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RESEARCH ARTICLE

The renewability and quality of shallow groundwater in Sanjiang and Songnen Plain, Northeast China

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Abstract

Groundwater is a key component for water resources in Sanjiang and Songnen Plain, an important agriculture basement in China. The quality and the renewability of irrigation groundwater are essential for the stock raising and agricultural production. Shallow groundwater was sampled and analyzed for various variables. The salinity sodium concentration and bicarbonate hazard, were examined with regard to the United States Department of Agriculture (USDA) irrigation water standards. The concentration of chlorofluorocarbons (CFCs) was determined to analyze the age of groundwater. Most groundwater samples labeled as excellent to good for irrigation with low salinity hazard or medium salinity hazard. Four groundwater samples were good and suspected for irrigation with high salinity hazard. Generally groundwater in Sanjiang Plain was younger than the groundwater in Songnen Plain. Meanwhile, groundwater nearby river is younger than the groundwater further away inside the watershed. The mean age of groundwater in Sanjiang Plain is in average of 44.1, 47.9 and 32.8 years by CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and CFC-113 ($C_2Cl_3F_3$), respectively. The mean ages of groundwater in Songnen Plain is in average of 46.1, 53.4, and 40.7 years by CFC-11, CFC-12 and CFC-113, respectively. Thus, groundwater nearby rivers could be directly exploited as irrigation water. Partial groundwater has to be processed to lower the salt concentration rather than directly utilized as irrigation water in Songnen Plain. Both water quality and renewability should be put in mind for sustainable agricultural development and water resources management.

Keywords: groundwater, irrigation water quality, renewability, agricultural development, Sanjiang and Songnen Plain

1. Introduction

Groundwater almost accounts for half of the global freshwater demand for domestic and agricultural use (IAEA 2006). Groundwater provides a reliable source to sustain agricultural production (Steward *et al.* 2013). The water quality for irrigation is dramatically important for soils and crops yield, especially for the saline-alkali soil. Salinity and sodium haz-

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ard indicators are used as criterion to classify the suitability of irrigation waters (Nishanthiny *et al.* 2010). The sodium absorption ratio (SAR) is an effective evaluation index for most irrigation water (Al-Bassam and Ai-Rumikhani 2003). Elevated values of SAR indicate hydraulic conductivity, aggregate stability, clay dispersion, swelling of expandable clay, surface crusting and reducing tillage (Suarez *et al.* 2006). Meanwhile, the water quality might furtherly jeopardize food security and public health *via* agriculture and food (Zhang X N *et al.* 2015).

Safety of sustainable extraction yield depends on groundwater flow and renewability of the related aquifer (Bruce 2011). Chlorofluorocarbons (CFCs), including CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and CFC-113 ($C_2Cl_3F_3$), were gradually used commercially and industrially during the second half of the 20th century (Hurtley 2011). These nonflammable, noncorrosive and nonexplosive CFCs were low in toxicity and resistant to degradation, making them an ideal marker for modern groundwater (Plummer and Busenberg 2000). The detectable CFCs are only related to groundwater after 1940 or its mixtures (Szabo *et al.* 1996; Han *et al.* 2012). The CFCs were devised for quantifying modern groundwater recharge (Clark and Fritz 1997; IAEA 2006; Qin *et al.* 2011).

The Sanjiang Plain and Songnen Plain are the main grain production bases in Northeast China. The wetlands dramatically shrunk due to agricultural development during the last 60 years, especially in Sanjiang Plain (Huang *et al.* 2010b; Zhang *et al.* 2010). Songnen Plain is one of the three major regions with its soda saline-alkali soil in the world (Zhang *et al.* 2007). The area of saline-alkalization land was 2.4×10^6 ha in the 1950s, reached to 3.20×10^6 ha at the beginning of the 1990s, and is still increasing at a rate of 2×10^4 ha yr^{-1} in Songnen Plain (Wang *et al.* 2004). Most upland crops are wheat, corn, and soybean. The crop-growing season is May to September. The average grain yields of rice, wheat, corn, and soybean during the period of 1978–2008 were 5.23, 2.81, 4.36, and 1.82 t ha^{-1}, respectively (Heilongjiang Land Reclamation Bureau 2009).

To raise grain production and agricultural revenue, the wetlands and saline land were consistently reclaimed and cultivated to farmland, especially after 2004. The irrigation area, especially groundwater irrigation area, thus significantly expanded since then. The bulk grain production, especially the rice and corn, increased resultantly. Many water and environmental issues were related to the large amount of groundwater irrigation. The groundwater table declined sharply in Sanjiang Plain (Wang and Tian 2003). Groundwater with high salinity was abstracted arbitrarily from the unconfined aquifer for irrigation by local farmers, causing a large area of secondary saline-alkaline phenomena (Zhang *et al.* 2007).

Sanjiang-Songnen Plain was once well known for its massive production of quality beans, corn, and rice. The research on groundwater is essential for its sustainable agricultural production (Pereira *et al.* 2002). To assess the renewability and irrigation water quality, the groundwater was sampled and analyzed. The objectives of this study include: (1) assessment of the irrigation water quality; (2) calculation of groundwater ages *via* CFCs; and (3) discussion on the sustainable agricultural water management.

2. Materials and methods

2.1. Study area

The Sanjiang Plain (129°11′–135°05′E, 43°49′–48°27′N), is an alluvial deposit of rivers and lake in Northeast China, including the Songhua River, Heilongjiang River (Amur), Wusuli River (Ussuri), and Xingkai Lake (Khanka) (Fig. 1). The annual precipitation is 500–650 mm, and 80% of rainfall occurs during May to September. The frost-free period is 120–140 days (Huang *et al.* 2010a). The annual potential evaporation is 550–840 mm. The mean annual temperature ranges from 1.4 to 4.3°C.

The two most common landscape types are wetland and farmland occupying area of 0.9 and 4 million ha, respectively (Zhang *et al.* 2010). The main soil types are albic soil, meadow soil and marsh soil. The natural land cover is mainly marsh vegetation, with woodland meadow scattered on relatively high altitudes. The water and soil in marshes are completely frozen from October to next April, and begin to thaw in late April (Pan *et al.* 2010). The unconfined aquifer consists of sand, sandstone, and gravel. The groundwater table is about 3–5 m in depth, flowing from southwest to northeast (Fig. 1).

The Songnen Plain (121°27′–128°12′E, 43°36′–49°45′N) is an alluvial, lacustrine and aeolian deposit in the central part of Northeast China, which is developed on a faulted basin in the Mesozoic (Fig. 1). The whole area of this plain is 1.87×10^5 km^2, surrounded by Changbai Mountain in the east, Daxing'an (Greater Khingan) Mountain in the west, and Xiaoxing'an (Leesser Khingan) Mountain in the north. The annual precipitation is 350–600 mm, with 70–80% of precipitation occurring during June to September. The average annual temperature is 4.0–5.5°C. The potential evaporation depth is 700–1 100 mm. The main types of soils are black soil, chernozem, meadow soil, swamp soil, halic soil, sandy soil, and paddy soil (Zhang *et al.* 2007). The major types of aquifers are Quaternary unconfined aquifer. Neogene Taikang Group confined aquifer and Da'an Group confined aquifer. The depth to groundwater table is about 6–8 m with flow direction from the east, north, and west mountain areas into the central area (Fig. 1).