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An economic valuation of groundwater management for Agriculture in Luancheng county, North China

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ABSTRACT

The North China Plain (NCP) is one of the most productive and intensively cultivated agricultural regions in China but it experiences severe water shortages; thus field irrigation relies heavily on groundwater. The extraction of groundwater for irrigation has sustained increased grain yield, although the value of the irrigation water has not been estimated. Here, we propose an evaluation model for underground water used for irrigation, which took into account the infrastructure price, resource price and environment price based on monetary values. We classified underground water into total extracted, actual consumption and over-exploited water according to the hydrological cycle. We then performed a benefit-cost analysis of three underground water irrigation scenarios—actual irrigation, equilibrium irrigation and maximum water productivity (WP) irrigation—using the proposed model and Luancheng County of NCP as a case study. The results showed that (1) the volume of irrigation water varied in the order of actual irrigation scenario > equilibrium irrigation scenario > maximum WP irrigation scenario. The amount of different components of water—extracted groundwater, actually consumed groundwater and over-exploited groundwater- varied similarly, although the yearly variations in extracted groundwater were smaller; (2) the total water price should include the infrastructure price, resource price and environment price, although farmers merely pay for the infrastructure price; the resource price constituted the largest proportion of the total water price, especially in the dry years; (3) equilibrium irrigation was the most suitable scenario based on net benefits by our valuation method of underground irrigation water.

1. Introduction

It is general understanding that China is short of water. The average amount of water per person in China is only 2300–2400 m^3/year, about one quarter of the world average. Water scarcity is most intense in northern China, particularly the North China Plain (Webber et al., 2008), which is one of the most productive and intensively cultivated agricultural regions in China. More than 75% of the nation's wheat and 32% of its maize are produced in this region (China Statistics Bureau, 2011). The main cultivated grain pattern, winter-wheat and summer-maize, have an estimated annual evapotranspiration (ET) of 850 mm—far in excess of the long term average annual precipitation of 550 mm (Moiwo et al., 2010). Approximately 70% of extracted water resources for agriculture, of which approximately 70% is for wheat irrigation, are pumped from groundwater in Hebei Province of the NCP (Lv et al., 2013). As the groundwater withdrawal largely exceeds the recharge, the groundwater table is dropping rapidly. Groundwater depletion is especially severe in the Piedmont region of Mount Taihang (Foster and Perry, 2010).

There are two research aspects of underground water irrigation and agricultural production. The first aspect is exploring the relationship between irrigation and yield through crop modeling, such as DASSAT, APSIM, etc. The agronomic research recommendations involve use of less water to gain stable yields (Chen et al., 2010; Mo et al., 2005) while hydro-geologic research mainly focuses on the

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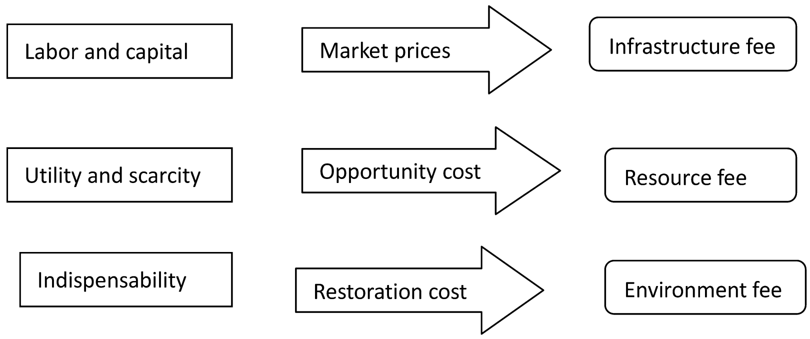

Fig. 1. Valuation methods of water resource.

negative impacts of irrigation or the maximum amount of water for irrigation to ensure sustainably of the hydrological cycle (Kendy et al., 2004; Martinez-Santos et al., 2008; Martínez-Santos and Martínez-Alfaro, 2010; Nakayama et al., 2006; Van Camp et al., 2010). Eco-hydrology studies have suggested a cut down on the amount of irrigation water to support a recovery of the groundwater level, considering the appropriate reduction in yield (Hu et al., 2010a,b; Huo et al., 2012; Kendy et al., 2003; Wang et al., 2008; Yang et al., 2006a,b).

Another aspect involves the assessment of environmental and economic impacts of underground water by methods of environmental economics. This includes the ecosystem services provided by water, environmental accounting and management of underground water (Engel and Schaefer, 2013; Kløve et al., 2011; Zander et al., 2013), groundwater footprint (Gleeson et al., 2012), etc., on a large scale. Studies on water management based on water resource value at the farm scale have considered (1) the profitability of using underground water for irrigation (Varghese et al., 2013) and (2) the adverse effects of irrational allocation of water resources, such as over-irrigation or planting more water-demanding crops due to the fuel subsidy policy, especially in regions relying on underground water for irrigation (Gül et al., 2005; Shiferaw et al., 2008a,b).

Most studies on groundwater management in the NCP are associated with crop water use efficiency (WUE). Appropriate tillage method can increase plant population and improve the WUE and grain yield under rain-fed conditions (Wang et al., 2014; Guan et al., 2015). The optimum irrigation amounts in the NCP were developed from different standpoints to protect groundwater resource (Zhang et al., 2006; Li et al., 2008; Hu et al., 2010a,b). In the NCP, the pricing of groundwater in most available studies mainly was based on the expense on power and equipment (Yang et al., 2003). Water itself is deemed free without considering its resource value (Zhen et al., 2005). In addition, it is generally understood that irrigation water has different end uses other than its use by crops. Few studies have priced the different components of underground water (i.e., the extracted amount of groundwater, the actual amount consumed and the volume over-exploited) based on its different end uses. The volume of different end use of irrigation water is based on the hydrological cycle of farmlands. Our objective in this study was to explore the sustainable groundwater management for agriculture based on underground water valuation, using Luancheng County of the North China Plain as a case study. This objective was achieved through: (1) developing an economic assessment model to establish the value of underground water used for irrigation, considering its essential attributes and the hydrological cycle; (2) summarizing the grain yields under different irrigation scenarios and (3) calculating the irrigation costs and grain output value. Variations in the amount and prices of irrigation water, and the differences between water and grain value under the different irrigation scenarios were analyzed. The optimal irrigation management option was then proposed based on the value of underground water in the study area.

2. Economic theories and models for assessing the value of underground irrigation water

2.1. Economic theories of pricing water

The classical economic theories of value include the labor theory of value and the utility theory of value. However, the labor theory considers that natural resources have no value since no labor is embodied in them. This has led to excessive use of water resources for free and exposed people to the plight of water crisis. It is therefore not suitable to value water resource using the labor theory alone. The utility theory of value evaluates goods based on whether they can satisfy people's desire on the perspective of subjective psychology. It is necessary that the goods are useful and scarce. It is appropriate to evaluate water resource using the utility theory considering the essential attributes of water.

The price that farmers should be charged for the water they use on their farms typically combines an infrastructure fee, a resource fee and an environment fee (Fig. 1). The infrastructure fee is the fee charged for pumping underground water, including the capital cost of constructing and operating an irrigation system. A resource fee seeks to capture the opportunity cost of water in its best alternative use since water is scarce and useful. An environmental fee is the restoration costs of over-exploiting groundwater. The underground water system needs enough water to sustain its environment, including as a habitat for living things, the stability of underground rock layers, etc. It would be dangerous, once the underground water is exhausted and the resulting cost falls under the environmental (external) cost, which is rarely a concern for farmers. In this evaluation, we considered the restoration cost as the environment fee, since payment for the damaged underground system was difficult to value.

2.2. Model for appropriate pricing of underground irrigation water

We developed an economic assessment model for the appropriate pricing of underground irrigation water. The whole assessment model included pricing for three sub-components, infrastructure price (P_1), resource price (P_2) and environment price (P_3).

(1) Infrastructure price (P_1) was defined as the cost of using groundwater, covering items such as machines, energy, etc., based on current market prices. The infrastructure price covers electricity bill for pumping underground water (P_{11}), the cost of constructing wells (P_{12}) and the cost of pumping equipment (P_{13}).