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J China Univ Mining & Technol 2007, 17(1): 0085 - 0089

Geological Environment Problems Caused by Controlling Groundwater Exploitation in Jiangyin City

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Abstract: Geological environment effects caused by the control of groundwater exploitation in Jiangyin city are discussed thoroughly, including the dynamic variation of groundwater levels and quality and the development of land subsidence and ground fissures. According to the dynamic characteristics of groundwater levels, some advice about groundwater exploitation is offered. Our research will provide a basis for using groundwater resources and the prevention of geological disasters in Jiangyin city and the Suzhou-Wuxi-Changzhou area. The following results are deduced from our research. First, groundwater levels vary with the exploitation of groundwater in Jiangyin city and are affected by hydrogeological conditions. The groundwater levels remained rather stable before and after the implementation of control of groundwater exploitation in the northwest of Jiangyin city along the Yangtze River. A suitable level of exploitation should be allowed. In the southeast, the speed of recovery of the groundwater level has been rather rapid after the control of exploitation. We conclude that groundwater might be exploited locally after the groundwater level has recovered. In the southwest, the speed of recovery of the groundwater level is rather slow and exploitation of groundwater should be prohibited. Second, groundwater quality is stable in Jiangyin city and the contents of the main chemical indices of groundwater varied only slightly before and after the control of exploitation. Third, after controlling the exploitation, the speed of land subsidence has clearly slowed down and the development of ground fissures has been controlled effectively.

Key words: controlling groundwater exploitation; dynamic effects; geological environment effects; Jiangyin city
CLC number: X 143

1 Introduction

Groundwater levels have declined significantly owing to long-term over-exploitation in the Suzhou-Wuxi-Changzhou area, which caused some environmental geology problems[1-2], such as land subsidence, ground fissures and deterioration of groundwater quality. To the south of Jiangyin city a serious land subsidence has developed, which has become a depression area[3-4]. In order to protect limited groundwater resources and completely solve the environmentally challenging geological problems caused by over-exploitation of groundwater, deep ground- water exploitation in the area of Suzhou-Wuxi-Changzhou was prohibited.

Long-term over-exploitation of groundwater is the main extrinsic factor causing land subsidence and ground fissures. Many investigations focused on the effects of exploiting groundwater on land subsidence and ground fissures[3-6], the mechanisms for land subsidence[7-8] and establishing interrelated models[9-10]. Only a few studies were conducted about the effect of controlling the exploitation of groundwater and on controlling the development of land subsidence and improving the geological environment. The prohibition of groundwater exploitation will be helpful for controlling the development of land subsidence and ground fissures, but it is not a scientific method[11]. In order to evaluate efficiently its effect and practicability, the environmental effects in geo-

Received 11 May 2006; accepted 09 July 2006
Projects 2002CB412702 supported by the Special Funds for Major State Basic Research Projects of China and KZCX2-YW-113 by the Special Funds of Research Innovation Projects of CAS
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logical terms caused by controlling the exploitation of groundwater were investigated in Jiangyin city by studying the dynamic change in the level and quality of groundwater and the development of land subsidence and ground fissures. A reasonable evaluation on controlling groundwater exploitation in Jiangyin city will be given, which will provide bases for using groundwater resources and preventing geological disasters in the Suzhou-Wuxi-Changzhou area.

2 History of Groundwater Exploitation and the Process of Sealing Wells

Deep groundwater has been exploited since the 1980s,. There were 21 deep wells in Jiangyin city in 1984, distributed over more than ten villages and towns. Since then, with rapid industrialization and improvement in the standard of living of people, the demand for water has increased. There were 140 wells for exploiting deep groundwater in 1990. In the 1990s, the scale of deep groundwater exploitation had reached a climax; the number of new wells had increased to an average of 50 wells each year; in 1994, the number reached 82. Little by little, groundwater exploitation began to be controlled in Jiangyin city by 1995, which slowed down its accelaration.. Since 1998, the Jiangyin government has enhanced its management of groundwater exploitation and exploitation began to reduce slowly. Because of unsustainable groundwater exploitation over long periods, the groundwater level continued to decline, which caused some environmental geology problems, such as land subsidence, ground fissures, deterioration of groundwater quality and so on. In order to solve these problems completely, the Jiangyin government began to forbid the exploitation of deep groundwater. The last deep groundwater well was sealed on Sept. 2, 2005. During the period from 2001 to 2005, a total of 465 wells were sealed off and the exploitation of deep groundwater declined from 2 945×10^4 m^3 in the end of 2002 to about zero in the end of 2005 (see Fig. 1).

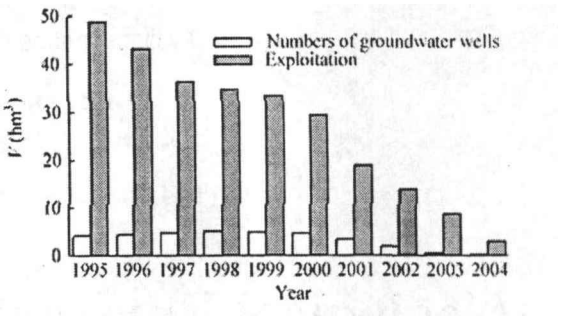

Fig. 1 Development of groundwater exploitation in Jiangyin city

3 Dynamic Effects on Groundwater After Control of Exploitation

3.1 Dynamic variation in groundwater level

Pore water in a loose rock mass is the main source of groundwater in the area, which is divided into a phreatic aquifer, the first confined aquifer, the second confined aquifer and the third confined aquifer. It is the second confined aquifer which has experienced the greatest exploitation in Jiangyin city and therefore the dynamic variation of its water level has largely been studied in our research. As the main exploited aquifer in Jiangyin city, its water level is controlled mainly by exploitation, but because of its variable hydrogeological conditions, there are clearly different dynamic characteristics at play in the south and the north of the area. Owing to the lateral supply of the Yangtze River water, the groundwater level declines slowly and is rather stable in the north for years (Fig. 2 a). In the south, because of the shortage of ground water supplies, the water level declined rapidly due to a long-term extra-exploitation over a number of years, at a speed of more than 3 m/a in most areas. Since 1998, the Jiangyin city government has enhanced its management of groundwater exploitation and the extra-exploitation was controlled effectively. Especially after beginning to implement its prohibition of deep

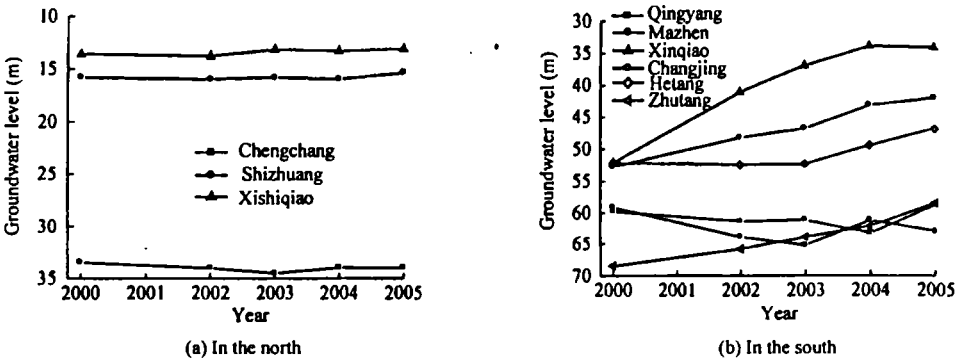

Fig. 2 Variation of groundwater levels in Jiangyin city

groundwater exploitation, the water level of the second confined aquifer has, on the whole, recovered slowly in the south (Fig. 2b).

Given recent dynamic changes of groundwater levels in Jiangyin city, except for a few zones,, the water levels are recovering rather quickly, such as in Xin-

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qiao. In most areas, the speed of recovery of water levels has exceeded people's expectations. The reason for this is that the recovery of groundwater levels is controlled not only by exploitation but also by regional hydrogeological conditions. We provide a detailed explanation.

First, Xinqiao town is located in the border region of Jiangyin city and Zhangjiagang city and easyly supplied laterally by high water levels in the zone along the river of Zhangjianguang city and the bedrock mountain water in the northeast. Moreover, the slightly confined aquifer above the main exploited aquifer is thick, which supplies the lower aquifer intensively. So the speed of recovering of the water level in Xinqiao area is clearly more rapid than that in other areas.

Second, in the area along the river in the northwest of the city, the Quaternary loose sandstone aquifer is very thick with rich groundwater and easily supplied laterally by water from the Yangtze River. The intensity of groundwater exploitation is rather low and the groundwater depth is shallow in the area along the river. The water level is obviously affected by intensive exploitation and the depression cone of groundwater in Changzhou city to the south. That is to say that the water depth increases continuously from the zone along the river to the south. At present, the water level is recovering rapidly in the center of the cone in Changzhou city, but in the areas affected, like Jiangyin city, the speed of recovery of the water level is rather slow. All this shows that the water level is rather stable in this area.

Third, the groundwater was exploited intensively in the south of Jiangyin city in the past, which is the center of the groundwater depression cone in the study area. In this area, corridor type sediments were the main sedimentary facies of the ancient stream channel of the Yangtze River during the Middle Pleistocene. This sedimentary region was clearly controlled by bilateral bedrock. The thickness of the sandstone stratum gradually thinned from the center of the ancient stream channel to both sides and aquifers are clearly absent in front of the mountain. The sediment consisted of fine-grain clay soils during the Late Pleistocene and Holocene eras, with the result that the main exploited aquifer only slowly and difficulty recharged. Because of the long-term extraexploitation of groundwater, a condition called a "runoff pattern" exploitation had formed in local areas. Because the supply source is extremely limited, it is difficult for water levels of aquifers to recover rapidly in a short time after the implementation of control of groundwater exploitation.

In short, the hydrogeological conditions are good in the area along the river in the northwest of Jiangyin city, where the water level is rather stable with a rich recharge from the Yangtze River. The water level is only slightly affected by the variation in groundwater exploitation, so that appropriate exploitation should be allowed. But exploitation of groundwater should still be controlled in the north, where karst water develops. The speed of recovery of groundwater levels has been quick after controlling the exploitation in the southeast, approaching Zhangjiagang city, which shows that the supply conditions are good in the area. So groundwater may be exploited locally after the water level has reached 20 m. Exploitation should be prohibited in the center of the groundwater level cone to the southwest approaching the Xishan area.

3.2 Dynamic variation of groundwater quality

In order to understand completely the quality of deep groundwater in Jiangyin city, 16 groundwater samples were collected for water quality testing in August 2005, including four samples from the first confined acquiver, seven from the second confined acquiver and five from bedrock water. Conventional items and five toxic substances were analyzed. The results indicate that the quality of deep groundwater meets Chinese health criteria for drinking water; only a few samples with abnormal values of ferrum ions and fluoride in different water sources were found.

Because of a lack of monitoring data of groundwater quality in Jiangyin city over time, the test results were compared with the results in the report on the investigation and evaluation of groundwater resources in Jiangyin city in March, 1998. The result shows that groundwater quality is rather stable in most areas in Jiangyin city and affected only slightly by the exploitation of groundwater except that partial indices changed slightly in the local area (Table 1).

4 Land Subsidence

Land subsidence is caused mainly by long-term extra-exploitation of groundwater in Jiangyin city, which is closely related with groundwater exploitation. There are clear spatial and temporal relations between them. Before 1985, the exploitation of groundwater was small and land subsidence not obvious. From 1985 to 1995, when the number of wells and the exploitation of groundwater increased sharply, the land subsidence developed rapidly and the speed of subsidence exceeded 100 mm/a in most towns. Since 1995, the exploitation of groundwater has been controlled and the rapid decline of the groundwater level was arrested, but the level continued to decline slowly. The speed of subsidence was more or less reduced, but still continued at about 50 mm/a. After the prohibition of groundwater exploitation, started in 2001, exploitation reduced rapidly and the groundwater level, in general, began to recover.. The subsidence speed also began to decline, but because of a delayed effect, it will still continue over a period of time. In order to understand the trend in development of land subsidence over time, advanced GPS tech-

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Table 1 Comparison of groundwater quality of main exploited aquifers in Jiangyin city

Test items		Normal value (mg/L)	Range of content (mg/L)	
			1998	2005
General chemical indices	pH	6.5–8.5	7.8–8.9	7.4–8.5
	Total hardness	<450	21–454	142–279
	Total dissolved solids	<1 000	256–1194	404–698
	Cl^-	<250	6.3–376	15.5–50.3
	SO_4^{2-}	<250	0.36–160	<1–4.74
	Fe	<0.3	0.004–1.16	<0.02–0.48
	F^-	<1.0	0.1–0.95	0.53–2.35
Toxicology indices	Arsenic	<0.05	<0.005–0.015	0.001 9–0.004 6
	Cyanide	<0.05	<0.005	<0.005
	Phenol	<0.002	<0.002	<0.002
	Hydraryrum	<0.001	<0.000 2	0.000 092–0.000 18
	Sexivalent chrome	<0.05	<0.01–0.004	<0.001
Organic contaminants	NO_3^-	<20	0.004 4–0.15	<0.2–3.3
	NO_2^-	<0.02	0.000 3–0.004 5	<0.004
	NH_4^+	<0.15	<0.02–1.42	<0.02–0.17

nologies were applied to monitor land subsidence in Jiangyin city. The technique had been applied four times, respectively in June 1999, May 2000, June 2002 and July 2005. According to the four monitoring results, the speed of subsidence has been reduced to a large extent in most areas to the south of Jiangyin city since 2002 and had begun to reduce in a few local area already in 2000. The rebound of ground elevations occurred in some northern areas along the Yangtze River such as in Shengang and Shizhuang, which indicates two different effects. One is the delaying effect of land subsidence. The other is that the land subsidence is caused primarily by elastic deformation of the sand stratum in the north along the river, which will rebound when the water level has been restored and the effective stress between the sand grains has receded.

The center of the land subsidence cone is located in the Mazhen area in the south of Jiangyin city. Fig. 3 shows the cumulative value and speed of land subsidence in Mazhen town over 25 years. The figure indicates that land subsidence has developing in the area since the 1980s, whose cumulative value exceeded 1300 mm in 2005. The speed of subsidence increased continually from 1986 to 1994, but has declined since 1996; after 2002 the speed was about

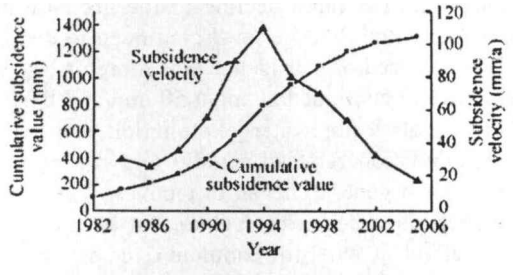

Fig. 3 Cumulative value and speed of land subsidence in Mazhen town

equal to that before 1986. Variations in the speed of subsidence were affected by the control of groundwater exploitation in Jiangyin city. Land subsidence in the center of the cone has basically been under control.

Fig. 4 shows the distribution of the speed of land subsidence in Jiangyin city from 2002 to 2005. It can be seen that, at present, the subsidence speeds are smaller than 10 mm/a in most areas of Jiangyin city. The values are larger in the south, about 20–40 mm/a, but these are still far smaller than the values before the control implementation. Clearly, owing to the control of groundwater exploitation, the speed of land subsidence has been reduced markedly and the trend of a worsening geological environment has also been arrested in Jiangyin city.

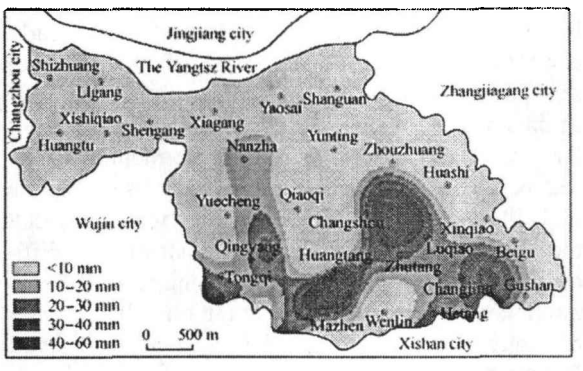

Fig. 4 Distribution of land subsidence speed in Jiangyin city from 2002 to 2005

5 Ground Fissures

Ground fissures were found in three areas of Jiangyin city, Changjing, Hetang and Zhutang, which have caused enormous economic losses in Jiangyin city, especially in the three towns.

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In 1995, ground fissures began to occur in Changjing town, which developed rapidly in 2000. According to local statistics, 387 houses were endangered by ground fissures in Changjing town and a further 336 houses were slightly endangered. Two bridges, Renmin Bridge and Xiayao Bridge, were damaged. Many roads were damaged and underground pipelines were destroyed to different extents. The direct economic loss was about 11 million RMB and indirect losses exceeded 121 million RMB.

Ground fissures began to occur in Hetang town towards the end of 1995 or at the beginning of 1996 and developed rapidly in 1998. Because the ground fissures were concentrated in the north of the town where large numbers of buildings are situated, the damage caused was enormous. The direct economic loss amounted to 10 million RMB.

Ground fissures began to occur in Zhutang town in 2001 and developed rapidly in 2002. According to an investigation, more than ten houses were damaged by ground fissures and three seriously damaged houses were demolished.

Ground fissures resulted from asymmetric land subsidence in Jiangyin city, which was caused by intensive groundwater exploitation and affected by specific environmental geology conditions. It could be thought of as a new deteriorating form of land subsidence, which occurred in some special places. It was a disastrous development of land subsidence. Since groundwater exploitation was controlled in 2001, the land subsidence has been effectively arrested. The speed of subsidence decrease from 60–100 mm/a to 20–30 mm/a in Changjing, Hetang and Zhutang after controlling groundwater exploitation. The speed of asymmetric subsidence has also reduced, which prevents further development of ground fissures. At present, the ground fissures are still developing, but in the last few years no new ground fissure disaster spots have been found. The speed of development of the three existing ground fissures has reduced gradually and damages to houses and roads did not recur. This shows that the development of ground fissures has been effectively arrested by controlling groundwater exploitation.

6 Conclusions

First, groundwater levels in Jiangyin change with the exploitation of groundwater and is affected by hydrogeological conditions. Groundwater levels remained rather stable before and after controlling its exploitation in the northwest along the Yangtze River, so suitable exploitation should be allowed. But groundwater exploitation should continue to be controlled in the north where karst water develops. The speed of recovery of groundwater levels was rapid after controlling the exploitation in the southeast towards Zhangjiagang city. Groundwater may be exploited locally after the groundwater level has reached 20 m. The speed of recovery of groundwater levels was rather slow in the southwest towards the Xishan area, so exploitation of groundwater should be prohibited. Second, groundwater quality is good and stable in Jiangyin city and the contents of main chemical indices of groundwater vary slightly after implementing control of exploitation. Third, after controlling exploitation, the speed of land subsidence has clearly slowed down and the development of ground fissure has been effectively arrested.

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