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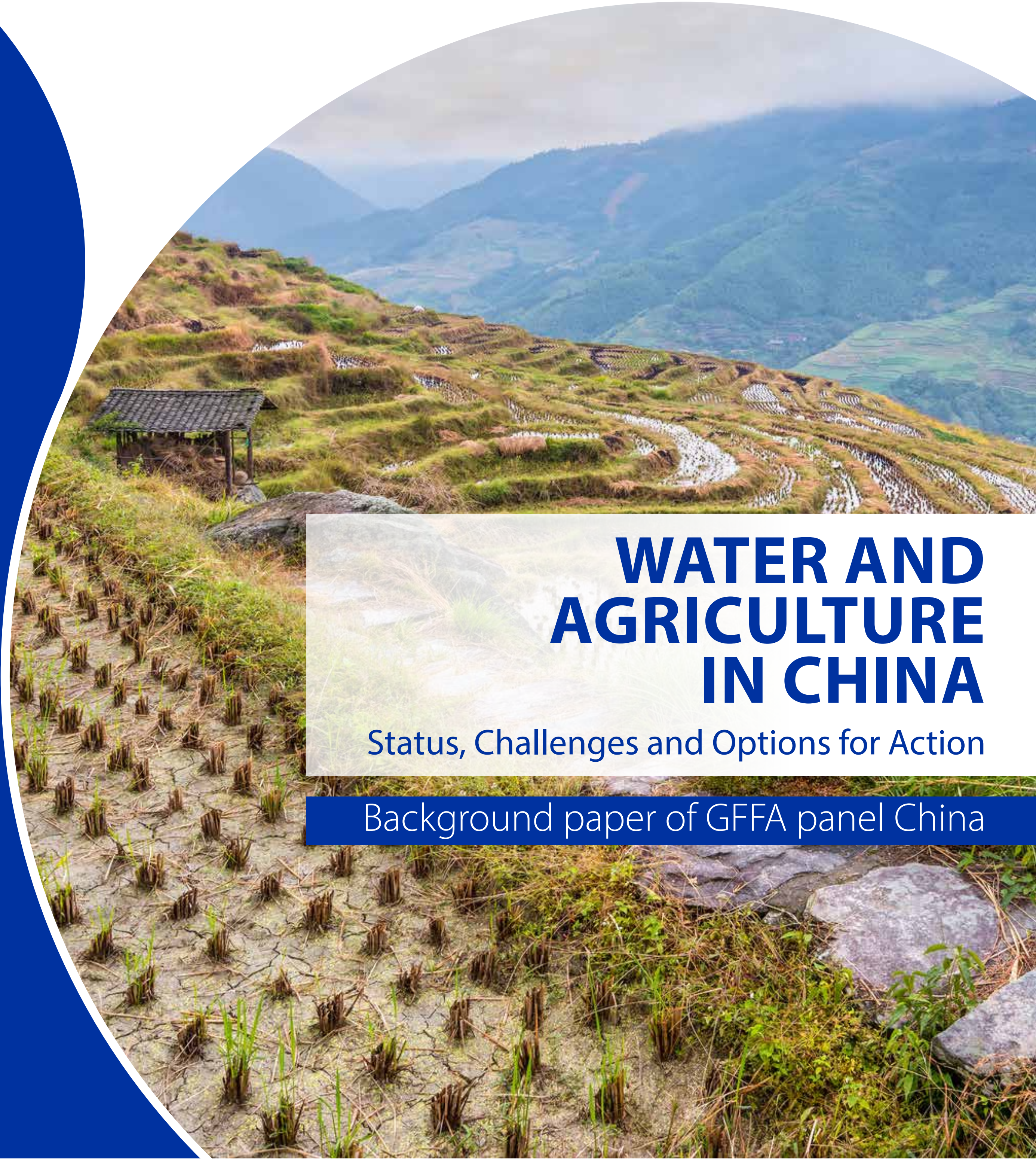

WATER AND AGRICULTURE IN CHINA

Status, Challenges and Options for Action

Background paper of GFFA panel China

German Agribusiness Alliance

IAMO
Leibniz Institute of Agricultural Development in Transition Economies

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EXECUTIVE ABSTRACT

Water is of paramount importance to Chinese agricultural production and food security. Yet water is extremely scarce in China; spatially and temporally uneven distribution, water pollution, inefficient water use, fragmented water management and the effects of climate change further exacerbate the problem of water scarcity. Against this background, this paper presents recent insights into the complex role of water resources in agricultural production in China. The document highlights the critical problem of water scarcity and the spatial mismatch of water resources and agricultural production, discusses groundwater extraction and depletion, and demonstrates the importance of integrated water management. Based on these analyses, we list potential options for action to tackle the water problem and sustain food security. This paper is intended to provide important background information to facilitate the panel discussion, "Three Sides of One Coin: Agriculture and Water in China", at the Global Forum for Food and Agriculture (GFFA), Berlin, 2017.

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I INTRODUCTION

China's progress in agriculture and rural development over the past few decades has been remarkable: It accounts for two-thirds of world hunger reduction since 1990, and has pulled about 700 million people – mainly rural residents – out of poverty. However, China faces an uphill battle when it comes to meeting its food security needs given its natural resource constraints. Besides its limited arable land – with less than 15% of its surface, scarce water resources put a severe constraint on agricultural production in China. Accounting for 20% of the world's population and only 7% of its available fresh water, China is one of the most water stressed countries in the world. With an average of around 2,100 m^3 of water per capita per year, China ranks 112th in the world despite relative abundant total water resources. Estimates of renewable water resources amount to 2,711 – 3,540 billion m^3 of surface water and 829 billion m^3 of groundwater. Additionally, the spatial heterogeneity and the mismatch of water resources availability, population and agricultural production area result in even lower water availability in the northern and north-western regions further exacerbating the water stress. Precipitation and its distribution vary greatly from north to south. While precipitation is higher and more evenly distributed over the year in the southeast, in the northern regions there is less in absolute terms and it is concentrated in the summer months.

China has been under a fundamental socioeconomic transition. It has experienced neck-breaking economic development and rapid urbanization in the past few decades. More than 500 million people – six times the whole German population – have moved to the cities since early 1980s. Now more than half of China's population lives in cities. The urban population will continue to grow at the rate of 1% a year over the next couple of decades. By 2030, cities will contain around a billion people – about 70% of China's population. This urban transformation has profound impacts on food consumption, water demand, and agricultural production.

Climate change has profound impacts on water resources and crop production. Over the past several decades, China has already experienced some devastating climate extremes. Due to its vast size, the future impact of climate change on the water resources in China varies across the country. Many regions lie in transitional zones where water resources, and hence agricultural production, could be affected positively or negatively by changes in climate. Climate change is speeding up the melting of glaciers on the Tibetan Plateau, which is affecting the run off of the major rivers. Increasing temperatures and changing precipitation patterns are causing increasingly frequent droughts. Irrigation, which proves to be an effective way to fight droughts, is becoming even more critical to ensuring the sustainability of agricultural production.

Against this background, this discussion paper presents recent insights into the complex role of water resources in agricultural production. The remainder of this introduction provides a brief characterisation of the different functions, effects, and implications of limited water availability for the agricultural sector. The spatial mismatch of agricultural production and water resources are further discussed in-depth in the second section of this document. The third section complements this assessment by describing regulation attempts to balance ground and surface water use by three district authorities in one north-western province, Gansu. Insights from another case study, the Tarim Basin in Xinjiang, are presented in the fourth section. Finally, the fifth section summarises current research findings and attempts to project the future development of China's agricultural sector taking into account climate change, like potential changes in water availability, and increasing water-related conflicts. Based on the analysis, potential options for action are provided.

China's agricultural sector

Traditionally, the agricultural sector has been dominated by crop production. However, livestock production has increased substantially since the start of the economic reforms at the end of 1970s. Whereas livestock contributed 15% to agricultural gross value added in 1978, its share increased to 28% in 2014. Crop production still has the largest share, with a contribution of 54%, to agricultural gross value added in 2014. Employment in the agriculture sector has declined continuously since the start of the economic reforms and dropped below 30% in 2014.

Due to the Household Responsibility System Reform - started in 1979, under which rural lands were distributed among all rural households, the average farm size is very small. However, driven by emerging land rental markets and rural-urban migration, the average operational farm size has been increasing slightly since 2000 and is now at 0.68 ha. More importantly, middle-sized family farms and large-sized cooperative farms started to emerge.

Agricultural production and water

Figure 1 illustrates the development of water use per sector in China. It shows that agriculture accounts for 63% of total water use in 2014 (including surface and groundwater), down from 70% in 1997. However, total water use increased to more than 609 billion m^3, compared to 392 billion m^3 in 1997. This is partially caused by the increase of livestock production driven by the demand from growing urban residents. Urban populations with higher incomes tend to consume more meat. The average meat consumption in China has quadrupled over the past 30 years to reach 63kg per capita per year. China now consumes 28% of the world's meat, including half of it pork. Livestock production has a significantly larger water footprint: producing 1 kg of animal protein requires about 100 times more water than producing 1 kg of grain protein. In addition, on average, urban residents consume three times as much water and energy as rural residents.

A regional imbalance between arable land and water can be seen by the fact that the water-scare China's north hosts 65% of China's arable land but only has 19% of the nation's water resources. Of the total arable land, approximately half, equal to 50 million ha, is irrigated and accounts for roughly 80% of the food produced. More details about the spatial imbalances in agricultural production potential and water availability is provided in section two.

In the most water stressed regions, groundwater exploitation offers one way to increase water supply. During the 1990s and 2000s, many villages and farmers explored this source. However, increased use of groundwater resulted in adverse effects on groundwater tables (see section three for detailed analysis).

Due to water scarcity, it is especially important that available water is used as efficiently as possible. Evaporation and percolation in canals and on the fields represent the major sources of water loss. Water use efficiency (WUE or water productivity) expresses the quantity of crop output produced per amount of water use, including precipitation and irrigation applied. Estimates show a water use efficiency of 0.23 kg/m^3 in 1949. Increasing crop yields, e.g. due to the introduction of new varieties and mineral fertilisers as well as better soil management, resulted in increased WUE. Recent estimates report WUEs between 0.74 kg/m^3 and 1.1 kg/m^3. However, values are still far below efficiency levels generated at experimental sites in China or reported for comparable climatic regions of Australia.

Water-efficient agriculture includes several measures such as water-saving irrigation, limited irrigation or dryland cultivation. Water-saving irrigation relies on various technological tools to reduce water leakage and evaporation in order to increase the amount of water available for plants. Examples are, among others, lining up irrigation canals, sprinkler or drip irrigation, mulching of fields, or the use of plastic film to cover the soil. Limited irrigation reduces the amount of irrigation up to a critical point for plant growth. Dryland cultivation implies the cultivation of crops which can rely on natural precipitation, and the management of runoff and rainfall water (e.g. collection and storage of rainfall). The applicability of these water-saving measurements is conditional upon the local context.

Livestock production shows signs of regional specialization, too. Whereas pork and poultry production is concentrated in the southeast and east (e.g. Sichuan, Jiangsu, Hunan, Guangdong) near the major urban centres, sheep meat, dairy and wool production is concentrated in the northwest. An increasing specialisation in livestock production resulted in a stronger dependence on imported fodder especially soy-based products. Currently, China is the world's top importer of soybeans, accounting for two-thirds of the globally traded volume. Implicitly, importing agricultural products allows for the import of "virtual" water.

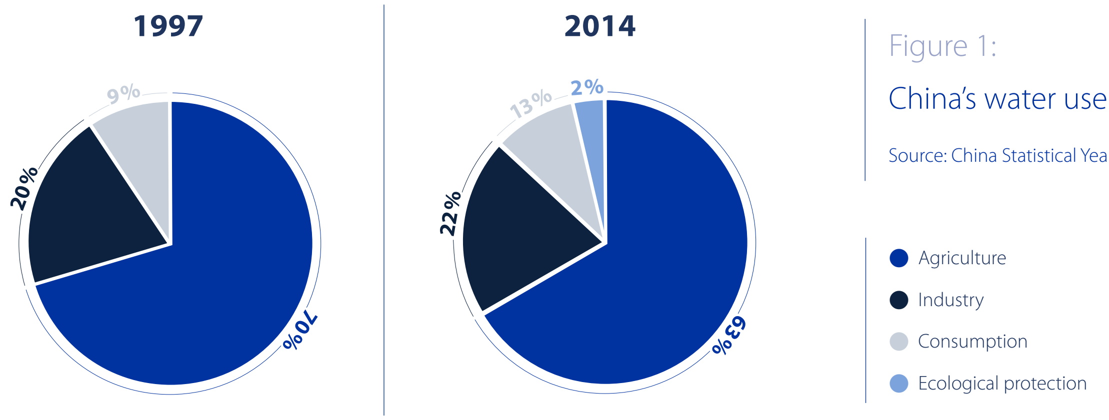


Figure 1:

China's water use by sector

Source: China Statistical Yearbook, 1998, 2015

Water pollution causes very serious and diverse problems in China. Most rivers, fresh water lakes, and groundwater in China suffer different degrees of pollution. On the one hand, water pollution caused by mining and heavy industry exacerbates the water scarcity problem for potable water supply and agricultural irrigation. On the other hand, agriculture is also an important source of water pollution. Fertilisers, plant protection chemicals, and livestock waste is carried into lakes, rivers, wetlands and coastal waters. The reasons behind the high contribution to water pollution from agriculture are that Chinese agriculture has a very high fertiliser consumption per ha; and most animal waste (e.g., manure) in livestock production are discharged directly into water systems. The first national pollution census in 2010 indicates that animal production is responsible for around 20% of nitrogen and 40% of phosphorus pollution in aquatic systems. The increasing livestock production put more pressure on the water system.

Political efforts

Governmental authorities at various administrative levels, national, provincial, and local, are aware of the water challenge. Probably the most prominent example is China's 13th National Five Year Plan (2016–2020) which places significant emphasis on tackling water issues, second only to achieving the country's energy targets. The Plan acknowledges the relatively poor quality of China's water resources and the severe over-extraction of groundwater in some regions, setting the stage for more stringent regulation, enforced with strengthened environmental laws. The various policy measures aiming at coping with a limited water supply range from the transfer of water from south to north, through restrictions on crop production, to the closure of groundwater wells. The effectiveness and efficiency of such measures is hotly debated (see section three and section five).

II SPATIAL MISMATCH OF AGRICULTURAL PRODUCTION AND WATER RESOURCES AVAILABILITY

China's water is unevenly distributed geographically: much more water exists in the south than in the north (see Figure 2). Northern and southern China is approximately divided by the geographic line of Huai River – Qing Mountains, which approximates the 0°C January isotherm and the contour line of 800 mm of annual precipitation. But the Huai River Basin itself is part of the North. Southern China, including the river basins of Yangtze River, Pearl River Basin, and rivers in the southwest (e.g. Mekong River) and southeast coast, accounts for 53.5% of China's population and 36.5% of its total territory, while its water resources amount to 80.9% of the country's total. Conversely, northern China, including the river basins of Liao River, Hai-Luan River, Yellow River, and Huai River, contains 46.5% of the country's population and 63.5% of its territory, while its water resources merely amount to 19.1% of China's total.

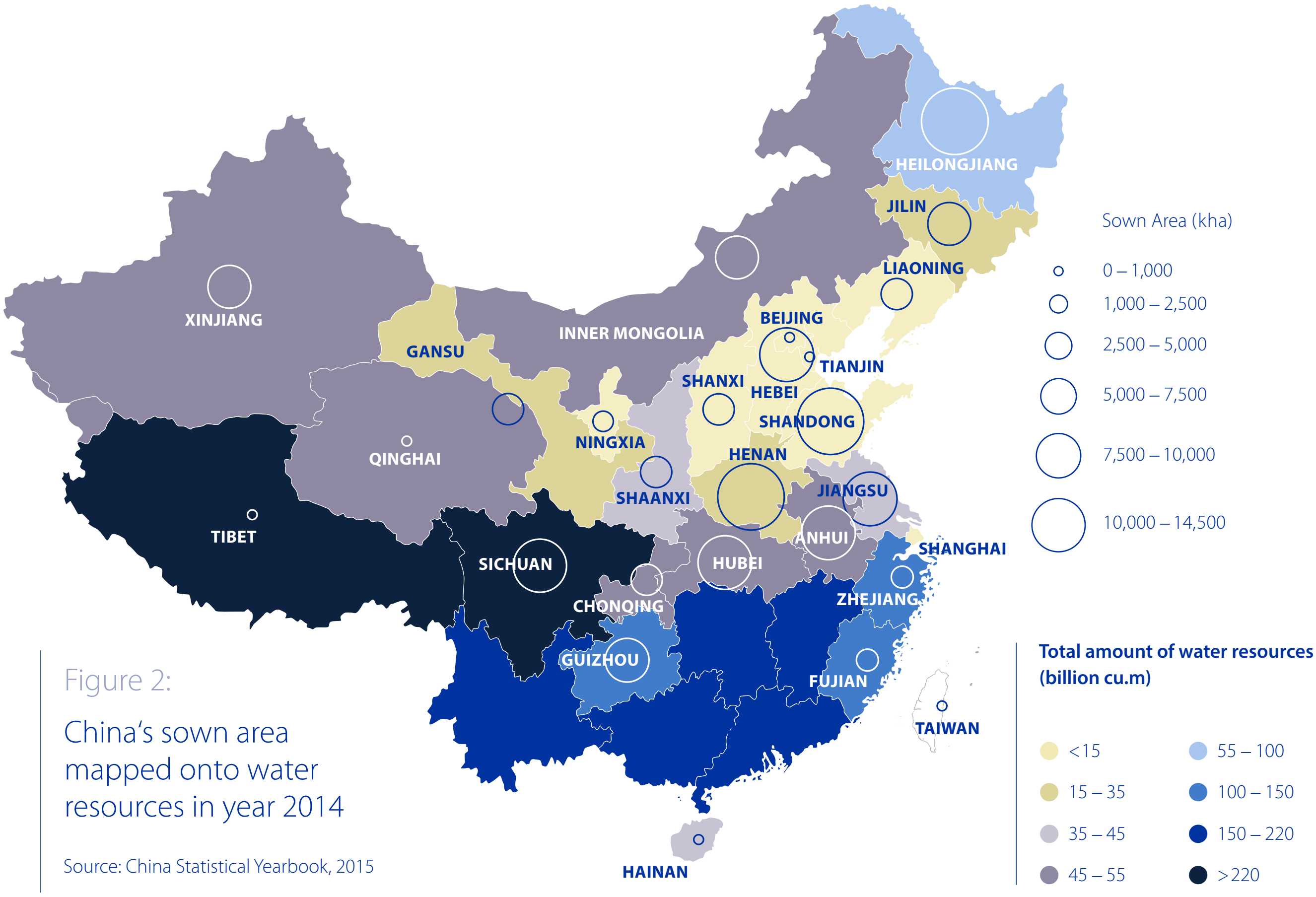


Figure 2:

China's sown area mapped onto water resources in year 2014

Source: China Statistical Yearbook, 2015

In recent decades, the centre of food production has been shifting from the south to the water-limited north. Grain production has shifted from the south to the north, exacerbating the problem. As a result, the groundwater table is dropping by 1.5 m per year in parts of the north of China.

Figure 3 shows the evolution of food production and irrigation in the north and south China since the start of the economic reforms in 1978. Figure 3a shows that staple food production has increased in the water-scarce north. The driving forces of this development include both natural and economic factors. The arable land and food production areas in the north are larger and generally flatter than those in the south (Figure 3b). Due to the higher share of mountainous areas in the south, efforts by the Chinese government to take erosion prone arable land out of production have had a larger effect there.

Among economic factors, the increasing labour costs and the limited income from crop production are other major reasons for the changing distribution of the sowing areas and food production between south and north. From 2010 to 2014, the national average labour cost for planting rice, maize, and wheat (RMW) doubled, disadvantaging more labour intensive rice cultivation in the south. Although machinery service is becoming increasingly popular, especially for harvest, fields are less suitable for mechanization in the south. It will be difficult to maintain terrace cultivation in the future as it completely relies on manual operations. Therefore, the sowing area in the south has continued to decrease since 1978. In the north, it is easier to use agricultural machinery to manage the upland fields because most of these are distributed in plain areas. This is helpful for reducing the labour cost. Therefore, the north was able to maintain or increase the sowing area, especially after the price protection policy for RMW in 2004. After 2016, however, maize was no longer in the price protection list. This can result in the reduction of maize production in the future.

The agricultural technological development is another reason for the increase of food production in the north. Traditionally, rice showed higher land productivity than maize and wheat, but in recent years the productivity gap between the crops has been declining which translates into a narrowing productivity gap between south and north (Figure 3c). Development of plant breeding and the increased application of fertilisers have played important roles causing the maize and wheat productivity rates to increase faster than rice. For instance, from 1985 to 2013, the average yields of maize per hectare increased by 67%, those of wheat rose by 72%, but rice only saw a 28% growth. Finally, another reason is the faster expansion of irrigation area (Figure 3d) in the north. Much of the expanded irrigation area relies on groundwater extraction. The number of irrigation wells increased from 2.7 million in 1978 to 5.0 million in 2010, and more than 90% of the wells are located in the north.

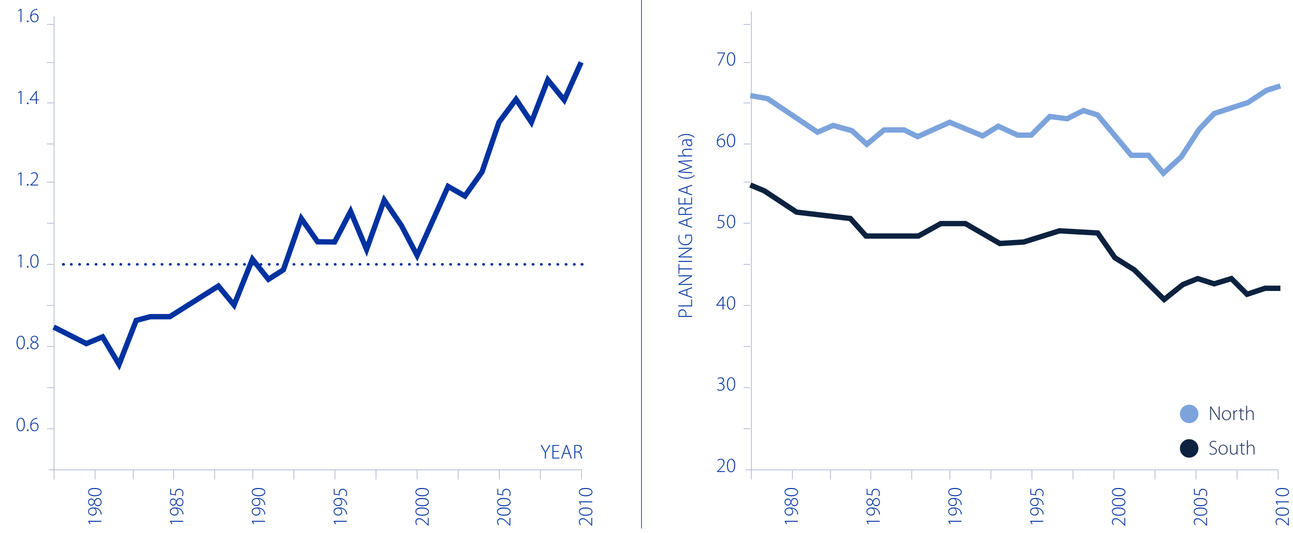
Figure 3:

Spatially disaggregated development of food production in China between 1978–2010

Source: China Statistical Yearbook, 1979-2011

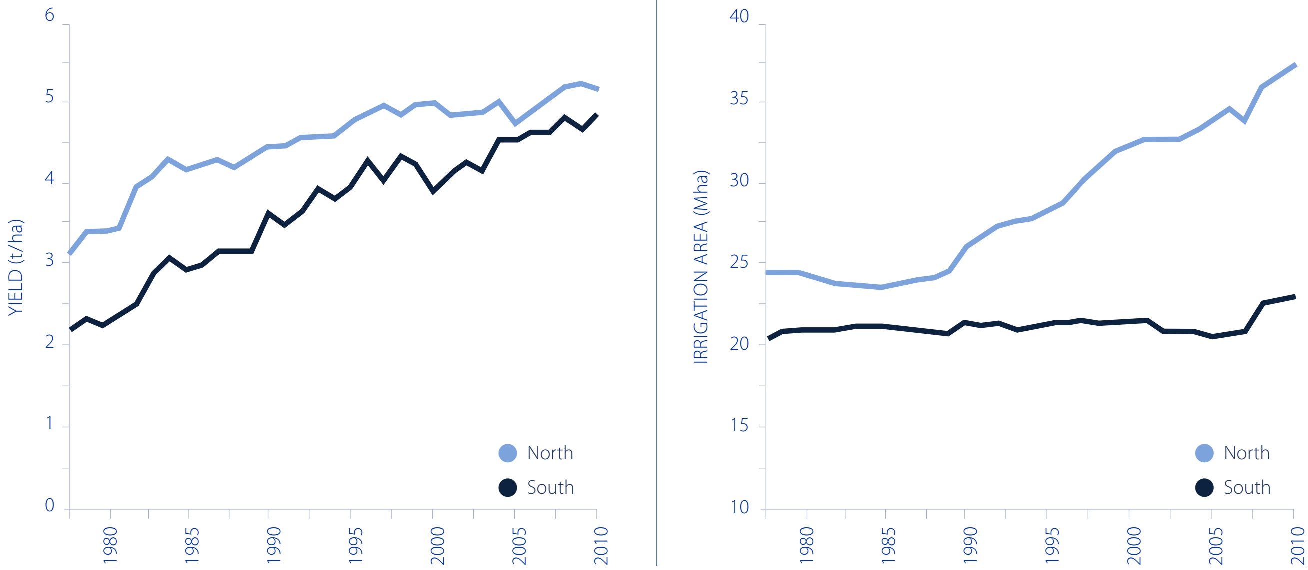
(a) North to south rate of food production

(b) Planted area



(c) Average yield of staple food per hectare

(d) Area under irrigation



III REGULATION OF AGRICULTURAL WATER USE IN CHINA: EXAMPLES FROM GANSU PROVINCE

Access to groundwater allows farmers to increase their agricultural productivity. However, intensive groundwater use is extremely hard to monitor and to regulate in rural China, leading to falling groundwater tables and related socio-economic and environmental problems. As the down-side of groundwater pumping in China begins to surface, the government is trying to get a grip on farmers' excessive groundwater use.

Surface water and groundwater use for agriculture in northern China

In China's water-scarce northern provinces human water withdrawal (including water use for agriculture, industrial development, domestic use, etc.) gobbles up more than 80% of the available water resources. Because in the northern part of China rainfall is low and condensed in the summer months, irrigation water is an important input factor to increase agricultural productivity.

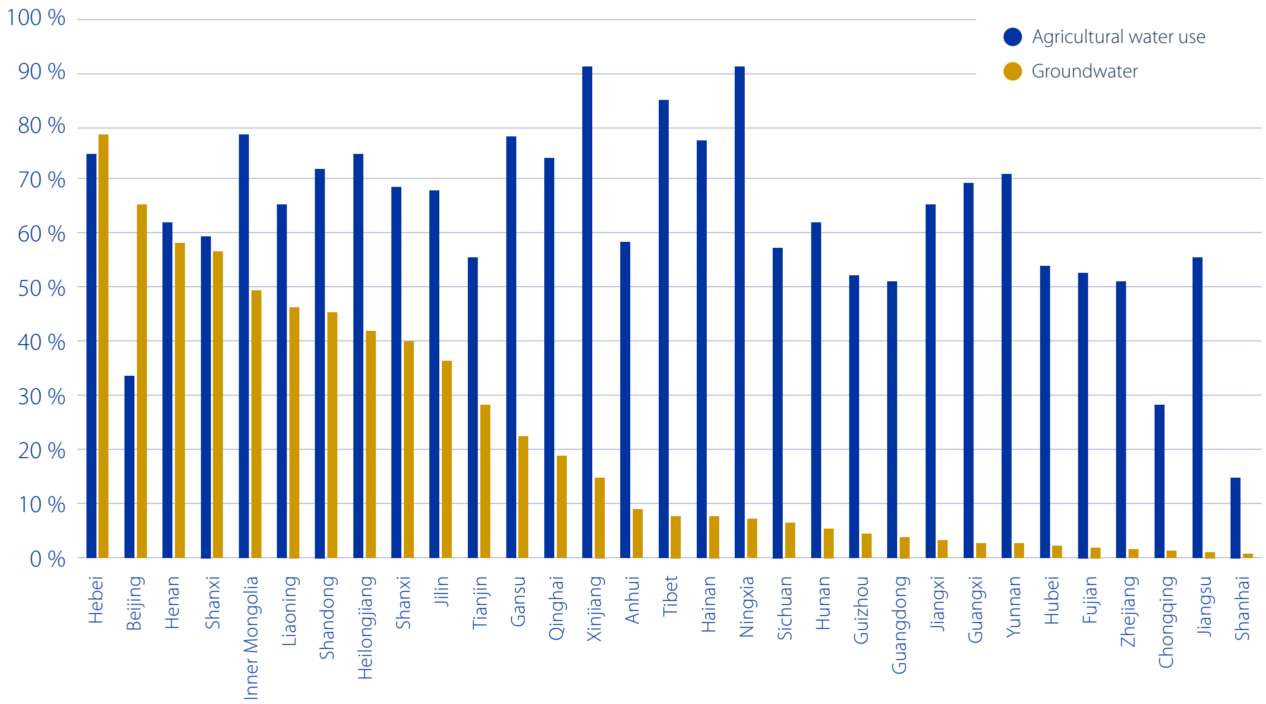
Both surface water resources (water from rivers and reservoirs) and groundwater resources (water stored in aquifers) are used for agriculture. Surface water irrigation systems usually depend on large scale infrastructure financed and managed by the State. Since the 1960s, over 85,000 smaller and larger dams have been built in China, many of which are used to divert water to the agricultural sector. In contrast, pumps and wells for groundwater irrigation are usually paid for and operated by the farmers themselves. Most wells are privately owned by individual farm households or by small groups of farmers. Currently around five million irrigation wells are in use in northern China. This has led to a tremendous increase in China's groundwater withdrawal, which rose from almost nothing in the 1960s to more than 100 billion m^3 per year, accounting for one-tenth of the global groundwater withdrawal.

Figure 4 presents the percentages of agricultural water use (from surface and groundwater) and percentages of groundwater use in total water consumption (agriculture and others) for all provinces (averaged over the period 1997–2014). The top ten provinces in terms of groundwater use percentages are all in northern China; these provinces accounted for 47% of the national agricultural planting areas in 2013.

Figure 4:

Average percentages of water used for agriculture and percentages of groundwater in total water consumption during 1997–2014

Source: Ministry of Water Resources, China Statistical Yearbook, 1998-2015



The total groundwater storage in the plain areas of northern China reduced by 109 billion m^3 during 1996–2014, which is about five fold the annual water resources in Hebei Province, home to 61 million people.

Two important drivers triggered the boost in agricultural groundwater use. First, the opening up of markets and the launch of the household responsibility system motivated farmers to intensify their agricultural production. The unconstrained, flexible access to groundwater is often used to produce high-value, high-water demand crops. For example, in Shandong Province, where 10% of the national vegetable production takes place, most farmers rely on groundwater for vegetable cultivation in greenhouses. Second, agricultural groundwater use is driven by the diminished access to surface water. In fact, most groundwater use takes place at the tail-end canal irrigation districts where surface water supply conditions have worsened over time. With the rise of cities and industries, more and more surface water is transferred away from the agricultural sector. Growing concerns over the environment also prioritises water allocation to vulnerable ecosystems. The alarming running dry of the Yellow River mouth in the late 1990s led to a reallocation of water rights within the river basin. The reallocation meant a transfer of water away from the traditionally irrigated agriculture in western provinces to the more industrialised eastern provinces.

The current rate of intensive groundwater use in northern China gave rise to a range of socio-economic and environmental problems. Falling groundwater tables lead to an increase in farmers' energy costs to pump up the groundwater and costs to drill deeper wells. Also, in arid areas natural vegetation dies when groundwater levels drop below the root zone, causing degradation of valuable ecosystems. This is one of the main causes of the surging desertification rate in northern China and the lingering occurrence of sand storms. In urban areas, the emptying of unconsolidated groundwater aquifers easily leads to land subsidence. Because of groundwater pumping Beijing is found to sink on average 11 cm per year, causing dangerous situations as urban infrastructure, such as tunnels and bridges, may collapse. Moreover, in coastal areas the intensive use of groundwater leads to salt intrusion from sea water, leaving local aquifers unsuitable for agricultural use or potable water use. This can also lead to soil salinisation which reduces the agricultural productivity substantially.

Recently the daunting problem of intensive groundwater use has received considerable political attention in China. New policies on the regional and local level are being adopted to curb farmers' groundwater use. Although groundwater resources are officially owned by the state, farmers long experienced a virtually open access situation in China. The revised Water Law of 2002 for the first time endorses groundwater use restrictions in case of overdraft, i.e. when groundwater withdrawal exceeds groundwater recharge. Since then groundwater regulation policies have been developed locally where intensive groundwater use poses a problem. So far, there are no uniform national or even provincial groundwater regulation policies.

Photo:

Groundwater irrigation allows this farmer to grow tomato seeds for export, Zhangye, Gansu

The case of the Hexi Corridor

IRRIGATED AGRICULTURE

The Hexi Corridor is a strip of fertile, flat land located in Gansu Province, northwest China. The area is crossed by three inland rivers – the Shiyang, Hei and Shule River – which run from the Tibetan Plateau in the southwest to the Gobi Desert in the northeast. The alluvial plains are characterised by a semi-arid climate with annual temperature of 5.8 – 9.3 °C, with little precipitation (50 – 200 mm/year), and high evapotranspiration (2,000 – 3,500 mm). Despite the low amounts of precipitation, both surface water and groundwater are easily accessible on the plains. The river inflow depends on melt water from snowfall and glaciers in the Qilian Mountain range. Annual inflow per river reaches between 1,500 – 2,100 million m^3.

The plains know a long history of agriculture. Food and other agricultural products for trade were provided to travellers on the ancient Silk Road who were obliged to pass the natural corridor. After collectivisation of agricultural production under Mao Zedong, wheat and maize became the most important crops in the area. Yet, over the last decades farmers' crop choices are rapidly changing. Regional advantages are made use of to grow more profitable crops. For example, Zhangye Prefecture, located on the middle reaches of the Hei River Basin, became China's number one maize seed producing area. Zhangye provides at least one-third of China's national maize seed production. Other cash crops newly established in the Hexi Corridor are melon, cotton and grapes for wine production.

With the arrival of new cash crops the area experienced a boost in agricultural production, which was enabled by the intensification of surface water irrigation in upstream areas and groundwater irrigation in downstream areas. In the downstream areas, groundwater is generally used in conjunction with surface water. Surface water is applied during the early stages of the cropping season, whereas groundwater is applied during later stages of the cropping season.

GROUNDWATER REGULATION POLICIES

Due to the intensified exploitation of surface water and groundwater resources for agriculture, the downstream reaches of the inland river basins are faced with falling groundwater tables and degradation of natural vegetation. This has caused a tremendous loss of land to desertification in the region, which again induces the occurrence of sand storms. Originally, the inland rivers ended in tail-end lakes, like the Qingtu Lake in Minqin County and the Erjina Lake in Inner Mongolia, but over time these lakes have almost disappeared. Local water authorities in all three river basins have developed some kind of groundwater regulation over the last two decades to tackle these problems. The type of measures which are used to regulate groundwater use and the impact of these measures differ strongly depending on: 1) the severity of the problem; 2) the level of interference by higher level authorities; and 3) the integration of surface water and groundwater management structures. In each of the three rivers, river basin organisations have been established since the early 2000s, following national water policy reforms. These river basin organisations were normally given responsibility for surface water management, but did not necessarily have control over groundwater resources. In fact, the responsibility for groundwater resources is held by different agencies in each of the three river basins discussed here. This strongly influences whether groundwater regulation at a local level is given priority or not.

1. STRICT GROUNDWATER REGULATION IN THE SHIYANG RIVER BASIN

The Shiyang River Basin is the most densely populated river basin in the Hexi Corridor. The downstream sub-basin of the Shiyang River, Minqin County, has experienced severe groundwater overdraft since the 1970s. Farmers used up to 600 million m^3/year, whereas recharge through river inflow reached approximately 100 million m^3/year. As a result, the county was confronted with soaring desertification rates. Since the 2000s, the problem has received a lot of attention from the national government. The then premier, Wen Jiabao, warned repeatedly that the complete disappearance of the tail-end lakes in Minqin should be prevented at all costs. To emphasize this he even paid a visit to Minqin County in 2007. Because groundwater and river basin management reforms coincided, the newly established river basin organisation for the Shiyang River is responsible for both surface and groundwater resources.

Currently farmers' groundwater use in Minqin is strictly regulated. Over the last decade, 3,000 wells have been cut off from the electricity supply and sealed with cement. On the remaining 4,000 wells, so-called smart card machines have been installed. Smart card machines are a kind of ATM machine with built-in water meters. The machines are used to implement a per capita water quota. The quota is set at half the amount of the previously pumped water volume. As a result, farmland at the edges of the desert is being abandoned and farmers grow fewer high-water demand crops. Particularly obvious is the reduction in melon production. Ten years ago 40% of cropping area was still planted with melon, nowadays farmers only occasionally grow melon for their own consumption.

2. INEFFECTIVE GROUNDWATER PRICING IN THE SHULE RIVER BASIN

The Shule River Basin is located in the most remote corner of the Hexi Corridor, bordering Xinjiang Province. Groundwater overdraft is most severe in the downstream reaches of the river basin, part of Guazhou County. Here, farmers started to use groundwater in the 1990s. At that time a state led migration project brought inhabitants from the mountainous areas in Gansu to the Shule River basin. To accommodate the migrants the state drilled groundwater wells in their new settlements. Private investments in well drilling by other farmers followed rapidly.

Currently the area is confronted with groundwater overdraft, although not as severe as in the Shiyang River Basin. So far the issue of groundwater overdraft in the river basin has not received any special attention from the central government. In 2002, a river basin organisation was established, independent from the municipal government. The river basin organisation took over all tasks with regard to surface water management. However, groundwater management stayed with municipal government bodies.

After the river basin management reforms from 2002, the income from surface water fees moved from the municipal government bodies to the independent river basin organisation. In response to this, the municipal government bodies implemented a volumetric groundwater price. For this purpose, they installed smart card machines on farmers' groundwater wells. Officially, the groundwater pricing was introduced to restrict farmers' groundwater use, but the current groundwater price is too low to impact farmers' behaviour. Moreover, the volumetric water price is not passed on to individual farmers due to shared well ownership by groups of farmers.

3. UNRESTRICTED GROUNDWATER USE IN THE HEI RIVER BASIN

The Hei River Basin is the largest inland river basin in the Hexi Corridor. Surface water is naturally abundant on the plains of the Hei River Basin. Groundwater use only started to develop in the 2000s, right after farmers' access to surface water was reduced. Farmers' surface water use was restricted in order to transfer more water to the downstream Erjina Lake in Inner Mongolia. At the same time farmers' income from crop cultivation increased due to the shift to high-value seed production. This made it attractive for farmers to enlarge their cropping area with the use of groundwater irrigation.

In 2000 a river basin organisation was established for the Hei River Basin. The main task of the river basin organisation is to oversee the surface water allocation between the upstream and downstream provinces, Gansu and Inner Mongolia. Water authorities at prefecture level are responsible for surface water distribution within the provinces and for groundwater management. Effectively, groundwater regulations had been absent for a long time. Drilling permits existed, but could be easily obtained. Strict water management focused on surface water only. This seems to have prompted the local water authorities to close an eye to the rapidly expanding groundwater pumping over the last decade. Only recently, in 2014, a ban on drilling new wells was issued on behalf of the Wuwei prefecture land management authorities. They convinced the water authorities that further land reclamation for agriculture at the edge of the desert should be avoided to reduce the risk of desertification and devastating sand storms.

Lessons learned

The three cases show that despite the clausal on groundwater regulations in the revised Chinese Water Law, effective groundwater policies at local level only appear when the negative effects of groundwater overdraft are advanced and regulation targets are set by higher level authorities like river basin organisations. Moreover, the institutional integration of surface water and groundwater management helps to set the right incentives for local water authorities. Otherwise, local authorities may prioritise short-term benefits over long-term costs, a common phenomenon which often hampers groundwater regulation in other countries faced with agricultural groundwater overdraft.

IV SUSTAINABLE WATER MANAGEMENT: A CASE STUDY IN THE TARIM RIVER BASIN

The Tarim River Basin and water crisis

The Tarim (also known as Talimu) Basin is located in Xinjiang Uyghur Autonomous Region, northwest China. It is surrounded by the mountain ranges of the Tian Shan in the north, Kunlun in the south, and Pamir in the west. Taklamakan Desert, the second largest desert in the world, occupies the central part of the basin with the Tarim River flowing along its northern rim.

It is the largest internal drainage basin in China, with a total area of about one million km^2 – almost three times the size of Germany. The climate is continental with an average annual temperature of 10.6 – 11.5 °C and with large temperature amplitude, annually and daily. It is, globally, the most remote area from the oceans; rainfall is extremely rare and low and does not exceed 70 mm per year while the potential evaporation is about 2,000 mm per year. The Tarim River Basin is one of the driest areas in the world.

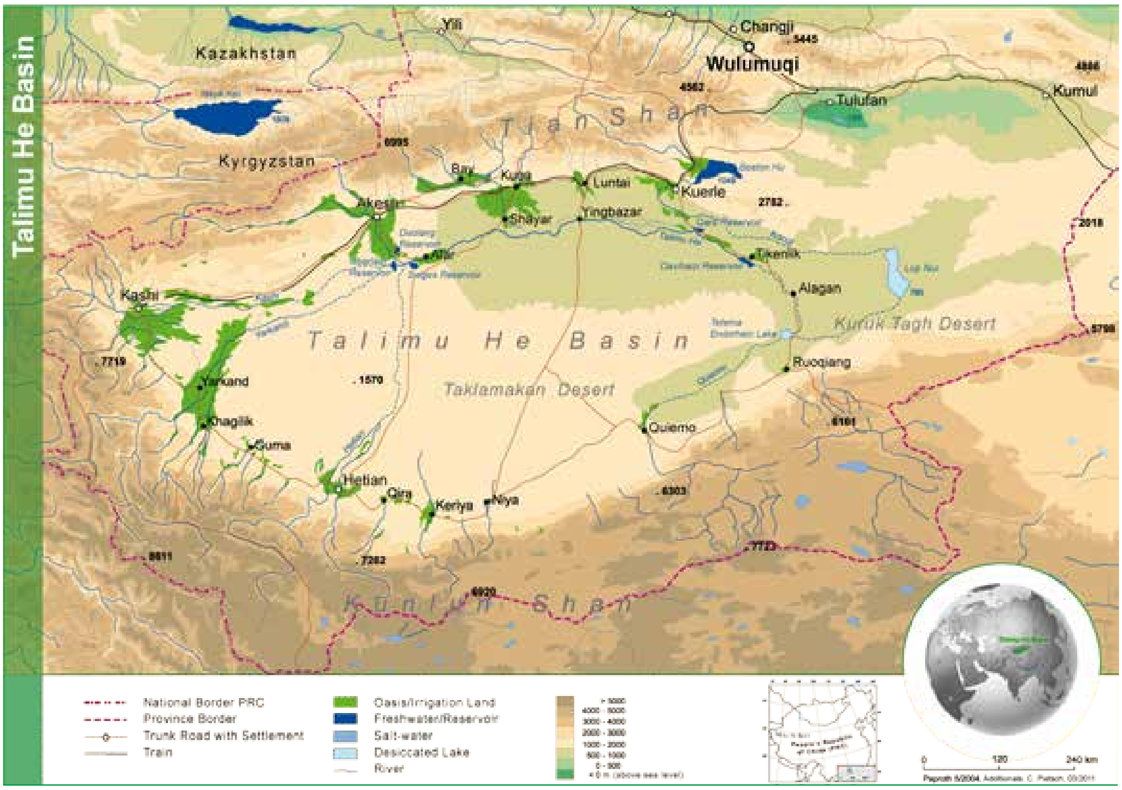
The 1,300-kilometer long Tarim River is the largest river of the Tarim Basin and receives its water mainly from snowmelt and glacier-melt from the surrounding mountains. The river is a vital resource to support all kinds of economic activities, especially agriculture and domestic daily life, as well as the natural ecosystems. Already in ancient times, people settled along the Tarim River, resulting in a series of oases forming the historical Silk Road. Today almost 10 million people live along the banks of the Tarim River.

In the past six decades, however, the area of oases has been greatly increased by land reclamation mainly used for cotton fields. The dry and warm conditions make the region suitable for cultivating high-quality cotton. Despite water shortage, the region became an important cotton and fruit production base for China. About 40% of China's cotton is produced here. This corresponds to around 10% of global cotton production. The characteristics of the landscape and the socio-economic situation of the population have changed considerably in the past few decades.

Figure 5:

The Tarim (Talimu) River Basin and its location in China

Source: SuMaRiO Project



While cotton brings considerable economic benefits to the region, it also brings along negative effects. Cotton growing demands a lot of water for irrigation. On average, the cotton requires about 4,000 m^3 of water per hectare – higher than other crops. Currently, there are two million ha of irrigated land in the basin. Agriculture consumes over 90% of available water resources. Due to the high water demand from cotton planting, more and more water has been extracted from the river and the groundwater. This has led to serious ecological and socio-economic problems:

Changes in hydrological conditions and desertification: The Tarim River no longer reaches its terminal lake, Lake Taitema, and dried up halfway. Lake Taitema has dried up completely. The ecosystem in the basin, especially the lower reach of the river, continues to deteriorate. Water shortage causes the degradation of the surface vegetation, which further leads to the increasing desertification.

Ecological degradation: Many species have disappeared; the population of some species has decreased. The poplar forests (tugai) have declined significantly and are endangered in the lower river area. Between the 1950s and 1990s, 3,820 km^2 of poplar forest and 200 km^2 of shrub and grassland were lost in the lower reaches of the Tarim River. The poplar forests offer various important ecosystem services. Among others, the so-called "green corridor" represents a (vitally) important barrier to the silting of the desert oases and the adjacent infrastructure. The forests also help keep down temperatures through evaporation.

Water quality and water pollution: The water is contaminated with fertilisers and plant protection chemicals, and often has a high salt-concentration. This leads to soil degradation and impacts not only the agricultural production, floodplain forests and river ecology but also human health.

Soil degradation and salinisation: Inappropriate irrigation and drainage practices cause soil salinisation, which threatens the productivity of agriculture.

Social tensions: The unequal access to the scarce water resources among different regions, sectors, and stakeholders cause social tension and disputes, threatening the stability of the society.

Long-term water availability: Climate change is expected to have a profound impact on the precipitation and water resources in the Tarim Basin. Given the predicted increase in the annual average temperature, surface water availability from snow and glaciers in the mountains are expected to decrease in the long run.

Potential solutions

Facing these problems, the central challenge is how to manage land use sustainably, i.e. irrigation agriculture and utilisation of the natural ecosystems, as well as water use in a very water-scarce region, with changing water availability due to climate change and overexploitation, such that ecosystem services and socio-economic benefits are maintained in the best balance for a sustainable development.

Specifically, the following measures are recommended:

Balance of economic needs and ecological conservation: There is a clear trade-off between generating income from irrigation agriculture, mainly cotton, and ecosystem services. Policies should consider the health of ecosystems, which in turn affects the agricultural production in the future and the welfare of the society. In other words, sustainable development should be the overreaching goal of water resource management.

Ecological restoration: Reforestation and renaturalisation along a strip of land at least 50 to 100 m wide along both banks of the river can help stop or even reverse the deterioration of the ecosystem services. Such measures can allow the groundwater to be replenished during the annual summer flood and will also reduce erosion along the river banks.

Increased water use efficiency: Given the extreme water scarcity, the water use efficiency in agricultural production, as well as in other sectors, must be improved to make the best use of the limited water resource. Water saving technologies and practices (e.g. dripping irrigation), appropriate pricing strategies (e.g. increasing block tariffs), and increasing farmers' and land managers' awareness of saving water are all important factors.

Market-driven mechanism: The market-driven mechanism has the potential to lead to a more efficient use of water resources. However, the natural capital should be factored into decision making (e.g. by designing payment for ecosystem service programs) to avoid market failure and ensure proper amount of water reserved for ecological usage.

Stakeholders' participation: Stakeholders, including decision makers from political and economic departments, large farms, and small farms from different regions, as well as ecological conservation departments, water management authorities, researchers and experts should all have their voices heard when it comes to water management and planning in order to ensure equality and rational water distribution. The setting up of a water management platform at the community level and basin level in which stakeholders

Photo:

Cotton field
in the Tarim Basin

participate can be very beneficial. Decision support systems showing the potential trade-offs of a particular policy or a measurement can facilitate the achievement of optimal decisions.

Knowledge-based agriculture and scientific decision-making: Holistic and better knowledge of water dynamics and trade-offs in various ecosystems and ecosystem services can lead to a better informed decision making and sound policies. Enhancing the scientific and technical level of monitoring, management, and restoration of water resources and associated water and soil components of local ecosystems are all vital in offsetting water problems.

Crop diversification of the cotton-dominated agricultural sector can also achieve both ecological and economic benefits.

Integrated water management system: An integrated water management system promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. It can facilitate the rational distribution and effective utilisation of resources, and ensure the implementation of the aforementioned measurements. Recent research shows that the Tarim River Basin Management Bureau, established in 2010 to unify water management, as well as basin-wide laws and regulations have led to the reduction of unreasonable man-made water diversions, better water distribution and utilisation, as well as a better and improved ability to manage and control the river runoff. Better management of water resources can also lead to higher crop yields, crop diversification, and increased social welfare and local employment opportunities. However, underground water management has not been fully implemented. The monitoring of underground water usage and well drilling in the region still have a long way to go.

V FUTURE CHALLENGES AND POTENTIAL OPTIONS FOR ACTION

China's agriculture is facing complex and fundamental challenges. Meeting the ever growing food demand with limited water resources remains the greatest challenge for Chinese agriculture. The scarcity of water continues to threaten the sustainability of agricultural production in the future against the backdrop of continuing industrialisation, urbanisation and climate change. The ever increasing water demand will put further pressure on the already stressed water resources and divert water from agriculture.

Due to climate change, competition for water will most likely become more severe in the future. If China wishes to supply clean and adequate water for its agricultural needs, China cannot sustain the development path it has taken for the past several decades. Certain changes to policy, pricing and practices are necessary.

Invest in water infrastructure: We suggest further investment in the water infrastructure. One of the measures that should be implemented is the underground storage of floodwater in preparation for extreme droughts especially in the north, through the construction of distributed infiltration basins for retaining floodwater and converting it into groundwater. The risks of carrying out agricultural activities in the infiltration basins should be considered by assessing both flood and drought risks, as well as the benefits of recovering groundwater table.

"More for each drop": increase water use efficiency: As demonstrated in the two case studies, increasing water use efficiency is an effective way to maintaining food production with limited water. This entails the development of water-saving technologies (e.g. new irrigation technology), innovative cropping rotation patterns, new crop varieties (drought resistant crops), among others. Innovations supporting water saving should be encouraged, for example, by financial subsidies and organizing trainings to farmers. Traditional irrigation should be replaced by more efficient irrigation methods. In the 13th State Plan, China aims to increase the area of high-efficient irrigation land to 192 million ha by 2030. Additionally, developing agricultural technology to increase food productivity without additional water use is an effective approach to reducing water resource consumption for irrigation. The cropping structure change, for example, growing more maize, and less wheat and rice, may be effective in saving groundwater usage. Furthermore, it is also important that each water user should be aware of the need to save water.

Reduce water and related soil pollution: Reducing water and related soil pollution is another important issue for food production and food security. In 2014, 60% of river sections and 80% of the monitored groundwater were heavily polluted with water quality worse than class IV standard. Pollution threatens the safety of food and of drinking water, as well as human health. China needs to control pollution from industrial sources by closing down and relocating polluting plants, establishing water treatment facilities, and promoting industrial modernisation with clean technologies. In addition, pollution from agricultural production also

Photo:

Water-saving irrigation

needs to be curbed by improving waste management from the livestock sector and reducing the overuse of fertilisers and plant protection chemicals in agricultural production. All this calls for the creation and enforcement of strict environmental laws and regulations, as well as awareness raising measures and interdisciplinary exchange.

Moderate food import: The scarcity of water means that China will struggle to grow all its food alone. Self-sufficiency is not possible for all the major grains and oilseeds. Given the current agricultural policy agenda, moderate food imports of certain crops (e.g. maize, soybeans mainly for animal feed) is necessary to release the pressure from the land and water resources in China while maintaining a high self-sufficiency rate for major staple crops like wheat and rice. A further exploitation of the trade-off between increased water use efficiency at the sectoral level and the substitution of less water efficient crops by imports implies a revision of food and trade policy goals. This was reflected by the revised interpretation of "food security" and grain self-sufficiency in the Document No. 1 from 2015.

Integrated water resource management: As demonstrated in both case studies, integrated water management systems can rationalise water utilisation, reduce water pollution, and increase water use efficiency. This entails breaking the administrative boundaries and barriers. A comprehensive water resource management also requires coherent management policies on surface and groundwater to avoid unintended policy effects. For example, the limitation of surface water usage may lead to the over exploitation of groundwater. Building an effective water use monitoring system of both surface and groundwater usage is crucial for the implementation of the integrated water resource management.

Market mechanism and institutional changes: Water as a natural resource has long been directly managed by all levels of governments. This has led to inefficient water usage. The government has begun to rely more on market mechanisms (e.g. water trading) to enable efficient water utilisation. To facilitate this, clear water rights, regulations and laws which encourage water saving practices and penalise water waste and pollution need to be established and implemented. The water management institutions need to delineate their responsibilities to ensure seamless coordination in water management. Last but not least, laws need to be more strongly enforced in order for all the above measurements to be implemented.

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