetlands and streams and reduces the ability of aquifers to serve as a buffer for extreme weathers exacerbated by climate change. Unsustainable use of groundwater needs to be urgently addressed through sustainable rehabilitation and management strategies, in order to assure the availability of groundwater today and for future generations.

Recognizing the groundwater over-exploitation issue in the North China Plain, the Swiss Agency for Development and Cooperation (SDC) and the Ministry of Water Resources of the People's Republic of China co-launched the project "Rehabilitation and management strategies of over-pumped aquifers in a changing climate" in 2014. The overall goal of the project is to test and implement groundwater management and water saving policies in order to strengthen the capacity for adaptation to climate variability and climate change. The project has proposed innovative solutions in monitoring groundwater pumping, developed cutting-edge real-time groundwater models, and has tested various groundwater management policies.

Based on the tangible results and rich evidence generated by the project, SDC would like to invite experts from both China and the international community to further policy discussion and debate, which will lead to a series of Policy Brief.

This first Policy Brief intends to give an overview of groundwater managing policies to start the policy dialogue.

It is a summary by Dr. Liyan WANG, Senior Advisor of SDC, based on the research carried out by Prof. SHEN Yanjun and Dr. LUO Jianmei of the Center of Agricultural Resources Research, Institute of Genetics and Developmental Biology of the Chinese Academy of Sciences in Shijiazhuang.

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The Hebei province plays an important role for the food security for China

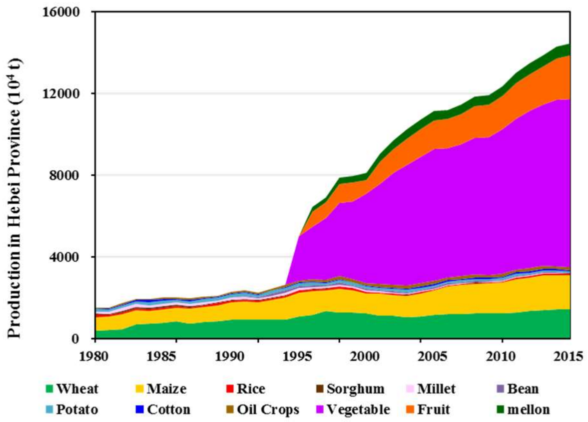

Figure 1 Crop production in Hebei province

Food production in Hebei can be traced back to 10'000 years ago, with planting from drought resilient crops like millet and sorghum in the long history to biannual cropping system of winter wheat and summer maize in recent 3 to 4 decades, plus vegetables and fruits that have quadrupled in terms of the sown area from the 1980s to 2010s (see figure 1).

Table 1: Yield comparison between Hebei and other countries (2011-2015, kg/hm2)

Country	Wheat	Maize	Apple	Tomato	Cucumber
Hebei/ China	5796/ 5103	5338/ 5867	15185/ 17510	68720/ 52170	70731/ 47181
Germany	7812			228936	84562
Israel		27344			
France			39897		

Data source: Hebei and China are from annual statistic book. Other countries are from FAO database.

Today, the four dominant crops in Hebei are wheat, maize, vegetables and fruits. In terms of production, Hebei produces 11% wheat, 8% maize, 11% vegetables and 8% fruits of the total production of China, ranking in the top 3, 6, 2 and 3, respectively. Table 1 is a comparison of the yield of Hebei/China with the highest yields in the world. The main fruits are apple and pear with similar yields. For vegetables, cucumber is an exemption that the production is at the same level as the best in the world. Tomato represents the comparative gap level of most vegetables. It shows the high production in Hebei, but low efficiency because the water and fertilizer uses are 1.2 to 5.7 times of the world average.

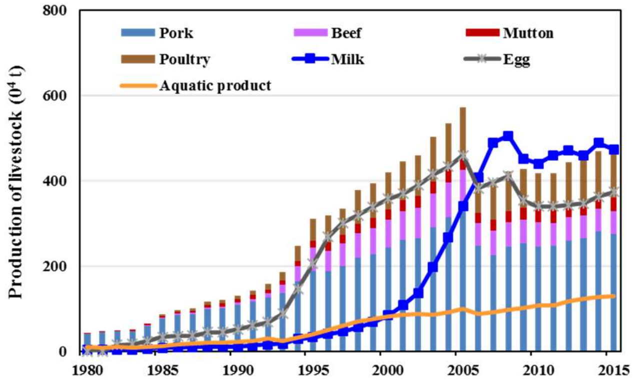

Figure 2 Production of livestock, poultry and aquaculture in Hebei

Hebei's production of meat, eggs and milk also ranks respectively the top 5, 3 and 3 in China. From the 1980s to 2010s, pig production increased about 5 times, beef increased about 54 times, poultry about 17 times, lamb about 10 times, egg about 19 times, and milk about 127 times.

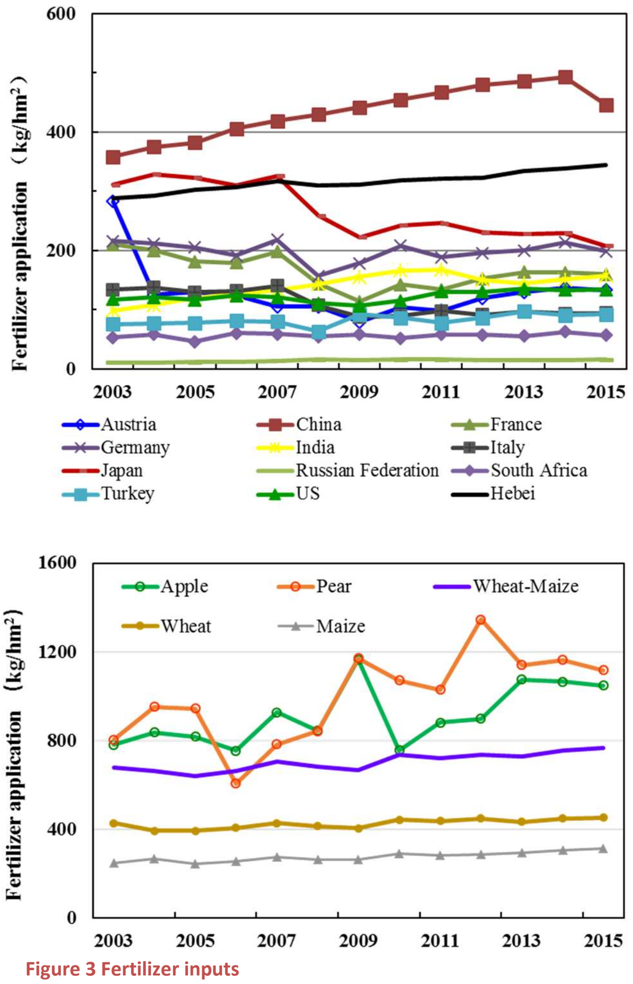

Figure 3 Fertilizer inputs

Figure 3 compares the fertilizer input in Hebei/China with other countries. Hebei (321kg hm^{-2} averagely from 2005 to 2015) is lower than the average of China (446kg hm^{-2}), but still higher than the world average (lowest level is below 85kg hm^{-2} for Russia, South Africa and Turkey, middle level around 105-257 kg hm^{-2} for Italy, Australia, USA etc.)

Fertilizer inputs vary widely in Hebei, with a higher level for fruits (around 1000kg hm^{-2}), followed by vegetables (656 to 13651kg hm^{-2}) and grain crops.

Figure 3 also indicates that the pesticide use for fruits is about 3 times of vegetables, and 16 times of crops. Total pesticide use doubled from about 40'000 tons in 1990s to 83'000 tons in 2018. Pesticide use in Hebei is lower than the average level in China taking into account its share of production.

Overuse of chemicals pollutes the water bodies, particularly the shallow groundwater and surface water. Investigations at local experimental station discovered that nitrate has already moved to 24m in depth, which is a concern to cause groundwater pollution risk in the future. (Chen et al., 2005). Surface water pollution is serious in Hebei with nearly 60% of water body worse than IV-V grade.

Agriculture causes groundwater table declines and pollutes the environment

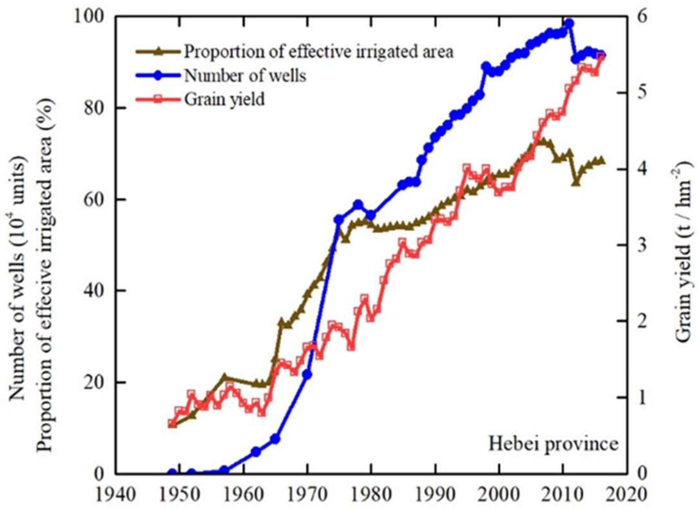

Figure 4 Number of pumping wells, irrigated area and grain yield

Figure 4 indicates that the number of wells increased dramatically with the cropping system shift from historically dry farming to nowadays irrigated agriculture in Hebei in the past decades. This is the fundamental reason for the groundwater depletion in Hebei and the North China Plain.

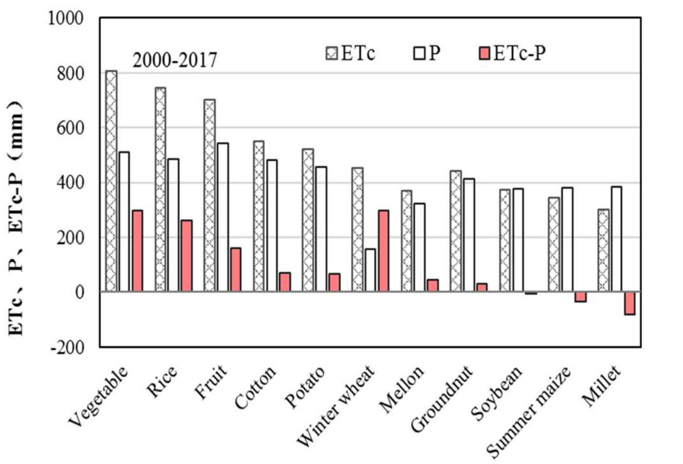

Figure 5 Water demands of different crops during its growing period

The precipitation, ET for different crops are calculated as shown in Figure 5 (Luo, in submission). In Hebei, vegetables and winter wheat are the two largest water deficit crops during the growing period (cultivated area of rice is very small). The total water deficit in Hebei is 9.1 billion cubic meters that have to be met through irrigation, and the top 3 water deficit crops are winter wheat (6.4 billion cubic meters), vegetables (1.6 billion) and fruits (1.3 billion) considering the size of the areas.

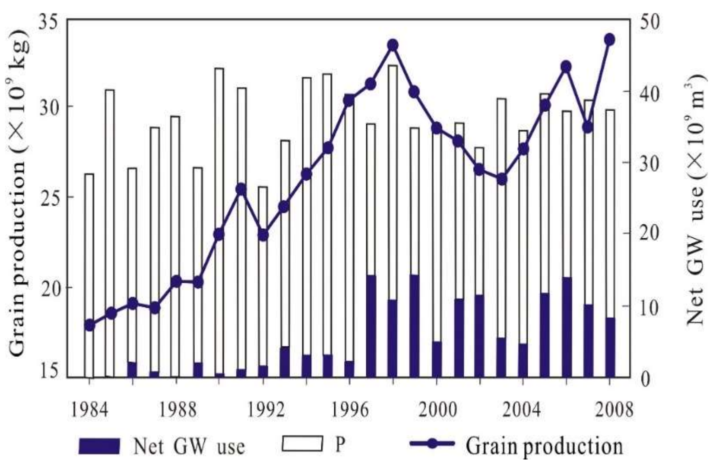

Figure 6 Increase of grain production versus groundwater use

Figure 6 shows, in the past decades, the agriculture production scale increased accompanied by over-pumping of groundwater, causing the draw-down of both shallow and deep water levels (Yuan et Shen, 2013).

Water use for livestock production

Table 2: Water consumption for animals in Hebei (2012 to 2016, dairy and beef data is for 2018)

Animal	Production (10000 Head)	Average annual blue water footprint (m^3 per animal per year)	Total annual blue water consumption (billion m^3/year)
Chicken	97228	2	1.94
Pig	3494	39	1.36
Dairy & Beef cattle	106+329	154 and 28	0.26
Sheep & goats	1485+700	4 and 2	0.07
Total			3.63

The research used a water footprint calculation to analyse the water consumption of livestock. The concern is with the blue water footprint. Table 2 gives an overview of the production of different animals, and the blue water consumption calculated by the cited average annual blue water footprint for each animal. Total blue water consumption of livestock in Hebei is 3.63 billion cubic meters per year, with poultry and pig consuming the most, followed by cattle and sheep.

Water Footprint of Livestock & Poultry

Water footprint is an indicator to assess the freshwater consumption during the production of livestock. There are three types of water footprint (Hoekstra A Y, 2011):

1) Blue water includes the direct water consumption by the animal, indirect water consumption such as the water used to produce the animal feed, and the water used for cleaning the animal space. It includes both surface water and groundwater.
2) Green water refers to the rainwater that penetrate into the ground and up-taken by the crops of animal feed, other than becoming run-off.
3) Grey water is the water used to dilute the polluted water generated by livestock production, so that the effluent from a livestock plant doesn't pollute the local water body.

Our concern is with the blue water footprint.

Assessment to the current groundwater management policies in Hebei provinces

The effectiveness of the current groundwater management policies in Hebei/NCP/China are assessed from below aspects:

Groundwater metering through transforming electricity consumption to water pumped

"Electricity-to-Water" method

"Electricity-to-Water" is an alternative method of groundwater metering through measuring the electricity consumed to pump groundwater, and multiplying the electricity used for irrigation by the electricity-to-water conversion factor.

In 2016, the State Council started the reform of agriculture water prices aiming at charging groundwater use for irrigation. Since 2017, the "Electricity-to-Water" method has been widely promoted in Hebei province because the method is simple and easy to be implemented. Since 2019, the national Action Plan recommended to use "Electricity-to-Water" method for regions that are not equipped with or do not have conditions to install groundwater metering devices.

Positive effectiveness of implementation

The method is based on the electricity-to-water conversion factor. It saves largely the work for installing water metering and corresponding cost for the operation and maintenance of the meter devices. The installation cost is roughly estimated at about 7.36 billion CNY for the 920'000 wells in Hebei. Therefore, "Electricity-to-Water" method has low investment and high implementability. The method is also welcome by farmers because it doesn't need extra installation.

The "Electricity-to-Water" method successfully solves the measurement of thousands of small wells, thus has been promoted in Hebei, Tianjin, Jiangsu with high expectation to be generalized in the irrigation area in north China.

Problems in implementation

The method has three major constraints in implementation:

- The Electricity-to-Water conversion factor is not a constant. It is affected by the well location, pump and the irrigation season. Such dynamic nature of the conversion factor makes it necessary to verify the factors ideally in a real-time manner, but not possible in reality due to the high amount of wells.
- In practice, a regional average conversion factor has to be used which reduces the accuracy. In extreme cases, the error can be as large as 66%.
- Institutional separation of electricity and water administration making the coordination and cooperation between the two departments a practical challenge in China.

Recommendations

The study made three recommendations for the up-scaling of the "Electricity-to-Water" method from a long term perspective:

- Establish and continuously improve a database of Electricity-to-Water conversion factors, to facilitate its upscaling and updating. Such EtW conversion factors shall be verified periodically..
- Realize data sharing between agricultural water consumption and electricity consumption through a cooperation mechanism between the water and electricity management departments.
- Establish farmers' water cooperative organizations to encourage farmers' autonomy for the long-term implementation of relative policies.

Groundwater quota system

The economical instruments in water resource management in China

Hebei adopted both the water use limit and water right to calculate the water abstraction amount. The water use limit is used to decide if water resource taxes shall be levied on farmers. Hebei uses the water right to allocate the water quota from the province to cities, then to counties and villages according to the available water resources and the water needs and the size of the arable land. The water right goes with the farmers and the land.

Problems in implementation

- There is a gap between the water right and the water needed for agricultural production because the water right is calculated from the available water amount and the size of arable land. The available water resources vary. The arable land also changes for various reasons. The water right thus cannot reflect the dynamic nature.

- The water right is the available water resource amount minus the residential water consumption, the industry water consumption and the reserved ecological amount. Agriculture water use is not prioritized. In Hebei, the water right is 130 to 150 m^3/mu, which is the minimum level that can assure the production of winter wheat-summer maize. In some counties, the water right is determined much higher than the available water resources, which caused the over-pumping of groundwater.

- The metering devices are not in place yet in most places in China though metering is the basis for implementing the water right or quota system.

- In practical water trading, there is also a phenomenon of "Agriculture transforming to Non-agriculture" that non-agriculture purpose water use enjoys the favorable policies for agricultural water use.

Positive aspects

It is helpful to limit the total amount of water abstraction. In the cases of Gansu and Xinjiang provinces in the northwest of China, the introduction of water rights or water quota showed effectiveness in the reduction of total water consumption for agriculture production, and the increase of groundwater level.

The water use efficiency is increased because of the introduction of water metering devices needed for implementing the water quotas in some places. In Xinjiang, the water irrigation coefficient was increased from 0.59 to 0.62.

The water use limit and water rights introduced thresholds for levying water resource taxes. To some extent, it increased farmers' awareness of water saving. In the pilot in Hebei, water use within the limit enforced basic water price. Water use above the limit will levy 0.1CNY water fee. Water saving within the limit will receive a reward of 0.2 CNY/m^3.

In places where water trading is practiced, it showed that farmers changed their irrigation behaviour so that the saved water can generate profit through trading (the traded price can be 3 times higher of the basic price, and up to 10 times higher if sold to the 2^{nd} or 3^{rd} industry purpose) or be rewarded by the local government. Water trading can happen between individual villagers or through a village collectively.

Water User Group (WUG) realized water use autonomy in rural areas. In Shandong province, WUG collectively constructed and maintained the irrigation engineering channels which increased the management efficiency.

Recommendations

- Establish the emergency mechanism assuring agriculture water use by determining the water right dynamically, taking into account the variable water storage, prediction of a dry or wet year, crop varieties etc.

- Optimize the water quota system by considering from water demand first to water supply (availability) capacity to prioritize the water use for different sectors.

- Enhance metering of irrigation water for improved quota monitoring and the facilitation of water trading.

- Improve the legislative framework for water withdrawal, and the platform to promote the water right and water trading market.

In agriculture water resources management, several terms are used in China. Their meanings are not the same for all contexts and may be different from international knowledge and customs. These terms are cross-used without clear boundaries. Therefore, the authors of this Brief shared their definitions of these terms.

Water use limit: it is for collecting water resources taxes, not the cap. In Hebei, it is the amount of water that can meet the demand of major crops and livestock production. The limit varies from province to province and is determined locally by different approaches.

Water use quota: general term regarding water abstraction, referring to the recommended amount of irrigation water needed for the growth of crops. It is a value per unit of cultivated area, and depends on the location, water use efficiency, the hydrological year feature and the crops.

Water right: general term for the right to use the water. The agriculture water right is determined by the available water amount for agriculture production and the size of the arable land. The available water amount is the total water resources minus the residential water consumption, industry water consumption and reserved water for ecological purposes.

Water withdrawal permit: it is the individual who applies and receives administratively and legally the permit to withdraw water from rivers and underground.

Groundwater resource taxes and fees

China reform on agricultural water prices

Since 1980, China has been implementing a water fee system. Since 2016, the government started to reform the water price system by levying water resource taxes instead of or on top of water fees. Hebei province was selected as the first pilot province of this reform. In 2019, China announced Resource Tax Law, which legalized the "fee-to-tax" or" fee + tax" for abstracting surface or groundwater. The tax on groundwater (1.5 CNY/m^3) is higher than the tax on surface water (0.4 CNY/m^3). The tax in over-pumped regions is higher than in other regions. The tax on agriculture water use is lower than the taxes on water for domestic, commercial, industrial and special industries (80 CNY/m^3). Agriculture water use below the quota or during drought years is exempt from water resource taxes. The tax and fee levels are determined by local provinces. In practice, agricultural water use is often exempt from fees or taxes. For instance, in China only 7 provinces under severe water stress collect water fees (0.003~0.1 CNY/m^3). In Hebei, the water quota is 300 m^3/mu. Water is free within the quota. Water use within the quota is rewarded 0.02 CNY/m^3. Above the quota, 0.2 CNY/m^3 tax is levied in addition to 0.1 CNY/m^3 water fee.

Positive aspects of collecting taxes instead of fees

The reform on water prices has increased the water saving awareness, and encouraged water saving in practice. Special industrial water users turn to surface water or invest to use recycled water.

Furthermore, the tax system has a strict legal procedure, more transparent in its enforcement, thus can be widely monitored by the society and the public. Since the enforcement of water tax in 2016, the revenue of Hebei province increased by 65% compared to 2015, and the revenue of the year 2017 is doubled compared to the year 2015.

Hebei has established a collaborating, data sharing and joint management system between the departments of water and taxation.

Problems in implementation

- Agriculture is the major user of water, but it is difficult to determine a reasonable threshold of water resource tax in practice because too high tax would increase farmers' load, while too low tax cannot incentivize water saving. In reality, the quota is often high enough to meet the irrigation demand, thus doesn't contribute to water saving effectively.

- In practice, it is a lack of refined norms to determine the water taxes and fees to differentiate the water withdrawal for different agriculture use.

- Precise measurement of water withdrawal is not in place. "Electricity-to-Water" method is not accurate. All these issues limit the implementation of collecting water fees or taxes

- Finally, it is anyway extremely difficult to collect the taxes for agricultural water use from the farmers.

Recommendations

- It is suggested to determine a reasonable water resource tax level (affordable and effective) and a reasonable quota system that rewards conservation and penalizes over-pumping, such as the "raise+refund" policy implemented in Hebei. (Raise: governmental subsidy is allocated to agricultural water use. Refund: the subsidy is later partly returned to farmers according to the size of arable land by the WUG)

- It is suggested to implement progressive water prices to increase the water tax stepwise for agriculture water use above the quota.

- It is suggested to implement a differentiated tax system that levies low tax for grain production, and high tax for cash crops and livestock production.

- It is suggested to establish farmers' water use groups and implement water autonomy.

- It is suggested to develop the water tax collection and management information system to improve the tax collection and management. It is also suggested to implement a mechanism to assess the water saving performance within the quota, and make benchmarking horizontally among villages and counties.

Winter wheat fallow policy

Fallow policy

Fallow is regarded as sustainable use of arable land by not cultivation or even not tilling, thus reducing the consumption of water and nutrients and improving the subsequent soil production capacity through soil and water resources regeneration. Fallow is mostly used on land that is over-cultivated causing soil erosion, water and nutrient depletion and soil pollution.

The fallow policy was first proposed by China central government in 2014. In Hebei, under national program of rotation and fallow, "one season fallow, one season rain-fed (spring corn, potatoes, or drought resistant grains and beans)" policy was piloted to reduce the irrigation of winter wheat. Government subsidized 500CNY/mu for not planting winter wheat.

Positive effectiveness in implementation

- Implementing fallowing policy largely reduced the abstraction of groundwater by 180 cubic meters per mu. It is one of the major measures in the 5-Year groundwater management program 2018-2022 in Hebei, combined with the adjustment of crop varieties. Hebei has reduced the groundwater pumping by 2.66 billion cubic meters by the end of 2017.

- It is helpful to fertilize the soil thus improve the production capacity. This is in line with China's strategy of "storing food in land". Experimental measurement by the province show that the soil organic matter content increased by 0.2 to 0.3%, chemical fertilizer use reduced by 20 to 30% and yield increase by 15 to 20% (2016).

- It benefits also the regional agro-ecology for the dual function of water conservation and land nourishment.

- Farmers maintain their income level due to the subsidy (in 2016, government subsidy was about 686 million CNY).

Problems in implementation

- Hebei is one of the 13 grain production areas in China. Wheat production accounts for about 10% of national wheat production. Implementation of fallowing policy has to balance the water conservation and food security.
- The current fallow policy is highly subsidized by the government. 500CNY/mu is the net income of farmers in a good year. The survey carried in the Sino-Swiss project by team lead by Prof. Wang Jinxia from Peking University indicated that farmers will not accept this policy when the subsidy is below 300CNY/mu. In addition, the current subsidy level is the same for all, without considering the land quality and geographic (incl. water resources) differences.
- There is a lack of proper guidance to farmers and supervision of the results of implementing winter wheat fallow policy. In many places, the fallowed land is abandoned other than planting green manure for soil nourishment purpose. In some cases, more water demanding vegetables are planted.

Recommendations

- Implementing winter wheat fallow policy requires top-level design and collaboration among multiple departments that are relevant to grain cultivation, yield, income, soil, water and fertilizer management. It needs well-balanced goals of water saving and food production that in normal years, systematically implement the fallowing policy, and in emergency situation, the land production potential can be recovered.
- Farmers' willingness to participate in the fallow depends on their incomes. The government needs to design a reasonable subsidy system. From a long-term perspective, it is needed to help farmers develop other high-quality agricultural products or explore other job opportunities.
- Provide guidance to farmers with appropriate crop varieties and planting skills after the land is fallowed.
- Government shall supervise the impacts of the fallow policy on the reduction of grain production, recovery of groundwater levels, inputs of chemical fertilizer and pesticide, the improvement of soil fertility, and the impacts on farmers' income.

Application of water conservation technologies

Agriculture irrigation is the main factor of groundwater over-pumping in the North China Plain. Water conservation and increasing water use efficiency in agriculture can contribute substantially to the better governance of groundwater and avoiding overdraft. Application of water conservation technologies are analysed from the three aspects:

Policy and management

A comprehensive long-term water saving mechanism is required, which shall consider multiple perspectives of groundwater monitoring and protection, incentives to encourage water saving, and assessment of various policies for the ultimate goal of water resource protection.

High water use efficiency in agriculture production is only possible when the production reaches certain scale. China is exploring various land reforms aiming at large-scale operation, which include land transferring, land subcontracting, land exchange, land lease, land shareholding and land use right auction etc. The purpose is to accumulate patches of fields, so as to reduce the production costs and increase the water use efficiency.

Defining a total water use cap and achieving such goal through economic instruments of water use right & trading market, as well as water resource taxes and fees. These economic instruments are helpful in encouraging water saving awareness and behaviours.

A monitoring and management information system is suggested to collect data of groundwater levels, metering of water abstraction, the water quality, water users, taxes and fees, and water trading. Such a comprehensive management information system shall share data across multi-departments for concerted governance of the water resources.

The research also stressed the importance of the legislative framework. So far, China has announced many relevant regulations such as the Water Law, Water Pollution Prevention and Control Law, Water and Soil Protection Law, Regulation on water permit, Regulation on implementing water right trading etc. *China has no lack of laws and regulations. The over-lapping of provisions, their feasibility, their enforcement and administration are the real challenges.*

Various techniques applied

Various water conservation technologies have been applied in China. Drip and sprinkler irrigation have constraints in promotion for large fields in China compared to pipe irrigation, channel lining and furrow bed irrigation. In addition, deficit regulating irrigation techniques in response to crop water deficit during its growth period can increase the water use efficiency.

It is suggested to breed drought-resistant and high-yielding crop varieties, and encourage water saving farming techniques. For example, late sowing and early harvesting of winter wheat, early sowing and late harvesting of summer corn are highly encouraged in the winter wheat-summer maize regions. Such "dual early and dual late" cultivation techniques can make full use of summer light and heat resources, thus significantly increased the crop yield potential and water use efficiency. In the winter wheat fallow areas, plant spring corn and potatoes which are drought resistant.

Ground cover technology by mulch or straws is inexpensive, simple and effective in reducing ineffective evaporation in arid and semi-arid areas. This technology is widely used for the summer maize in Hebei.

Mechanical water storage and moisture conservation is a traditional method of reducing soil ineffective evaporation, which includes deep tillage, early tillage, little or no-tillage.

Optional water resources

In addition to above-mentioned water saving and farming techniques, transferring water from the Yellow river (500 million cubic meters per year), replacing water resource by the South-to-North engineering (target is to provide 3.5 billion cubic meters by 2030) and nearby Wei river are optional water resources in the North China Plain. In total, external water resources can provide 4 billion cubic meters per year for Hebei.

Make good use of rainwater. Remote sensing results show that Hebei plain area has water storage potential of 1 billion cubic meters because many rivers flow through the province to the east sea, which shall be well collected.

Making use of saline water can reduce the stress of freshwater resources in Hebei and the North China Plain.

Make good use of recycled water. Residential water use is about 13% of the total water use in Hebei. This part hasn't been well recycled yet, but discharged to rivers after wastewater treatment.

In this policy brief, we summarized relevant groundwater policies and instruments which have been tested in China.

Further debate on each policy instrument from a global perspective will be presented in the coming months.

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