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Indirect monitoring of groundwater abstraction using electricity consumption: the north China plain case study

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In brief – The method known as indirect monitoring, has been used successfully in the Guantao County project in China to quantify the amount of water pumped from individual wells. It is possible to use electricity data to estimate the amount of water that has been pumped from a well. This can be done by conducting a pumping test, which involves measuring the electricity consumption of the well pump while it is operating and determining the volume of water that was pumped during that time. The relationship between the electricity consumption and the volume of water pumped can then be used to estimate the volume of water pumped over a longer period based on the electricity consumption during that period. It should be noted that the precision of this method depends on the accuracy of the electricity-to-water conversion factor, which can be affected by various factors such as the efficiency of the pump and the characteristics of the groundwater aquifer.

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eGROUND WATER

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Introduction

The North China Plain (NCP) is a global hotspot of groundwater over-pumping. Known as the breadbasket of China, its typical cropping structure is double cropping of winter wheat and summer maize. The overpumping, which mainly takes places during the winter, is in the order of 15% to 20% above average recharge. With more than 8000 irrigation wells, the control of the abstraction is the main challenge for the regional authorities.

The Guantao County project main innovation is the large-scale conversion of electricity use to pumping water volume from the aquifer. The method has proven effective and feasible for metering pumping wells. The project aims at combining real-time monitoring, modelling, and control to ensure sustainable use of the groundwater resources. The project not only aimed at developing the real-time groundwater monitoring system, but also to hand it over to the Chinese local partners for the future use and maintenance of the system after the project's completion.

Case study presentation

Guantao County is located in the south of the Hebei Province in the NCP. It has an area of 456 km2, contains 277 villages and about 320,000 inhabitants. There are more than 8000 irrigation wells in Guantao County, most of which pump groundwater from the shallow unconfined aquifer, while the rest exploit the deep confined aquifer or lift surface water from canals. The irrigation area served by each shallow well is small, on average 3.3 hectares, and the water abstractions are not controlled due to the high costs of renewing and monitoring mostly old wells and pumps.

This situation, with many thousands of uncontrolled wells managed by individual farmers with relatively small parcels, leads to a risk of losing the control of the available common resources. Effective management to achieve sustainable groundwater use assumes that groundwater abstraction is monitored and quantified reliably (Wang et al., 2020). In 2017, the Department of Water Resources in Guantao County released a groundwater control policy to define a yearly water quota per ha. Effective groundwater abstraction monitoring is the prerequisite to implement the groundwater control measures. The existing electricity metering system is the central infrastructure for groundwater abstraction monitoring.

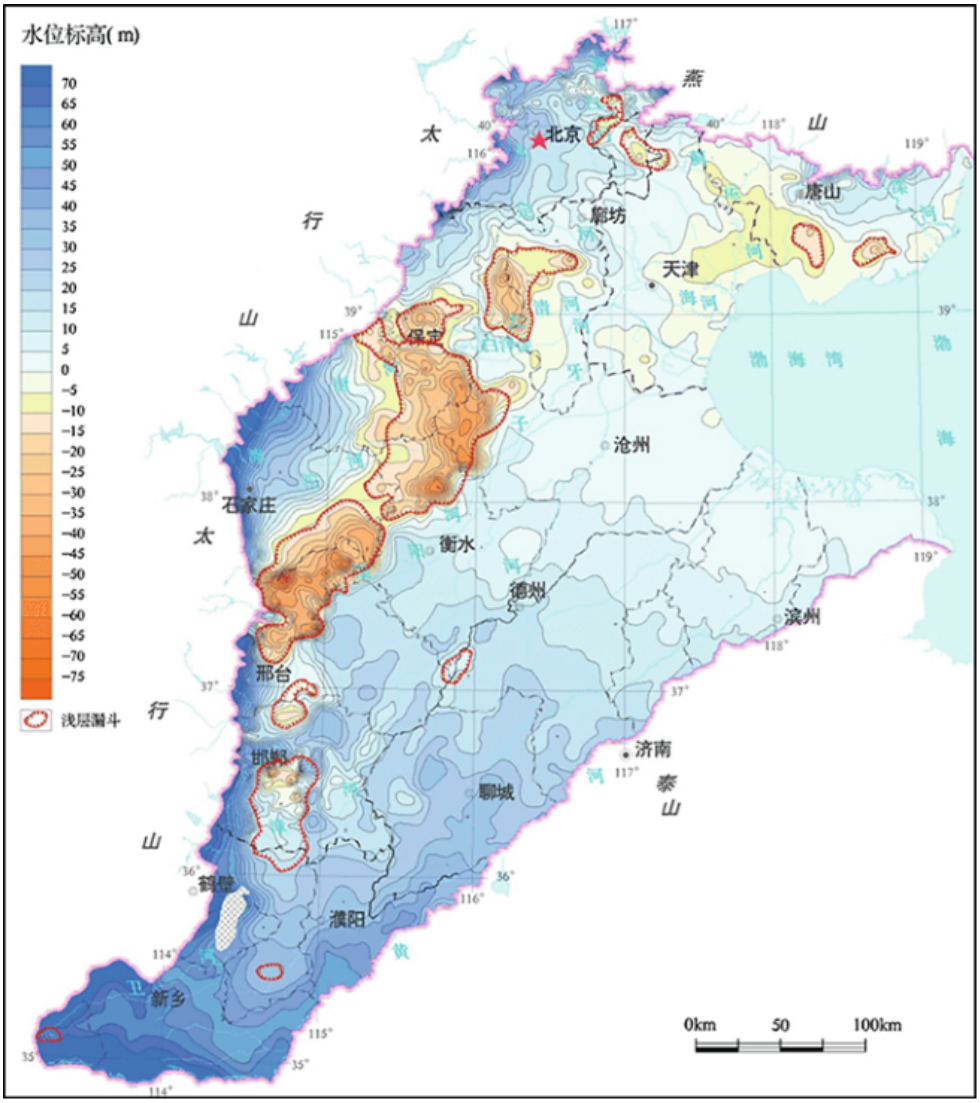

Figure 1. Spatial distribution of observed piezometric levels in the shallow aquifer. Source CIGEM, 2019.

Innovation

Emergence phase

In the North China Plain (NCP), groundwater is the major water resource for agriculture, accounting for more than 70 % of the total water supply. The unsustainable abstraction of groundwater caused a dramatic groundwater-level decline in the region. This severe groundwater-level decline causes land subsidence, drying up of the lower reaches of rivers and streams, salt-water intrusion at the Hebei coast, and municipal water shortages, while also increasing the cost of pumping water (Guo et al., 2015). All irrigation wells are equipped with electricity meters, most of which are traditional mechanical electricity meters without data transmission. To reach the goal of sustainable groundwater use, a management system has been set up in Guantao, integrating policy and a data-driven decision support system.

Development phase

In Guantao County, the Department of Water Resources (DWR) is responsible for groundwater management. The groundwater control policy released in 2017 entitles farmers

to pump groundwater not exceeding a water quota. Electric power is supplied and managed by Guantao Electric Power Supply Company (EPSC), which is affiliated with the State Grid Corporation of China. The EPSC is in charge of 11 Electric Power Supply Agencies (EPSA) at district level. The control area of an EPSA is generally determined according to the administrative boundaries of eight townships in Guantao; and one or two EPSA districts cover the area of one township. Each EPSA manages the electric power supply of about 20 villages. In each village, one or two electricians employed by EPSA are responsible for power infrastructure maintenance.

Many pumping tests were performed from 2016 through 2018 to determine the conversion factor between electricity consumption and pumped volume (Kinzelbach et al., 2022). The analysis of electricity-to-water abstraction conversion focused on shallow wells, as groundwater from the shallow unconfined aquifer is the main source of irrigation water in Guantao County. The control area of Shoushansi EPSA (located in Shoushansi Township, see Figure 1) was selected as the pilot area as all the wells in this area are shallow wells.

- Technical characteristics of the innovation

The electricity-to-water conversion factor is established via pumping tests. Four different groundwater models were developed serving different purposes (Kinzelbach et al., 2022): A box model computing the groundwater balance and the water gap of Guantao County; A distributed model of the shallow aquifer visualizing the spatial variation of groundwater levels and priority areas for pumping control; A real-time model updating and improving the distributed model by assimilating monthly observation data; And an upscalable data driven model using machine learning algorithms to forecast groundwater levels. All these tools together with monitoring data and current pumping control options are integrated in a web-based decision support system with a user-friendly interface. It allows local water managers without specialized knowledge to use complex technical tools in their groundwater management practice. The project development also involved creating a model for crop water demand, methods for identifying land use and, above all, a database for keeping all the information gathered so far.

A water balance of the county for 2019 shows that the pre-project agricultural water gap of about 37 million cubic meters per year has been halved. The shallow aquifer is now more or less in equilibrium while for the deep aquifer, a deficit of roughly 10 million cubic meters per year remains. To reduce the pumping from the deep aquifer by about 20 million m3/year, either demand should be lowered or supply should be raised.

Lessons learnt and replicability

The method developed in Guantao is transferrable to all areas or countries where wells mainly run on electric energy, such as the U.S., Jordan, Iran, Mexico and the Mediterranean region.

Diesel pumps are frequently used in many areas, e.g., Pakistan and India. A similar conversion can be achieved by relating the diesel energy and water volume pumped, although diesel fuel is not always metered. Cooperation between water and energy departments is crucial to achieve a successful system of groundwater abstraction monitoring using electric energy as proxy (Kinzelbach et al., 2022). Policy support and legislation are needed to achieve further multi-departmental cooperation to ease the procedures of data collection, data sharing, and quantification of groundwater abstractions and implementation of control methods.

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