Development of Groundwater Resources and Farmers' Response on Privatizing Tubewells: Empirical Research in the Rural Areas of Hebei Province

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Abstract: The purpose of this paper is to examine the development and emerging problems of groundwater resources, and farmers' responses to the changes of groundwater management through privatizing tubewells in the rural areas of Hebei Provinces. The data used in this paper were collected from a field survey in 20 randomly selected villages in Hebei Province in 2006. Our results show that the development of groundwater resources can be divided into three stages. Farmers started digging tubewells in the early 1950s and accelerated the development since the early 1970s. After the mid 1980s, the tubewells continued to increase with emerging of some environmental problems, such as the decline of groundwater table. With decline of groundwater table, farmers have responses to privatizing the tubewell ownership and management. The privatization of tubewells will increase the sown areas of high value crops (such as vegetables and fruits) and have some possible positive relationship with crops yield. When designing the management policies of groundwater resources, policy makers need to understand how farmers have made response and use their response to manage groundwater effectively.

Key words: groundwater resources; development; problems; privatization of tubewells; rural areas in Hebei Province

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1 Introduction

Water scarcity is one of the key problems affecting agricultural production in northern China - an area that covers 40% of the nation's cultivated area and houses almost half of the population[1-3]. Water scarcity in northern China has arisen both because of limited water supply and increasing water demand. Water availability per capita in northern China is only around 300 m^3, which is less than one seventh of the national average and far lower than the world average[4]. At the same time the demand from rapidly growing industrial sector and an increasingly wealthy urban population is beginning to compete with the agricultural water demand[5,6].

Over the last 20 years or so, groundwater has become the most important source of irrigation

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in northern China. Before the early 1980s, most of the increase in water availability in northern China came from the expansion of surface water systems, most of which were constructed during the 1950s and the 1960s. China's leaders invested in building reservoirs, constructing new canal networks and increasing the utilization of the region's lakes and rivers. By the end of the 1970s, most of the available surface water was already being utilized in most basins in northern China and the area irrigated by surface water more than doubled in the North China Plain[7]. However, due to poor management and lack of investment, especially in maintenance, many surface water canal systems began deteriorating in the 1980s[1]. Since then groundwater has become the important source of irrigation. In North China, the share of groundwater irrigated areas increased from 5% in the 1950s to 68% of the total irrigated area in the 2000s[8].

With increasing population and development of industry, can we meet the water demand of agriculture through additional groundwater extraction in northern China? The answer possibly is "no", since groundwater resource is not infinite and some environmental problems have already occurred as a result of over-exploitation of groundwater. According to Ministry of Water Resources (2001), between 1958 and 1998 groundwater levels in the Haihe River Basin fell by up to 50 m in some shallow aquifers and by more than 95 m in some deep aquifers. The central government in China is developing the mega project "water transfer from south to north" to alleviate the crisis of water shortage in northern China. However, facing with increasing water demand, we not only need supply augmentation measures, more importantly, we need effective policy and institutional measures that can manage water demand well. In order to design and implement rational policy and institutional measures, it is necessary to have one better understanding on development of groundwater and farmers' response on changing of groundwater management patterns. The overall goal of this paper is to examine the development and emerging problems of groundwater resources, and farmers' responses to the changes of groundwater management through privatizing tubewells.

The rest of the paper is organized as follows. In the first section, we describe the data set that forms the basis of this study. In the second section, we examine location and basic characteristics of the study area, including its geography, hydrology and socio-economic characteristics. In the third section we examine the development of groundwater resources and its problems. The fourth section analyzes the changes of tubewell ownership, management, adoption of water saving technologies and other responses made by farmers to cope with dwindling groundwater resources. In the fifth section, we understand the institution and regulations of groundwater management. The final section is summary and policy implication of the study.

2 Data

The data used for the study comes from both primary and secondary sources. For primary source, we interviewed local officials, and conducted field surveys using pre-designed questionnaires for village leaders and farmers who manage tubewells. The purpose of interview with local officials was to understand the general characteristics of groundwater use, policies and local environment in the study area. The secondary data is mainly from the local statistical bureaus. The

secondary data can help us to understand the history of the groundwater development.

The respondents in our field survey come from 20 randomly selected villages in two counties in Baoding City, Hebei Province. After discussion with the local officials, two sample counties were selected (Mancheng County and Qingyuan County). After selecting the sample counties, we randomly selected 10 villages in these two counties. In each village, three farmers who have tubewells randomly selected. Finally, the total samples size was 20 villages and 60 farmers. The survey collected data for two years, 1995 and 2005. Survey of village leaders was conducted in order to understand groundwater status at the village level. Questionnaires for village leader involved information on eight aspects in the specific year 1995 and 2005. These were village socio-economic situation, the changes in cropping patterns, local groundwater resource utilization, groundwater quality and security, the change in the number of tubewells, the change in tubewells ownership pattern and management structure and finally adoption of water saving technologies. In addition to village level survey, we also conducted household level survey by administering questionnaires to tubewell owners or managers. The purpose of tubewell manager's survey (or farmer survey) is to understand perspectives of the farmers and their behavior vis-à-vis groundwater. The questionnaires for tubewell owners involved eight aspects on groundwater use in 1995 and 2005: the technical characteristic of the tubewells and pump, the security and allocation of groundwater, water price and water market for selling water, regulations for groundwater use, the investment on tubewells and pumps, water volume consumed by different crops, income of farmers and their cost of agriculture production.

3 Basic characteristics of the study area

3.1 Climatic and hydrological characteristics

Baoding City is located in the central southern part of Hebei Province. Mancheng and Qingyuan are our two study counties out of the total 25 counties managed by Baoding municipal government. The climate of Baoding City is of the continental monsoon type. The annual temperature is 13.8℃, the average yearly sunshine duration is 2374.4 hours and the average yearly rainfall is 550.2 mm. Rainfall is distributed unevenly within the year with 61% of rainfall concentrated in July and August.

Daqing River, a tributary of Haihe River is the main river of the study area. Daqing River and its sub tributaries drain the entire basin. The southern part of Hebei Plain is an area with sediments from lakes and rivers, which belongs to Huabei fractured depression. It is surrounded by deep faults. Quaternary aquifers are porous layers and can be subdivided into four groups (Ⅰ, Ⅱ, Ⅲ and Ⅳ) from top to bottom according to local hydrogeology. The fresh water is mainly located in the first and the second aquifers and they are the main groundwater exploration aquifers. The general thickness of southern part of Hebei Plain is 70m to 80m, and the depth of 150m to 220m can be found to northeast of Shijiazhuang city and east of Baoding city. Generally speaking, the aquifers material changes from coarse to fine, from one layer to more layers and the water quality from good to worse as one moves from south to north.

There are many sources of groundwater recharge. Infiltration from precipitation, surface

water body, well irrigation and lateral seepage from mountain areas are the recharge sources for shallow groundwater in the southern part of Hebei Plain. Precipitation is the main source of groundwater recharge and it accounts for about 75% of the yearly average recharge. The main sources of discharge for shallow groundwater include artificial abstraction, unconfined groundwater evaporation and seepage to other layers. Of these, the artificial discharge is the main way which accounts for more than 80% of discharge. Seepage from deep karst, lateral flow from flood deposit fan, vertical infiltration or seepage is the main sources of recharge for deep ground water.

Groundwater flow direction of this area follows the topography and flows from west to east generally. Before 1960, due to small amount of groundwater abstraction, shallow groundwater flow direction was under natural state without being influenced by human activities. The gradient from mountain front to seashore was 2 to 0.1%. After 1960, the annual increase in groundwater abstraction had serious impacts on groundwater flow and several large groundwater depressions were formed. The shallow groundwater flow direction changed and the groundwater gradient changed to 2.29 to 0.05%.

3.2 Socio-economic characteristics

According to the Hebei Economic Yearbook (2006), the total population of the province was 68.51 million people. Within Hebei Province, Baoding is the most densely populated city (10.73 million) among 11 cities from Hebei. The per capita land availability in Baoding (0.07ha) is lower than the average of Heibei Province (0.09 ha). The agricultural GDP is 3.43 billion yuan ($\sim 4.4 \times 10^8$ US $) in 2005 and is the third highest in Hebei Province. The per capita agriculture GDP (3200 yuan, ~416 US $) is however lower than the whole province due to high population concentration in Baoding.

Since most of land area of Hebei Province lies within plain and has good irrigation network, the share of irrigated area to net cropped area is quite high. The total irrigated land area is 651461 ha and the share of irrigated land to net cropped area is 86%, which is higher than the average for the whole province (76%). In our sample villages, share of irrigated land is still higher, at 98%. Since the surface water is scarce, most of irrigated land depends on groundwater and it accounted for 87% of the net irrigated area.

For our samples villages (20 villages), the socio-economic situation is similar to Baoding city. Based on the survey data, the total population of these 20 villages was 52942 and land area was 4200 ha. The per capita land availability is 0.08 ha which is higher than that of Baoding city. The irrigated area is 4095 ha accounting for 98% of the farm land and 100% of irrigation was from groundwater. The gross sown area is 7203 ha and the cropping intensity reaches 1.71. Wheat, maize are the main crops, the others are fruit trees and cash crops such as vegetable.

4 Development of groundwater resources and emerging problems

Groundwater is the most important source of water in Baoding City and agriculture is the major water user. According to the Water Resource Bulletin of Hebei Province (2000), the annual

water availability (including groundwater and surface water) in Baoding City is about 3.1 billion m^3, of which groundwater accounts for 2.3 billion m^3 (74%). However, the annual water use is about 3.3 billion m^3 of water, which indicates that water use especially groundwater resources use is more than the water resources availability in Baoding City. Among all the sectors, agriculture is the main water user and 80% of water is used for irrigation while the rest 20% is shared by the domestic and the industrial sectors equally.

4.1 Development of groundwater resources in study areas

Until now, the development of groundwater resources in northern China can be divided into three stages. The first stage is from 1949 to the end of the 1960s. The major characteristic of this stage was that groundwater begun to be exploited but the scale of exploitation was very limited. In the second stage, groundwater exploitation was accelerated and the total volume of groundwater exploitation reached one large scale. This stage was from the early 1970s to the end of the 1970s. Since the early 1980s, groundwater has continued to be largely exploited and the over-exploitation has become an important issue.

The stage of groundwater development in the study area is also similar to the overall story of northern China, which we can check it from the development of tubewells. For example, the Qingyuan County began to dig tubewells in 1953 and until the end of the 1960s (end of the first stage), there were only 2000 tubwells. In the first stage, the average annual increase of tubewell was 235. Since the early 1970s, under the support of the local government, the exploitation of groundwater resources was accelerated and the number of tubewells in the county grew rapidly. By the end of the 1970s, the total number of tubewells reached near 8000. During the second stage from the early 1970s to the end of the 1970s, the average annual increase of tubewells was as high as 600. In the third stage, tubewells in the Qingquan County continued increase, but its annual increase number of tubwells (245) was lower than the second stage and similar to the first stage. Until 2005, there were nearly 14000 tubewells in the Qingyuan County. The path of tubewell expansion in Mancheng County is similar to that in Qingyuan County, but the average increase rate to tubewells is lower than that in the Qingyuan County (Fig. 1).

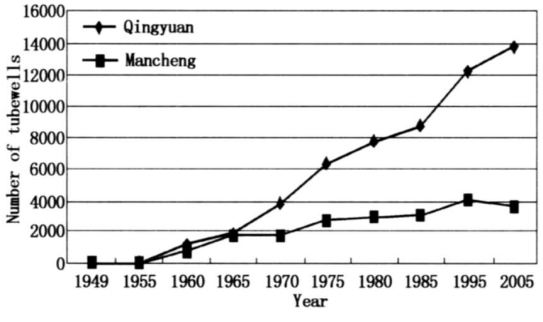

Fig. 1 Expansion in the number of tubewells in Qingyuan and Mancheng counties of Baoding City, Hebei Province

The path of tubewell expansion shown in the official data is largely supported by the information from our survey. Based on our survey, in these two counties, farmers started digging tubewells in the early 1950s and accelerated the tubewell development since the early 1970s (Table 1). Until the mid 1980s, the total number of tubewells in these sample villages reached 731, about 36 tubewells for each village. From 1953 to the mid 1980s, the annual increase of tubewells were 22, about increasing one tubewell for each village. After the mid 1980s, the tubewells con-

tinued to increase. Until 2005, there were 1214 tubewells in these sample villages, each village had about 61 tubewells. The tubewell increase rate in Qingyuan County is higher than that in Mancheng County, which results in higher tubewell numbers in Qingyuan County than in Mancheng County. In 2005, each sample village in Qingyuan County was as high as 98, while in Mancheng County, each sample village only had 23 tubewells.

Table 1 The change of tubewells number

Year	Number of total Tubewells	Deep tubewells		Shallow tubewells	
		Number	% to total	Number	% to total
Total					
1995	902	228	25	674	75
2005	1 214	709	58	505	42
Qingyuan County					
1995	570	210	37	360	63
2005	980	642	66	338	34
Mancheng County					
1995	332	18	5	314	95
2005	234	67	29	167	71

Data source: Field survey conducted in 20 villages in Baoding district in December 2006.

In the past 10 years, due to development of tubewells, the shallow groundwater was not enough and farmers have to turn to explore deep groundwater resources (Table 1). In 1995, 75% of the tubewells were shallow tubewells that exploring groundwater from the shallow aquifers. However, until 2005, the share of deep tubewells reached 58%, indicating the decline of available shallow groundwater resources and the deep aquifers have become the major groundwater sources. Similar trend can be found in these two trends. Especially in Qingyuan County, in 2005, the share of deep tubewells reached 66 percent, which is obviously correlated with relatively high increase rate of total tubewells. Although deep tubewells in the Mancheng County was still not the dominate one, the share of deep tubewlls still increased 24%.

4.2 Decline of Groundwater Table and Related Other Environmental Problems

With increase of groundwater abstraction, groundwater table in the study area has declined gradually over time (Table 2). Based on the data from observation wells in Baoding city, we find that the shallow groundwater table was 4.3 m in 1980. However, in 2000, the shallow groundwater table declined to 19.9 m, the annual crop rate was 0.8 m. The similar trend can be found for the deep groundwater table. From 1980 to 2000, the deep groundwater table dropped from 5.1 m to 16.3 m, the annual dropping rate reached 0.6 meters. Our survey data also reflect the decline trend of groundwater table. From 1995 to 2005, the annual average groundwater table declined about 0.9 m in both Qingyuan and Mancheng counties.

Table 2 Change of groundwater table in Baoding City

	1980	2000
Average depth /m		
Shallow groundwater table	4.3	19.9
Deep groundwater table	5.1	16.3
Annual drop rate (2000 - 1980) /(cm/yr)		
Shallow groundwater table	0.8	
Deep groundwater table	0.6	

Note: If the tubewell depth is lower than 80 m, the tubewell extracts shallow groundwater; if the tubewell depth is higher than 90 m, the tubewell extracts deep groundwater.

Data source: Xu Yueqing[10].

The decline of groundwater table also resulted in some environmental problems. For example, in some areas of intensive groundwater exploitation (mainly in the city areas), cones of depression have been formed. Two such large cones of groundwater depression appeared in Yimuquan district and the Baoding city. The cone of depression in Yimuquan is located in Yimu Spring water source area of northwestern Baoding city and had developed in 1967. The groundwater table depth at the funnel center has increased from 4.4 m in 1967 to 33.6 m in 2001. Cone of groundwater depression in Baoding city was discovered in 1974. The groundwater depth at the center of the cone of depression increased from 13.5 m in 1974 to 28.42 m in 2001. Until now, there are no cones of depression happening in the rural areas.

5 Privatizing tubewells

With development of groundwater resources and resulted drop of groundwater table, farmers have made responses by privatizing the tubewell ownership and management. In this section, we will examine three issues. First, we will examine how farmers privatize the ownership and management of tubewells. Second, we will understand the relationships between the privatization with declining groundwater table. Finally, we will identify the effect of privatization on agricultural production.

5.1 Privatizing tubewell ownership

In a pattern similar to that found throughout the Haihe River Basin[9], the patterns of tubewell ownership in our sample areas also have changed over time, with ownership shifting from collective to private. Survey data show that from 1995 to 2005, the share of collective owned tubewells declined from 82% to 49% (Table 3). At the same time, the share of private owned tubewells increased from 18% to 51%, the private ownership of tubewells have become the dominate pattern. The privatization of tubewell ownership has developed more quickly in Qingyuan County than in Mancheng County. In 2005, the share of privatized tubewells in Qingyuan County reached 56%, while it was only 30% in Mancheng County. Despite their different development rates on the tubewell privatization, their development trends are similar. Within the private sector, shareholding tubewell is the major type of tubewell ownership. In 1995, 98% of private tubewells were shareholding tubewells. In 2005, the share of shareholding tubewells only declined by 2%.

Table 3 Changes in pattern of tubewells ownership, 1995 - 2005

Year	No. tubewells	Share of tubewells/%	
		Collective	Private
Total			
1995	45	82	18
2005	61	49	51
Qingyuan County			
1995	57	81	19
2005	98	44	56
Mancheng County			
1995	33	85	15
2005	23	70	30

Data source: Field survey conducted in 20 villages in Baoding district in December 2006.

5.2 Privatizing tubewell management

With the change of tubewell ownership from collective to private, the management regimes of tubewell also have changed from collective to private (Table 4). Based on our data, we found that share of different management regimes is similar to the share of different tubewell ownership pattern. In 1995, the share of collective management regime was 83% but this share declined to 49% in 2005. At the same time, the share of private management regime increased from 17% to 51%.

Table 4 The share of different tubewell management regimes in the study area

	Collective management /%		Private management /%	
	Pure collective	Contracting	Shareholding	Individual
1995	97	3	95	5
2005	86	14	96	4

Data source: Field survey conducted in 20 villages in Baoding district in December 2006.

Within the collective management regime, there are two sub-regimes. The first sub-regime can be called pure collective management. In this case, the tubewell is entirely managed by village leaders. The second pattern is called contracting management. Contracting management implies that the village leader rents out the collective tubewell to individual farmers who are responsible for managing tubewells. Based on our data, we found that the share of pure collective managed tubewells was 97% in 1995, and only 3% of tubewells were rented out to individual farmers. This increased to 14% in 2005 and the share of pure collective managed tubewells declined to 86%.

Within the private management, there are also two regimes, shareholding and individual management. From Table 4 we can find shareholding management is the main management regime which accounted for 95% in 1995, the share of individual management regime is only 5%. In 2005 there are no significant change on the share of shareholding management and individual management. This result indicates that shareholding management is still the preferred mode of management for private shareholding tubewells.

5.3 Relationship between tubewell privatization and decline of groundwater table

We found that the privatization of tubewells has close relationship with decline of groundwater table. Our survey data show that when groundwater table is less than 28 m, the percentage of private tubewells to total tubewells is 18% (Table 5). However, when groundwater is higher than 28 m, the share of private tubewells increased to 30%. Such results indicate that with decline of groundwater table, farmers will make response to privatizing tubewells. A possible reason for this could be that private ownership gives better control over groundwater than access to collective tubewells, therefore, private tubewell will benefit the agricultural production. The problem of accumulating enough capital to invest in a tubewell is over come by the institutional mechanism of shareholding tubewells.

Table 5 The relationship between water table and tubewell ownership

Groundwater table	Sample size	Tubewell ownership /%	
		Collective	Private
12 - 27m	21	82	18
28 - 50m	19	70	30

Data source: Field survey conducted in sample villages in 1995 and 2005.

5.4 Effects of tubewell privatization on agricultural production

Our survey data show that the privatization of tubewells possibly induces changes in cropping patterns. Between 1995 and 2005 in the Qingyuan county villages, when the share of private tubewells increased from 19% to 56%, the share of wheat sown area under wheat declined by 35% and area under maize declined from 44% to 34% (Table 6). At the same time, the area devoted to vegetables increased from 3% to 24%. In Mancheng County the privatization of tubewells resulted in similar shift in cropping patterns, but here instead of vegetables, area under fruit crops increased from 19% in 1995 to 28% in 2005. This is because being partly a hilly county, fruit crops are the main cash crop in this county. Our results imply that with declining of groundwater table, farmers will make response to increase the sown areas of high value crops, especially for horticultural crops such as vegetables and fruits.

Table 6 Relationship between the privatization of tubewells and cropping patterns and yields

	Total number of tubewells	Share of private-owned tubewells /%	Share of sown area under /%				Crop yield /(kg/ha)	
			Wheat	Maize	Fruit	Vegetable	Wheat	Maize
Qingyuan								
1995	570	19	45	44	0	3	551 3	588 8
2005	980	56	35	34	0	24	615 0	690 0
Mancheng								
1995	332	15	36	36	19	0	525 0	658 5
2005	234	30	30	34	28	0	535 5	651 8

Data source: Field survey conducted in 20 villages in Baoding district in December 2006

Similar to the possible relationship between the privatization of tubewells and cropping patterns, there are possible some positive relationship between the privatization of tubewells and crop yields (Table 6). For example, in Qingyuan County, from 1995 to 2005, wheat yield increased from 5513kg/ha to 6150kg/ha, and maize yield increased from 5888kg/ha to 6900kg/ha. At the

same time, the share of private-owned tubewells increased from 19% to 56%. We also can find the positive relationship between the privatization of tubewells and crop yields in Mancheng County. Since agricultural production (such as cropping patterns and crop yields here) are also influenced by other factors, in order to identify the real relationship between the privatization of tubewells and agricultural production, we also need to establish the econometric model to control the effect of other factors on agricultural production. Even so, our descriptive statistics results here are consistent with the findings by Wang *et al*[9].

6 Summary and policy implications

The purpose of this paper is to examine the development and emerging problems of groundwater resources, and farmers' responses to the changes of groundwater management through privatizing tubewells in the rural areas of Hebei Provinces. Our results show that groundwater is the most important source in the Baoding City and agriculture is the major water user. The development of groundwater resources can be divided into three stages. Farmers started digging tubewells in the early 1950s and accelerated the development since the early 1970s. After the mid 1980s, the tubewells continued to increase with emerging of some environmental problems. Due to development of tubewells, the shallow groundwater was not enough and farmers have to turn to explore deep groundwater resources. Groundwater table in the study area has declined gradually over time, from 1995 to 2005, the annual average groundwater table decline about 0.9 m in both Qingyuan and Mancheng counties. In some areas of intensive groundwater exploitation (mainly in the city areas), cones of depression have been formed.

With development of groundwater resources and resulted drop of groundwater table, farmers have made responses by privatizing the tubewell ownership and management. From 1995 to 2005, the share of private owned tubewells increased from 18% to 51%, which becomes the dominate pattern of tubewell ownership. Within the private sector, shareholding tubewells is the major type of tubewell ownership. With the change of tubewell ownership from collective to private, the management regimes of tubewell also have changed from collective to private. Based on descriptive analysis, we found that the privatization of tubewells has close relationship with decline of groundwater table. The privatization of tubewells possibly induces changes in cropping patterns, increasing the sown areas of high value crops (such as vegetables and fruits). We also found some possible positive relationship between the privatization of tubewells and crops yield.

Our results imply that it is urgent to control over-exploitation of groundwater in the rural areas of Hebei Province. Investing in better understanding of groundwater resource availability is necessary and the volume of abstraction should be kept within the limit set by total availability. Construction of deep tubewells should be closely monitored and stopped if needed, because these contribute to over-exploitation of the deeper aquifers which are quite difficult to recharge. When designing the management policies of groundwater resources, policy makers need to understand how farmers have made response to the changes of groundwater use and results environmental issues. One effective policy is that the positive response of farmers to manage groundwater and keep the sustainable development of groundwater resource and socio-economy should be used.

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地下水资源利用的演变与农民的机井私有化反应：来自于河北农村地区的实证研究

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摘要：论文的目的是调查水资源利用状况，分析地下水资源在使用过程中存在的问题以及农民通过机井私有化而改变水资源利用的一些反应状况。研究以河北省农村地下水资源利用为例，论文中所用到的数据主要来自2006年在河北省随机调查的20个村。研究结果表明，河北农村地下水资源的利用主要分为3个阶段：20世纪50年代早期，农民开始打井利用地下水资源；从70年代开始，地下水资源的利用进入了加速期；而80年代中后期，地下水资源被过度利用，随着机井数量的继续增加，一些环境问题不断出现，例如水位的下降等。研究发现，伴随着水位的下降，农民也逐渐做出了适应性反应，他们开始将一些机井的所有权和管理权私有化。而机井的私有化将导致高附加值的作物面积增加(例如，蔬菜和水果等)，同时机井的私有化也同作物产量提高之间还存在着积极的关系。最后，研究提出，在设计地下水资源管理政策时，政策制定者需要充分掌握农民的反应，通过正确引导农民的反应提高水资源使用效率。

关键词：地下水资源；发展；问题；机井私有化；河北农村地区