A Brief Analysis of Land Subsidence Control Effect in Beijing-Tianjin-Hebei Region

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Abstract. This article describes the history and the hazard of land subsidence in Beijing-Tianjin-Hebei region, analyses the main inducement of land subsidence. And then, the change of land subsidence rate from 2015 to 2016 has been analysed. According to the analytic results, the land subsidence control effect in these two years in Beijing-Tianjin-Hebei region has been evaluated and the reasons of land subsidence changed has been analysed. At last, it points out the key measures in land subsidence control.

1. Introduction
Land subsidence refers to an environmental geological phenomenon that regional ground elevation is reduced due to the compression of crustal surface soil under the influence of natural and human factors. It is one of the important factors affecting the sustainable development of social economy [1,2]. Land subsidence in China is mainly distributed in the middle and eastern plain areas with relatively high level of economic and social development and relatively intense of human engineering activities, such as the North China Plain, the Yangtze River Delta, the Fenwei Basin, the Pearl River Delta, the Northeast Plain, the Huaihe Plain and other places, among which the North China Plain, especially the Beijing-Tianjin-Hebei region, is the area with the fastest development rate of land subsidence and the widest occurrence range [3, 4].

With the impact of global warming and the acceleration of urbanization, the influence of human factors on land subsidence is increasingly intensified, the harm caused by land subsidence is increasingly serious, and land subsidence management is also widely concerned. Taking Beijing-Tianjin-Hebei region as an example, this paper analyzes the key factors in land subsidence control, and analyzes the changes of land subsidence in Beijing-Tianjin-Hebei region from 2015 to 2016 and the reasons for the changes.

2. The history and hazards of land subsidence in Beijing-Tianjin-Hebei region
In the 1920s, land subsidence occurred in the Beijing-Tianjin-Hebei region which was slowly developing. Since the 1980s, land subsidence has expanded from point to surface and from urban to rural areas, and developed gradually in the areas with serious over-extraction of groundwater. The ground subsidence in Tianjin urban occurred in 1920s and became the earliest area of ground subsidence in North China plain. Land subsidence was also discovered in the Xidan to Dongdan area of Beijing in 1935. From the mid-1960s to the mid-1980s, land subsidence in the Beijing-Tianjin-Hebei region as a whole entered a period of rapid development. From the mid-1980s to the mid-1990s, due to the different management measures of groundwater extraction in different regions, the development of land subsidence showed regional differences. After the mid-1990s,
regional differences in land subsidence were still significant. According to the data, the accumulated subsidence of Tianjin Plain since 1958 is over 1m with an area of over 4000km$^2$, and part of it is over 3m.

As a kind of slow geological disaster, land subsidence is mainly manifested as the loss of ground elevation, which is easy to cause a series of problems such as foundation subsidence, building cracking, underground pipeline damage, well pipe lifting, flood and storm surge, and has the characteristics of long formation time, wide range of influence, difficult prevention and treatment, and difficult recovery. The rapid development of land subsidence seriously threatens the safety of people's life and property.

3. Analysis of the cause of land subsidence in Beijing-Tianjin-Hebei region

The land subsidence in Beijing-Tianjin-Hebei region is affected by many factors, and the stratum is the geological foundation of land subsidence. The strata in the Beijing-Tianjin-Hebei region are composed of Quaternary loose deposits, and the physical properties of the lithology determine that the strata are highly compressible. Several subsidence centers in the Beijing-Tianjin-Hebei region as well as areas with rapid development of land subsidence in recent years have a good correlation with the spatial distribution of compressible layer thickness\cite{5, 6}. Deep groundwater funnel in the Beijing-Tianjin-Hebei region are mainly distributed in the east-central plains, and three deep groundwater funnels have been formed in Langfang-Tianjin, Cangzhou and Hengshui-Dezhou. In the last 40 years, the water level in the deep layer has dropped significantly, and the area of serious land subsidence in the eastern plain of Beijing-Tianjin-Hebei is very consistent with the distribution of the ground water funnel in the deep layer (figure 1), which indicates that the over-extraction of ground water in deep layer is the main inducing factor of the land subsidence in this area.
The land subsidence is closely related to the recharge and discharge conditions of groundwater. The recharge conditions of deep confined water in Cangzhou and other places in the east-central plain are poor, which further aggravates the development of surface subsidence. The amount of water extracted from deep confined water in the Beijing-Tianjin-Hebei region, except for a certain amount of lateral recharge in the piedreland area and a small amount of over-recharge in the non-saline water covered area, is mostly used from storage resources, which is also the main inducing factor for the formation of ground subsidence [4] (figure 2).
In addition, weak unconsolidated soil layers of neritic facies and lacustrine facies are widely distributed in the coastal area of the Beijing-Tianjin-Hebei plain. Under the action of external forces such as sea reclamation and land reclamation, these soft soil layers will consolidate and drain and cause land subsidence.

4. Evaluation of the effect of land subsidence control in Beijing-Tianjin-Hebei region

Land subsidence rate refers to the decrease of surface elevation over a period of time. Normally, land subsidence rate refers to the settlement of a point in one year, in millimeters per year. The variation of land subsidence rate refers to the variation of subsidence rate in a certain period of time, which directly reflects the effect of land subsidence treatment in a certain period of time. Therefore, the land subsidence rate variation in the Beijing-Tianjin-Hebei region from 2015 to 2016 was selected to evaluate the land subsidence control effect in recent years.

The velocity variation diagram is obtained by subtracting the subsidence rates in 2016 and 2015, that can be seen from figure 3, the areas where the land subsidence rate increased (variation value<0) in 2016 were mainly located in the central part of the Beijing-Tianjin-Hebei plain, and the areas where the subsidence rate increased significantly were mainly located in the northwest of Cangzhou, the southeast of Shijiazhuang, the north of Xingtai, the southwest of Hengshui, the northeast of Baoding and the southeast of Baoding. The areas where land subsidence rate decreases (variation value > 0) are mainly located in the southwest of Cangzhou, the northeast part of Hengshui city, the north part of Cangzhou city and the south part of Xingtai city.

According to the spatial analysis of the velocity variation diagram, the area statistics of different variation values are shown in table 1 (Negative values indicate that the land subsidence rate is increasing). The area of the area where the land subsidence rate increases is about 31,847 km² from 2015 to 2016, and the area of the area where the rate decreases is about 56,618 km². Therefore, from a regional perspective, land subsidence in 2016 was somewhat slower than that in 2015.
Table 1. Area statistics of land subsidence rate variation (2015-2016)

| Variation value (mm/a) | Area (km²) | Total (km²) |
|------------------------|------------|-------------|
| -40--30                | 38.50      |             |
| -30--20                | 610.42     |             |
| -20--10                | 6,291.76   | 31,847      |
| -10-0                  | 24,906.39  |             |
| 0-10                   | 36,943.85  |             |
| 10-20                  | 13,404.84  |             |
| 20-30                  | 4,755.28   | 56,618      |
| 30-40                  | 1,490.94   |             |
| 40-50                  | 23.37      |             |

According to figure 3, the treatment effect of land subsidence in Beijing-Tianjin-Hebei region is divided into four grades: excellent treatment effect (land subsidence rate variation >10mm), good treatment effect (10mm>land subsidence rate variation >0), general treatment effect (-10mm<land subsidence rate variation <0) and poor treatment effect (land subsidence rate variation < -10mm).
Table 2. Area statistics of land subsidence treatment effect

| Treatment effect | Area (km²) |
|------------------|------------|
| Excellent        | 19,674     |
| Good             | 36,944     |
| General          | 24,906     |
| Poor             | 6,941      |

5. Cause analysis of land subsidence change in Beijing - Tianjin-Hebei region from 2015 to 2016

According to the data of water resources bulletin of Beijing, Tianjin and Hebei from 2015 to 2016 [7,8,9] (table 3), 2015 was a year of flat water and 2016 was a year of abundant water. In terms of the distribution of surface water resources and groundwater resources, the allocation in 2016 is much larger than that in 2015. In 2016, the inflow of south-to-north water diversion also increased compared with 2015. At the end of 2016, the average depth of shallow groundwater was lower than that in 2015, and the groundwater level rose.

Table 3. Distribution of water resources in Beijing-Tianjin-Hebei region (2015-2016)

| Rainfall (mm) | Surface water resource ($10^8$m³) | Groundwater resource ($10^8$m³) | Water from the south-north water diversion project ($10^8$m³) | Average depth to groundwater (m) | Total water supply ($10^8$m³) |
|---------------|----------------------------------|---------------------------------|-------------------------------------------------------------|--------------------------------|-----------------------------|
| 2015          | 2016                             | 2015                            | 2016             | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| Beijing       | 583                              | 660                             | 9.3              | 14.0 | 17.4 | 21.1 | 8.8  | 10.6 | 25.8 | 25.2 | 38.2 | 38.8 |
| Tianjin       | 536.2                            | 622.1                           | 8.7              | 14.1 | 4.1  | 4.8  | 4.0  | 8.9  | 25.7 | 27.2 |
| Hebei         | 510.8                            | 595.9                           | 50.9             | 105.9| 84.2 | 102.4| 1.5  | 3.6  | 17.5 | 17.3 | 187.2| 182.6|
| Total         | 689.8                            | 134.1                           | 105.7            | 128.2| 143  | 23.1 | 251.1| 248.6|      |

To sum up, the amount of precipitation, surface water resources and the inflow of the south-to-north water diversion project in 2016 were all larger than that in 2015, while the total water supply was slightly less than that in 2015. Therefore, it is speculated that the total groundwater exploitation in 2016 was less than that in 2015, which made the groundwater level rise in 2016 and the ground subsidence relieved.

In addition, the problem of groundwater over-extraction in Hebei province has attracted the attention of the CPC Central Committee, the State Council and related ministries, and under the guidance of the no.1 document of the CPC Central Committee in 2014, "carrying out comprehensive management of the overdraft funnel area of groundwater in north China", relevant ministries and commissions of the state have organized the implementation of the pilot project for comprehensive treatment of groundwater over-extraction in Hebei province, which will last for three years (2014-2016). By reducing the planting area of winter wheat, implementing water saving irrigation in well irrigated area, closing the well of groundwater exploitation, and other measures, the comprehensive treatment of overdrawn groundwater areas was implemented. With the action of multiple means, the total reduction of groundwater extraction in Hebei province was 539 million m³ in 2015 and 1.464 billion m³ in 2016 (figure 4). From 2015 to 2017, the total amount of groundwater extraction in Hebei province increased year by year, which provided a possibility for land subsidence treatment in Hebei province, especially in the pressure mining test area.
The data of groundwater over-extraction treatment in Hebei province showed that the groundwater level in the pilot areas (Cangzhou, Hengshui, Xingtai and Handan) rose as a whole. 2015 was a dry year. The shallow underground water level in the test area decreased by 0.28m, while the deep underground water level increased by 0.22m. 2016 was a wet year. The shallow groundwater level in the pilot area rose 0.59m, and the deep groundwater level rose 0.70m. In general, the trend of the continuous decline of the groundwater level in the test area has been effectively contained, and the groundwater level in wet years has an overall trend of rising, which makes the rate of land subsidence in the region decrease, and is also the main reason for the slight subsidence and rebound pattern of land subsidence in Cangzhou, Hengshui and other local areas.

6. Conclusion
Overexploitation of groundwater is the main external cause of land subsidence in the Beijing-Tianjin-Hebei region. Based on the analysis of the land subsidence rate variation data in the Beijing-Tianjin-Hebei region, it is found that the land subsidence treatment effect in 2016 is significant and the rapid development trend of land subsidence has been curbed. Therefore, increasing precipitation, reducing groundwater exploitation and raising groundwater level are the most direct and effective ways to control land subsidence.

Acknowledgments
This work was supported by the projects: China Geological Survey (Grant No. DD20190679), and the National Natural Science Foundation of China (Grant No. 41572309).

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