Decline of groundwater table and evolution of groundwater-overdraft regions in Linqing city

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Abstract. Groundwater is an important source of water, and continuous exploitation of groundwater makes groundwater over-exploited. Over-exploitation causes many environmental and geological problems, which will affect the stabilization of society and the healthy development of economic. This paper investigated the temporal and spatial variation of groundwater level and the area of over-exploitation and provide some measures to prevent the aggravation of groundwater. The results found that the groundwater level decreased obviously with time, and the groundwater funnel formed in 1990 in the study area. The groundwater overexploitation has become an unavoidable problem for the study area, Linqing city in Shandong. The government policymakers should pay more attention to the groundwater overexploitation problem.

1. Introduction
Groundwater plays an important role in the development of the regional social economy. With the rapid development of social and economic, the explosion of population and the development of industry and agriculture, more and more groundwater is being extracted, which leads to over-exploitation of groundwater. The universality and growing severity of over-exploitation of groundwater have drawn the attention and interest of many researchers and administrators around the world [1-2]. Because of over-exploitation of groundwater, surface subsidence occurred in all the 50 states in the United States in 1995 [3]. The Po Delta, Tokyo and Mexico also suffered serious ground subsidence due to over-exploitation of groundwater [4]. In China, the total area of over-exploited was 180,000 km² in the late 1990s [5]. Based on relevant statistics, over 100 large scale groundwater descent funnels have formed, with the over-exploitation area covering an area of over 620,000 km² in recent years [6]. Several studies have reported different ways to solve and alleviate the groundwater over-exploitation problem. Some researchers found that artificial recharge of groundwater can increase groundwater level significantly in the depression cone and depression area of the shallow groundwater in the city [7-8].

Forming or groundwater over-exploitation problem was affected by many factors, including agriculture, industry, climate condition and hydrogeological environment and so on. Hence, the forming of groundwater funnel in different areas depends on different reasons. Therefore, to investigate and figure out the cause of groundwater funnel formation and its spatial and temporal variation of groundwater level is of great significance for putting forward solving measures. Moreover, to determine and analyse the scope of over-exploitation area is very important for developing and using groundwater scientifically, as well as preventing environmental and hydrogeological problems.

2. Materials and methods
2.1 study area
The study area, Linqing city is located in Shandong Province (Figure 1), China. It extends from 115°27′E to 116°02′E longitude and 36°39′N to 36°55′N latitude with a total area of 957 km². The study area has a warm, temperate, semi-humid monsoon continental climate, with distinct seasons and abundant sunshine. Annual average precipitation is 532.2 mm and the annual average temperature is 13.1°C. The precipitation varies greatly between years, with the alternation of high flow years and low flow years. The regional distribution of precipitation is uneven, and precipitation mainly occurs from July to September in the study area. There are two main water systems in Linqing city, namely Tuhai River and Majia River, both of which belong to Haihe river basin.

Linqing city located in the Weishan Irrigated District, which belongs to the Yellow River flood plain. Aquifer formations can be classified into the following three types from top to bottom: (1) Upper shallow freshwater phreatic and slightly confined aquifer group. The lithology of the aquifer is fine sand, fine sand and sandy clay interbedded. The depth of the aquifer floor is generally around 25-60 m, and the aquifer permeability coefficient is around 12.45-17.00. (2) Middle and deep brackish water (confined water) aquifer group. The depth of the aquifer floor is generally around 60-250 m. The aquifer is mainly filled with brackish water with salinity of 2-5 g/L. This aquifer is not exploited because of a high degree of mineralization of deep groundwater. (3) Deep confined freshwater aquifer group. Aquifer lithology is fine sand, fine sand, some places appear medium sand, coarse sand.

In the study area, irrigation and precipitation are the main sources to shallow groundwater. There are two major ways of groundwater discharge, evaporation and groundwater exploitation. Shallow groundwater is one of the important water resources for industrial, agricultural, and domestic use. Agriculture consumes the largest part of water resources, main using for irrigation, which is about 90 percent of all and domestic use followed.

2.2 Materials and Methods
In this study, a total of 41 monitor stations were used for groundwater level observation during 1974 and 2012. Groundwater level depth has been measured via a water level logger monthly. Interpolation of embedding depth was carried out by ordinary kriging method.

Figure 1. Location of the study area and the groundwater monitor sites

3. Results and discussion
3.1 Annual changes in groundwater overexploited areas

The variations of groundwater depth and the area of groundwater overexploited with time from 1972 to 2012 are shown in Figure 2.

The variation of groundwater table depth and precipitation with time was shown in Figure 2a. As shown in the Figure 2a, groundwater table depth increased obviously from 4 m (in 1974) to 8 m (in 2012). Based on the correlation analysis, the result found that groundwater table depth did not have good correlations with precipitation. The increase of groundwater table depth was mainly owing to groundwater extraction. The average annual rate of water table decline was around 0.14 m/a.

There are four main reasons for the formation of groundwater funnel. Firstly, the shortage of surface water resources was serious. Based on the statistics, the average utilization rate of surface water was only 12.3% from 2001 to 2012. The data showed that the utilization of surface water seemed under-exploited, which was one of the reasons for groundwater over-exploration in the study area. Secondly, agriculture was the pillar industry in the study area. The flood irrigation method aggravates the water shortage problem. Thirdly, the continuous improvement of people’s living standards, coupled with the residents’ weak awareness of water conservation, both led to the continuous expansion of water demand for urban life and service industry, and resulted in serious water shortage. Extreme weather and climate change were another reason for water scarcity and groundwater extraction.

As shown in Figure 2b, the result showed that the changes of the overdraft area of groundwater were not stable. It mainly changed with a fluctuating growth trend. The overdraft area of groundwater has existed since 1974, and generally expanded with time. It increased to 700 km$^2$ in 1992, and increased to 900 km$^2$ in 2003. Once it passed 2003, it began to decrease. The overdraft area of groundwater decreased to around 500 km$^2$. The largest value (920 km$^2$) was found in 2003, and the lowest value (140 km$^2$) was found in 1980. The area of funnel area increases by 13.9 km$^2$ annually on average. In general, the overdraft area of groundwater was largely related to the variation of groundwater table depth during 1972 and 2012.

3.2 Changes in groundwater table depth in one year

The changes of groundwater table depth in the year of 1976, 1980, 1990, 2000 and 2011 at the Daxinzhuang observation station were shown in Figure 3. The variation trends in the groundwater table depth were similar for different years. As shown in figure 3, groundwater table depth changed slightly from January to March. And it slowly increased from April to August. While it decreased slightly from August to December. For different years, the value of groundwater overexploited area varied, which was obviously higher in the year of 2000 and 2011 than those in the year of 1976, 1980 and 1990. The average groundwater table depth was between 27-28.5 m. The results indicated that groundwater table depth increased with time. Meanwhile, the groundwater table depth was largely depended on the fast development of society and economy and the continually rising of urbanization.
Figure 3 The variation trends in the groundwater level at Daxinzhuang observation station

3.3 Annual variation of groundwater contour maps
The annual variation of groundwater contour maps in 1976, 1980, 1990, 2000 and 2011 was shown in Figure 4. As shown in Figure 4, after the 1976, there was an obvious increasing trend of groundwater level depth, areas of groundwater over-exploited and funnel region. In the year of 1976, groundwater over-exploited region just scattered in small areas. After 1980, groundwater over-exploited region mainly existed in the urban areas and parts of the southwest of the city. Till to 1990, the groundwater over-exploited region continued to expand, and the area of funnel area was gradually increasing, and becoming the centre of Weidong funnel area. The funnel area was mainly owing to over-exploitation of groundwater, which was used for irrigation and industrial consumption.
Figure 4 Annual variation of groundwater contour maps (a)1976 (b)1980 (c)1990 (d)2000 (e)2011

4. Conclusions
In this study, the spatial and temporal variation of groundwater level depth and area of groundwater overexploited was discussed. The results showed that over-exploitation area in the study area has become more and more serious. The government policy makers should pay more attention on the groundwater over-exploited problem. A series of measures must be taken to control the spread of the area of groundwater over-exploited, such as water-saving irrigation, wastewater reuse and comprehensive reform of agricultural water prices.

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