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Sustainable management of groundwater

title: **Sustainable groundwater management in the North China Plain: main issues, practices and foresights**

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The North China Plain in this paper denotes the Hai River Plain, the north part of the Vast North China Plain, as shown in Fig.1. It is the political center and the economically- developed region of China, including 5 cities or provinces of Beijing, Tianjin, Hebei, Henan and Shandong, with an area of 131000 km^2. The groundwater aquifer system in the North China Plain belongs to the Quaternary geological system, and the unconfined aquifer system can be classified into 3 types, i.e., the mountain-front alluvial and diluvial plain of abundant groundwater, the eastern alluvial and lake-formed plain of semi-abundant groundwater and the coastal alluvial and sea-formed plain of weak groundwater.

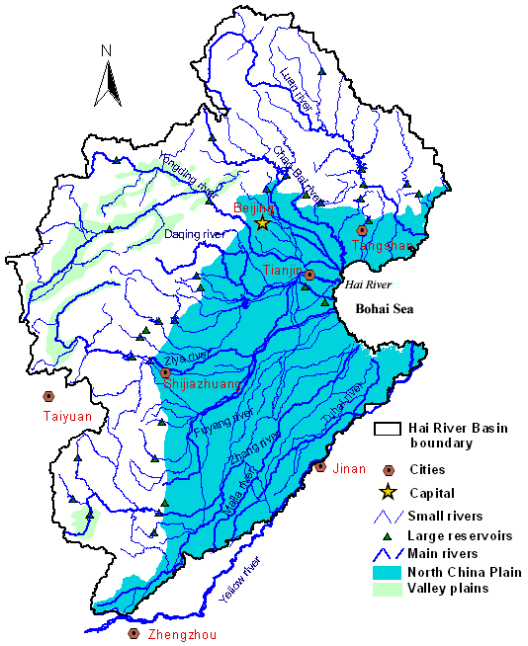

Figure 1. The North China Plain and the Hai River Basin.

Main groundwater issues in the plain are summarized, which include groundwater level declining (Fei et al., 2007), geological-environmental issues due to the overexploitation, groundwater pollution, drying up of river channels, shrinking of wetlands and decreasing of flow into the Bohai Sea. The followed is an introduction to the management practices conducted in the plain, which includes groundwater overexploitation control, water-saving, slightly-saline groundwater utilization, artificially recharging of groundwater aquifer and public participation.

Based on the above basic information, main issues and management practices, foresights and desired measures for the sustainable groundwater management in the plain are discussed by analyzing 9 scenarios using a dualistic model, in which hydrological conditions, water saving measures to reduce water use, groundwater use reduction and water diversions from the Yellow River and the Yangtze Rriver. It is concluded that the groundwater aquifer restoration in the plain is not optimistic in a short period, integrated implementation of technical, administrative and legal measures is desired to realize safe exploitation of groundwater in the plain and to increase the river flow into the Bohai Sea in 2020 above all things, and to restore the deteriorated groundwater system in the following decade subsequently.

MAIN GROUNDWATER ISSUES

Groundwater overexploitation

With the water use increase in the North China Plain, the groundwater overexploitation occurred in some area in 1970s. The groundwater overexploitation area gradually spread since then, and the accumulated overexploitation amount has been over 90 billion m^3 at present in which about 50% is from the shallow groundwater and the remaining 50% is from the deep groundwater. In 2004, the overexploited groundwater amount was 6.12 billion m^3, accounting for 30% of the total groundwater use in the plain. The total water use was 29.42 billion m^3, and 69% was from the groundwater with 16.25 billion m^3 from the shallow fresh groundwater (salinity <2g/L), 0.34 billion m^3 from the shallow brackish groundwater and 3.67 billion m^3 from the deep groundwater. The urban groundwater use and the rural groundwater use accounted for 1/3 and 2/3 of the total groundwater use respectively (He, 2006).

In the shallow groundwater system, the total overexploited area has reached 59600 km^2, with 11 big funnel-shaped groundwater depression areas. The deepest funnel was located at the southern Shijiazhuang with the maximum depth below the land surface of 52.3 m, and the maximum depth below the land surface in Beijing was 35 m (He, 2006). Because of the long-term overexploitation, the groundwater in the unconfined aquifer systems in the northern Tanshan, the southwestern Beijing and the Heibei plain in the front of the Taihang Mountain has been used up. As an example, Fig.2 shows the annual variation of groundwater level in the funnel center in Shijiazhuang city.

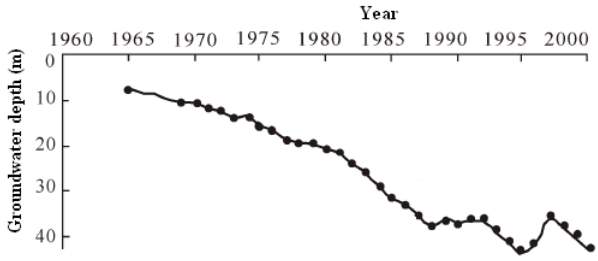

Figure 2. Annual variation of groundwater level in the funnel center in Shijiazhuang city.

In the deep groundwater system, the total overexploited area has reached 56100km^2, mainly distributed in Cangzhou and Hengshui of Hebei province, Tanggu and Hangu of Tianjin city, and Dezhou of Shandong province. The deepest withdrawl depth at the funnel center of Tianjin has been over 105 m. If the declining trend continues, the aquifer water will be exhausted and over 30 million people will be threatened by no groundwater supply.

Geological-environmental issues caused by groundwater overexploitation

The groundwater overexploitation has caused the following four main geological-environmental issues (HRWCC, 2002): 1) Regional land subsidence. Based on observations, area with the accumulated subsidence of over 500 mm reached 8200 km^2 in 1990, and 13700 km^2 in 1995. 2) Geological disasters. The declined groundwater level has caused over 200 cracks of land and river dikes in the plain, mainly distributed in Tianjin, Tanshan, Langfang and Baoding cities. A crack length has a range of several meters to 1000 m, the crack width is from 1 cm to 200 cm,

and the biggest depth is 10 m. 3) Seawater intrusion. The overexploitation in the coastal area caused the seawater intrusion into the fresh groundwater aquifer system. The most seriously impacted district was the alluvial area of Yang river and Dai river in Qinghuangdao city. The seawater intruded distance toward inland was about 6 m to 8 m, and the area was over 50 km^2 in 1993. Tianjing city is also threatened by the seawater intrusion. 4) Deep groundwater quality deteriorated by the moving down of the brackish groundwater front. The main influenced area reaches Hengshui and Cangzhou cities of Hebei province. For instance, in Cangzhou, the area with 10 m moving down of the brackish groundwater front was about 1959 km^2.

Groundwater pollution

Based on the investigation and assessment of groundwater in the Integrated Water Resources Planning of the Hai River Basin (Ren, 2007), the ratio of the polluted groundwater aquifer area (i.e. the groundwater quality is worse than the Class III) to the plain area is 76.4%. The monitoring and assessment results show that 41.7% of the polluted groundwater aquifer is originated in the human activities, with the lightly polluted area of 34496 km^2 and the seriously polluted area of 27892 km^2. The main pollution items are NH_3-N, salinity, COD-Mn, NO_3-N and NO_2-N. The three main reasons of the groundwater pollution are attributed to the infiltration of surface water polluted by urban and industrial wastewater, the infiltration of agricultural irrigation water including manure and chemicals, and the untreated industrial castoff and urban garbage (Zhang, 2006).

Drying up of river channels and shrinking of wetlands

The groundwater overexploitation reduced the river base flow from the groundwater drainage and even made the river water recharge the groundwater. Together with the dam construction in upstream mountain areas (31 large dams with a total volume of 24.9 billion m^3), many downstream river channels in the plain were dried up almost through a whole year, which further caused the desertification of river beds and sediments. River channels of Yongding, Hutuo, Zhanghe, Cihe and Shahe have become the source area of sandstorms in the plain.

The natural wetland area in 1950s was 9000 km^2, but the sum of natural wetland area plus reservoir-formed water surface area is only 3852 km^2 at present. Baiyangdian, the biggest wetland had become dry for many years in 1980s, and now it relies on the water diversion from the Yellow River.

The runoff discharge into the Bohai Sea has greatly decreased. It reduced from 11.6–24.1 billion m^3 in 1950s–1970s to 2.7–6.9 billion m^3 in 1980s–1990s. Due to the reduction of river water into the sea, the sedimentation issue at river mouths/estuary becomes quite serious, and the ecosystem in the river mouth area has been seriously damaged.

MANAGEMENT PRACTICES

Control of groundwater overexploitation

Control of groundwater overexploitation is the most important measure at present to prevent the aquifer system from a further deterioration. In 2007, the Ministry of Water Resources of China (MWR) worked out the Groundwater Exploitation Reduction Scheme for the Water Supply Area of the South-North Water Transfer Project, with the North China Plain as its main part. In 2004, the Ministry of Water Resources of China and the State Environment Protection

Agency of China (SEPA) jointly carried out a program called Integrated Water Resources and Environment Management in the Hai River Basin (the executive period: 2004–2010) at the support of the Global Environment Fund (GEF) of World Bank. The program includes a project called Strategic Study for Sustainable Groundwater Exploitation and Administration of Water Rights and Well Permits in the Hai River Basin (abbreviated as SSG hereafter), and a pilot project called Well Permits and Administration of Water Rights in Cheng'an county (abbreviated as PPG hereafter).

Water-saving

Agriculture is dominant in the groundwater users in the plain. Therefore, the water-saving is the main concern in the plain. The following agricultural water-saving practices were promoted in the plain: 1) turnover of traditional crops to different fitting ones, i.e., reducing the ratio of the highly water-consumed grain crops like winter wheat while increasing the ratio of the lowly water-consumed cash crops like cotton (with plastic film covered on farmland); 2) water use gauging facilities for well irrigation area; 3) small plot irrigation with low-pressure pipes; 4) application of micro-irrigation techniques like dripping irrigation; and 5) spreading of water-saving irrigation.

For industrial and domestic water uses, new ideas were put on adoption of water-saving facilities to reduce water leakage of pipes, toilet flashing water use, consumption of circulation cooling water of industries, and reuse of treated wastewater.

Utilization of slightly-saline groundwater

The slightly-saline groundwater is defined as the groundwater with salinity higher than 2 g/L but lower than 3 g/L, which has a total amount of 1.7 billion m^3 in the plain. Because of serious water shortage in the plain, some regions had tried the utilization of slightly-saline groundwater to replace the deep groundwater exploitation. A pilot project in Guantao County was established (IHRH & WCBGC, 2009).

Artificial recharging of groundwater system

Artificial recharging experiments for groundwater system were also carried out in the plain (Han, 2001). The first example is about an experimental site in the downstream Chaobai river channel, in which 9 weirs (width: 300–400 m, height: 3–5 m) were constructed from 1984 to 1998 to use the discarded flood from the upstream Miyu reservoir to recharge the overexploited shallow groundwater. The second example is about a site in the downstream Yongding river channel in 1981, which included artificial recharging to both shallow groundwater and deep groundwater. The third example is about a site in the Tianjin city in 1980, which artificially recharged to deep hot groundwater.

A recent example is well injection experiment for the planned groundwater reservoir in the Futuo river (i.e. upstream of Ziya river) reach in Shijiazhuang city. The experiment was carried out on 20 August 2009, lasting for 17 days and recharging 18 million m^3 water discharged from the upstream Huangbizhuang reservoir. In the experiment site, 12 observation wells of 50 m deep were prepared in the recharging zone, and 40 monitoring wells were drilled in the outside impacted zone.

Public participation

At the support of the World Bank GEF program mentioned above, the public participation in water resources use management in the well irrigation districts were enhanced through introduction and dissemination of Water Users Associations (WUA) and Community Driving Development (CDD). In addition to the above mentioned Cheng'an County, 4 counties of Guantao, Feixiang, Linzhang and Shexian (see Fig. 3) also implemented the WUA and CDD establishment.

FORESIGHTS

The fact of the serious groundwater issues, though many management experiments have been practiced, to restore the deteriorated groundwater system in the North China Plain is still a big challenge. Because of a close connection between surface water system and groundwater one, an integrated management of both systems is desired. What will be the future vision of water resources in the region?

We developed a natural-artificial dualistic water cycle model (2008) in combination with a distributed hydrological parameter model, a groundwater numerical model, a water resources allocation model and a multi-objective decision-making model, and they applied the model to analyze 9 scenarios of water resources development in the Hai River Basin in 2005, 2010 and 2020 (see Table 1) with due regard to socio-economic and environmental water demands, water-saving measures, hydrological conditions, groundwater overexploitation control, preferable river discharge into the Bohai sea, the South to North Water Transfer (SNWT) projects and the Water Transfer from the Yellow River (WTFYR).

Table 1. Scenarios of Water Resources Development in the Hai River Basin (unit: $10^8 m^3$)

Planning year	Scenario	Hydrol. series	Precip.	Overexploited groundwater	Water into sea	SNWT Middle Route	SNWT East Route	WTFYR
2005	actual	2005	1558.5	78.0	24.9	0	0	37.3
2005	S1	1980–2005	1596.2	80	35	0	0	46.2
2010	S2	1980–2005	1596.2	53	35	0	3.65	46.4
	S3		1596.2	53	55	0	3.65	46.4
	S4		1596.2	53	55	56.4×50%	3.65	46.4
	S5	1956–2005	1695.4	53	93	56.4×50%	3.65	46.4
2020	S6	1980–2005	1596.2	0	55	58.7	14.2	47.0
	S7		1596.2	0	93	58.7	14.2	47.0
	S8	1956–2005	1695.4	0	93	58.7	14.2	47.0
	S9	1980–2005	1596.2	0	35	58.7	14.2	47.0

Applying the analyzed results on the basis of 9 scenarios, through a intensive water-saving and reducing groundwater abstraction, it is possible to realize the target of reducing 1/3 groundwater overexploitation and increasing river water into the Bohai Sea to 5.5 billion m^3 besides guaranteeing the economic water use (S4 in Table 2). However, the target of zero groundwater overexploitation is difficult to realize a case of scenario (S6 in Table 2), which requires to reduce 9.5 billion m^3 of drawing groundwater, and 8.2 billion m^3 of the consumed groundwater. In addition to water-saving policy in agricultural groundwater use, large amount of agricultural groundwater use in well irrigation districts will need to be changed into surface water, which poses the requirement for constructing a lot of water dams, water conduits and water-

distributing facilities. Who will pay for the required heavy investment? This is closely related to action of new national and local government policies in the light of a deliberate study.

Therefore, a good management of groundwater resources is desired through control of groundwater abstraction, more intensive water-saving, efficient utilization of SNWT and WTFYR water, and integrated implementation of technical, administrative and legal measures.

CONCLUSION

As a reaction of rapid socio-economical development and irrational water resources development in the North China Plain, serious groundwater issues occurred in overexploitation, geological-environmental troubles, groundwater pollution, drying up of river channels, shrinking of wetlands and decreasing of water flow into the Bohai Sea. National projects to settle those problems were committed to field experiments, such as control of groundwater overexploitation, water-saving, utilization of slightly-saline groundwater, artificial recharging of groundwater aquifers and public participation. However, tested experiments on analyzed results along feasible scenarios showed still a big challenge to restore the deteriorated groundwater system in the North China Plain. Integrated implementation of technical, administrative and legal measures can meet to realize safe exploitation of groundwater in the plain and to increase river discharge into the Bohai Sea in 2020 at first, and to restore the deteriorated groundwater system in the following decade.

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