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The increasing effects in energy and GHG emission caused by groundwater level declines in North China's main food production plain

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ABSTRACT

Agriculture consumes a huge amount of energy every year and then emits lots of greenhouse gases (GHG). Reduction of agricultural energy consumption is important to sustainable agriculture and mitigation of climate change. Groundwater is the main irrigation source in north China's main food production plains, North China Plain (NCP). Many studies have shown that the groundwater levels here have declined a lot during past decades. However, the related environmental and economic impacts have been rarely researched. This study carries out a detailed research on the changes in energy cost and GHG emissions caused by groundwater level declines on the NCP. Results indicate that during 1996–2013, total agricultural groundwater consumption here has increased by 20%. Over-exploitation of groundwater has caused severe groundwater declines ($0.6\ m\ yr^{-1}$) and the decline rate has become faster in recent years. As a result, energy use rate for pumping unit water has increased from 0.50 to $0.61\ kWh\ m^{-3}$, by nearly 22%. Therefore, GHG emissions have increased from 6.16 to 8.72 Mt CO_2e, by 42%. Hebei suffers the most serious groundwater level declines and emits most GHG from pumping, accounting for 47% of the total emissions in the NCP. The economic cost of energy consumption and emission reduction for pumping irrigation is US$ 1.25 billion in 2013, reaching up to 10.3% of GDP in this region. The increasing cost is a great threat to sustainable development of agriculture. Water-saving irrigation is one of the most effective ways to reduce water and energy consumption without loss of grain output. To reduce GHG emissions and pressures on energy and groundwater resources, water-saving irrigation should be greatly promoted in this region. The study would contribute to the development of water-saving and energy-saving agriculture.

1. Introduction

Climate change caused by increasing energy consumption, and GHG emissions has become a common concern of the international community. The Paris Agreement fully embodies global change as not only significant for the interests and development of each country but to the whole world. In the past six decades, energy-consumption patterns in agriculture have changed enormously (Cleveland, 1995; Leach, 1976). Today the agriculture sector is one of main contributors to energy consumption and GHG emissions (Barker et al., 2009; Devi et al., 2009). Each year, agriculture emits 10–12% of the total estimated GHG emissions ($5.1 - 6.1 \times 10^3$ Mt $CO_2e\ yr^{-1}$) (Niggli et al., 2009). Studies of the direct energy use of on-farm operations suggest that groundwater pumping for irrigation is one of the highest energy-consumption processes (Lal, 2004; Mushtaq et al., 2009; Singh et al., 2003).

This issue is especially severe in China because of its agriculture depending largely on the groundwater pumping irrigation. China is the world's largest emitter of GHGs, and its GHG emissions have drawn widespread attention both domestically and internationally. As a signatory to the Paris Agreement, China has committed to reducing GHG emissions per unit of GDP by 2030 to a level that is 60–65% lower than the amount emitted in 2005. The national GHG emissions are estimated to reach a peak in approximately 2030. Meanwhile, as the world's second largest irrigator, GHG emissions from agriculture are responsible for 17–20% of the nation's total annual emissions (Wang et al., 2010), which is almost doubled from the world average level.

The North China Plain (NCP) is one of the most important agricultural regions in China, providing about 20% of China's total grain productionproviding about 20% of China's total grain production (Yuan and Shen, 2013). However, the NCP is also one of the areas with the greatest water shortages in China. To offset the water deficit, the high crop productivity in the NCP depends largely on groundwater irrigation (Zhang et al., 2004). In the NCP, approximately 70% of the pumped groundwater is consumed for agricultural irrigation and over 87% is consumed in the piedmont regions (Hu et al., 2010; Zhang, 2004). Sustainable development is greatly challenged by groundwater over-

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exploitation, which is approximately 4–4.5 $km^3\ yr^{-1}$ in this region (Bu et al., 2008). The severe overexploitation of groundwater results in a quickly declining groundwater levels, together with environmental degradation and has therefore attracted many research attentions (Feng et al., 2013; Jia and Liu, 2002; Wang et al., 2009; Yang et al., 2002). Many studies have recently focused on sustainable groundwater supplies and food security (Bu et al., 2008; Cao et al., 2013; Chen et al., 2007; Du et al., 2014; Foster and Garduño, 2004; Zhang, 2004). However, the research into energy consumption and GHG emissions from pumping irrigation is less. This paper presents a quantitative estimate of the change of energy consumption and GHG emissions from groundwater irrigation in the NCP. The specific objectives of this paper are as follows: (a) to estimate the related cost of pumping irrigation including energy consumption and GHGs reduction costs; (b) to investigate the changes in energy consumption and GHG emissions caused from groundwater level declines; (c) to analyze the factors influencing fluctuations in groundwater and energy consumption; and (d) to clarify the importance of water- saving irrigation.

2. Data and methods

2.1. Site description

The North China Plain (NCP) is also referred to as the Huang-Huai-Hai Plain. From the viewpoint of water resource management and economic importance, a narrower definition of the NCP is more commonly used. It is the region bordered on the north by the Yan Mountains, on the west by the Taihang Mountains, to the south by the Yellow River and to the east by the Bohai Gulf. It is located in the eastern coastal region of China between 34°46–40°25′N latitude and 112°30′–119°30′ E longitude (Fig. 1). The total area of this narrowly defined NCP is $1.39 \times 10^5\ km^2$, with a population of approximately 111 million. Because of the monsoon influence, rainfall is highly variable. The mean annual average precipitation is 550–650 mm, 80% of which occurs from June to September. The annual pan evaporation is approximately 1000–1500 mm. The proportion of evaporation from April to June to that of the full year is approximately 45%. The NCP contains 9% of China's population and 11% of its arable land, and produces 10% of the nation's gross domestic agricultural products. Currently 71% of its cultivated land is irrigated, with an irrigated area of 7.5 Mha.

2.2. Data sources

The average annual precipitation and temperature (1996–2013) were obtained from the Meteorological Bureau. Data on agricultural development (1996–2013), including grain output, grain value and grain planting area were obtained from the Ministry of Agriculture. Crop pattern data (1996–2013) were from National Bureau of Statistics. Data on water consumption for agriculture (1996–2013) were collected from the Water Resources Bulletin. Irrigation data (1996–2013), including the total irrigated area (1996–2013) and water-saving irrigated area (2004–2013), were collected from the National Bureau of Statistics. Average groundwater levels (1996–2013) were calculated based on data from China's Ground Water Information Center (195 observation wells selected in the NCP, of which 29 were in Beijing municipality, 21 in Tianjin municipality, 81 in Hebei province, 26 in Henan province and 38 in Shandong province). Data on the number of wells (1960s–2011) were acquired from Water Resources Yearbook. Data on groundwater exploitation (1996–2013), were collected from the Water Resources Bulletin. Electricity prices (2006–2013) in different districts were obtained from the Annual Report on Electricity Regulation. Data on groundwater levels and shallow groundwater extraction for 880 observational wells in the Hebei Plain were collected from the Hebei Department of Water Conservation (1950s–2013) (Table 1).

2.3. Estimation of pumping lifts

There are no valid statistics on groundwater pumping lifts in the NCP. Pump lifts (Y) were estimated by using the groundwater levels (X) based on data taken from 366 surveyed villages in Northern China (Wang et al., 2012a,b). The linear regression is shown in Eq. (1) and its coefficient of determination is $R^2 = 0.62$.

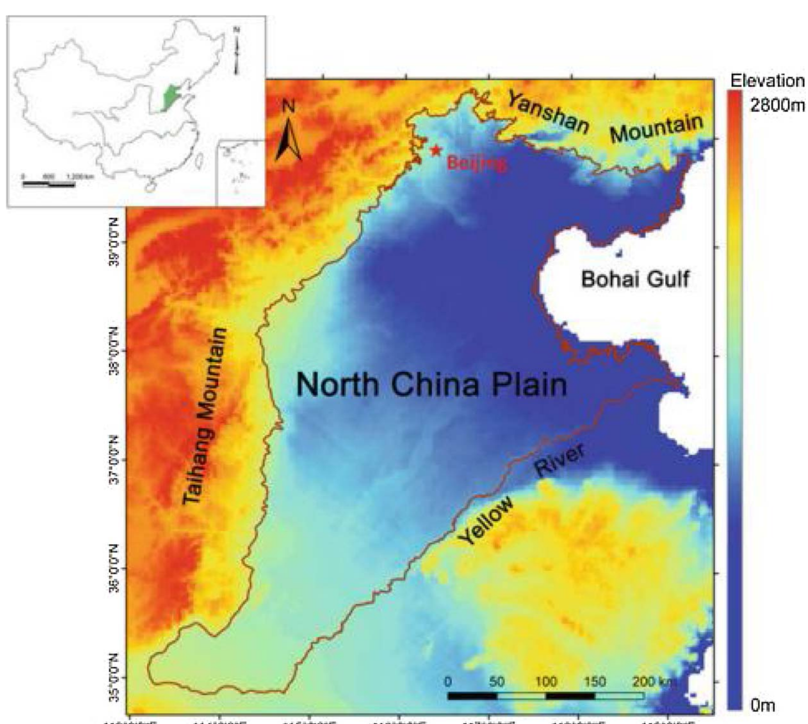

Fig. 1. Location of the study area, the North China Plain.