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Groundwater recharge and dynamics in northern China: implications for sustainable utilization of groundwater

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Abstract

This paper reviews diffuse recharge studies in (semi)arid northern China, which are mainly based on environmental tracers of the unsaturated zone (chloride mass balance, natural tritium, artificial tritium, and bromine). Diffuse recharge in the northwestern part is commonly less than 3.6 mm/yr, where precipitation is less than 200 mm/yr and groundwater is mainly recharged by mountain runoff. The recharge rates increase in the rain-fed Loess Plateau, ranging from 30-100 mm/yr beneath the main crop (wheat). Due to enhanced irrigation in the North China Plain, it can reach thousands of millimeters per year. Due to the limited recharge and sometimes thick unsaturated zone, some shallow groundwaters (e.g., the western Ordos basin and desert area) in northwestern China are even palaeowaters (1.6-30 ka). Insufficient groundwater recharge cannot make a mass balance aquifer under present water exploitation patterns. Mining unrenewable water resources has caused severe water-table subsidence (0.5-2 m/yr). Several suggestions based on the limited groundwater recharge rate and water table subsidence in northern China were proposed for groundwater sustainable utilization.

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Keywords: groundwater recharge; groundwater age; water-table decline; unsaturated zone; arid area; water resources.

1. Introduction

Groundwater is of fundamental significance for human development especially in (semi)arid areas [1]. Groundwater occupies 20% of total supplied water, 70% of drinking water, 40% of agriculture water and 38% of industry water in China. In the (semi)arid northern China, the share of groundwater supply is larger, such as in the North China Plain (56%). However, due to rapidly expanding urban, industrial, population and agriculture water requirements, in sub-humid to arid areas, the total global groundwater depletion has increased worldwide. Groundwater recharge is a key component in assessment of
groundwater systems for sustainable groundwater utilization. However, estimation of groundwater recharge is one of the most challenging issues in water resources research, which depends on lots of factors, and is further complicated by environmental changes. This study will review groundwater recharge studies and groundwater dynamics in the (semi)arid northern China during past 15 years and promote the future study and groundwater utilization model for sustainable development.

2. Groundwater recharge rate

At any single location, recharge rate is highly variable for a given amount of rainfall, soil type and thickness as well as vegetation covers [2]. This review chooses nine groundwater recharge sites for discussion (Fig. 1). In northern China, there are three type regions: (1) western arid area part with precipitation less than 200 mm/yr with case studies of the Tarim Basin, the Yongchang-Jinchang Basin, the Minqin Basin, the Badain Jaran Desert and the Tengger Desert; (2) middle (semi)arid area part with case studies of the Ordos Basin with precipitation ranging from 160 to 420 mm/yr and the Loess Plateau with precipitation ranging from 450 to 650 mm/yr; (3) eastern semiarid area part with case studies of the North China Plain (NCP) with precipitation ranging from 450 to 600 mm/yr.

In order to gain better estimation of groundwater recharge in (semi)arid areas, hydrogeologists have made efforts in using environmental tracers, such as tritium, chloride (chloride mass balance, CMB), and chloride-36 in the unsaturated zone [3]. Based on the CMB of soil profile, the diffuse recharge ranges from almost zero to 3.6 mm/yr (Table 1) for the arid Tarim Basin, the Hexi Corridor and the Gobi desert with precipitation less than 200 mm/yr [4-8]. The small recharge rate contributes little to groundwater amount of aquifer. Those studies promote the groundwater assessment in the arid area in China, in which some studies [9] suggested larger recharge from precipitation to aquifer.

In the Loess Plateau, the studies of groundwater recharge were mainly implemented in the 1970-1980s and focused on loess-plains using simple water balance measurements and showed the groundwater recharge were 33-94 mm/yr (6.7%-15% precipitation) [10]. Significant work using tritium-profiles [11-12] shows that it accounts for 12-13% of the annual precipitation. Most recently, the CMB has been used to estimate recharge rate in the typical sites and results show that the groundwater recharge was 33-90 mm/yr (6.3-18% of precipitation) beneath cultivated upland sites [13-14]. Stable isotopes show that the recharge is related to summer monsoon, during which more than 60% precipitation occurs [14].

In the NCP, precipitation ranges from 450 to 700 mm/yr and is also dominated by the Asia summer monsoon during July to August, which accounts for about 70% of annual precipitation. The main land
uses are winter wheat and corn (two crops per year). While local precipitation cannot support the two crops due to extensive cultivation and drip irrigation, additional groundwater pumpage supplements the deficit. While precipitation contributes about 89 mm/yr of recharge [15], the precipitation and irrigation contribute 50 to 1090 mm/yr recharge [16]. The higher recharge rates are mainly related to intensive irrigation.

Table 1. Groundwater recharge studies in northern China, the code can be found in Fig. 1 (P=Precipitation, R= Diffuse recharge, GA=Groundwater age; I=Irrigation). The references are not shown here.

| Code | Area                     | P (mm/yr) | R (mm/yr) | Aquifer           | GA                      |
|------|--------------------------|-----------|-----------|-------------------|-------------------------|
| 1    | Tarim Basin              | 50        | almost 0  | shallow unconfined| modern and premodern    |
| 2    | Low Heihe River          | 30-100    | /         | shallow unconfined| modern                 |
| 3    | Yongchang-               | 115-185   | /         | shallow unconfined| modern and palaeowater  |
| 4    | Minqin Basin             | 100       | 2.8       | shallow unconfined| modern                 |
| 5    | Badaian Jaran Desert     | 80-90     | 0.2-3.6   | shallow unconfined| palaeowater            |
| 6    | Tengger Desert           | 120       | 0.9-2.5   | shallow unconfined| palaeowater            |
| 7    | Ordos Basin              | 160-420   | 0.1-109   | shallow unconfined| modern and palaeowater  |
| 8    | Loess Plateau            | 450-650   | 33-94     | shallow unconfined| modern and premodern    |
| 9    | North China Plain        | 450-700   | 50-1090   | shallow unconfined| modern                 |

3. Groundwater dynamics

The dramatically declines of water table have occurred commonly in northern China both for shallow and deep groundwater (0.5 to 2 m/yr). Compared with the Tarim Basin, the Hexi-Gobi desert and the NCP, less attention has been paid to declines of water table in the Loess Plateau (1-2 m/yr) (Fig. 2). Intensive urbanization, oil exploitation and the greening project need much water and pumpage of groundwater is the only easy and cheap way to meet the deficit. Severe groundwater decline in northern China have been causing ecosystem deterioration [17], aquifer depletion, land subside and water quality deterioration [18-19].

Fig. 2. Shallow groundwater table changes from 1995 to 2009 in the Xifeng loess plain in the Loess Plateau

4. Conclusions and suggestion

The climate essentially determines the water shortage in arid and semiarid arid area. Insufficient groundwater recharge cannot make a mass balance aquifer under present water exploitation pattern.
Mining unrenewable water resources causing severe water table decline. Therefore, investigation on groundwater origin and recharge rate (following changing environments) and (1) agricultural water saving, (2) distributed city development, (3) water resources trade and (4) water environment protection are urgently needed for groundwater sustainable utilization in the (semi)arid northern China.

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