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Urbanization and land subsidence in China.

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Abstract: Land subsidence due to excessive groundwater exploitation is a type of regional geological hazard that develops slowly but has disastrous consequences. It is causing great economic loss and is proving difficult to control in China where over 50 cities are threatened by land subsidence, especially in the Delta region of the Yangtze River, the Northern-China Plain and the Fen-Wei River graben, where rapid urbanization is occurring. Since 1950, the total loss has reached 450~500 billions RMB (Chinese Dollars). The direct annual cost due to damage to structures and the infrastructure is about 0.8~1.0 billion RMB. The problems caused by subsidence include problems with drainage of low-lying areas, especially coastal regions, where flooding, saline intrusion to groundwater, and flooding of agricultural land are increasing in frequency. Due to the variable thicknesses of superficial deposits, subsidence in some areas is highly variable which gives rise to cracking of the ground and differential settlement problems, including the tilting and cracking of structures.

The paper describes the distribution, history and effects of subsidence in the different regions of China being affected by subsidence. Some success at reducing the rate of subsidence by stopping or controlling pumping and artificial aquifer recharge is described. In order to tackle this problem, a series of measures to be carried out over the next 10 to 15 years are suggested.

Résumé: L'affaissement de terre dû à l'exploitation excessive d'eaux souterraines est un type de risque géologique régional qui se développe lentement mais a des conséquences désastreuses. Il cause la grande perte économique et est s'avérer difficile à commander en Chine où plus de 50 villes sont par voie de terre menacé affaissement, particulièrement dans la région de delta du fleuve de l'Yang Tsé Kiang, la plaine de la Nordique-Chine et le fleuve de Marais-Wei graben, où l'urbanisation rapide se produit. Depuis 1950, la perte de total a atteint 450~500 les milliards RMB (dollars chinois). The direct annual cost due to damage to structures and the infrastructure is about 0.8~1.0 billion RMB. Les problèmes provoqués par affaissement incluent des problèmes avec le drainage des secteurs bas-menteur, particulièrement régions côtières, où l'inondation, l'intrusion saline aux eaux souterraines, et l'inondation de la région agricole augmentent dans la fréquence. En raison des épaisseurs variables des dépôts superficiels, l'affaissement dans quelques secteurs est fortement variable qui provoque fendre de la terre et des problèmes différentiels de règlement, y compris l'inclinaison et fendre des structures.

L'article décrit la distribution, l'histoire et les effets de l'affaissement dans les différentes régions de la Chine affecté par affaissement. Un certain succès à réduire le taux d'affaissement en arrêtant ou en commandant le pompage et de recharge artificielle de couche aquifère est décrit. Afin d'aborder ce problème, une série de mesures d'être effectué au cours des 10 à 15 années à venir est suggérée.

Keywords: subsidence, monitoring, pumping, urban geosciences, floods

STATUS AND TENDENCY OF LAND SUBSIDENCE

Land subsidence started in the cities of Shanghai and Tianjin in the 1920s, and was getting worse until the1960s when the Geological Survey identified the cause as over-pumping of groundwater. Since the 1970s, subsidence has affected a succession of major cities of the Yangtze Delta and the Northern China region, and extended to various other towns due to the increasing use of groundwater for agriculture, industry and domestic consumption. According to incomplete statistics, in the early 1990s the area affected by land subsidence was 48,700 km^2 in Shanghai, Tianjin, Beijing, Jiangsu, Zhejiang, Hebei and other provinces. In 2003, the land subsidence area had extended to 93,855 km^2 including severe subsidence zones in the Yangtze Delta, Northern China and Fen-Wei Graben. Over 50 cities including Shanghai, Tianjin, Taiyuan, Xi'an, Wuxi and Cangzhou have suffered over 2m of subsidence. The maximum subsidence is recorded as 3.1m in Tianjin. Ground fracture hazards occur in the subsidence area of Xi'an, Taiyuan, Cangzhou and Changzhou because the bedrock topography is uneven. Further details of the incidence and effects of subsidence in different parts of China are described below.

The Yangtze Delta Region

The Yangtze delta area, shown in Figure 1, is the most severely affected region for subsidence hazards. The subsidence started at Shanghai in the 1920s then extended to Suzhou-Wuxi-Changzhou of Jiangsu Province and Hangzhou-Jiaxing-Huzhou of Zhejiang Province in 1980. The area where total subsidence exceeds 200mm is 10,000 km^2 which is one third of the region. The amount subsidence in the central parts of Shanghai, Suzhou-Wuxi-Changzhou and Hangzhou-Jiaxing-Huzhou is 2.63, 2.8 and 0.82m, respectively.

In Shanghai, a monitoring network was established and the subsidence has been mitigated in the 1960s primarily by limiting pumping and using artificial recharge. But, since the 1990s subsidence in the downtown area has increased because the large-scale construction work has entailed the dewatering of excavations and also as a consequence of increased loading by about 5000 new high-rise buildings.

In Suzhou-Wuxi-Changzhou region of Jiangsu Province, the groundwater level of most boreholes is rising through the prohibiting of groundwater pumping, but the subsidence rate is still continuing at 20-40mm/a and, in places, up to 80-120mm/a. Since the mid 1990s, 20 new fractures have developed, the longest of which is over 3 km, in an area of differential subsidence controlled by the uneven bedrock topography.

In the Hangzhou-Jiaxing-Huzhou Plain, the area of subsidence is extending and several centres are present. The total subsidence was 828mm in 2000, with an average rate is 23mm/a from 1991 to 2003. In 2004 this had decreased to 14mm/a. Recently in the coastal zone of Zhejiang province, subsidence has increased rapidly due to over-pumping of groundwater. In 2002, the total in the Ningbo subsidence centre was 485mm, which affected an area of175km^2. while at it continues at a rate of 3 - 12mm/a. In the west of the Wenning Plain, the total settlement is 1300m in the centre, and the area with subsidence greater than 300mm is 36.45 km^2•which makes it the most severe hazard zone in Zhejiang Province.

The Northern China Plain

The Northern China Plain, including Tianjin, Cangzhou and north-eastern Beijing, is the most severely affected subsidence hazard zone in China. Subsidence in Tianjin started at 1920, and has been increasing so that the maximum subsidence is over 3.1m, the most in China. The subsidence mechanism is very complicated, especially, as the subsidence centre is moving towards the coastline where deep oil exploitation is also causing subsidence in an area of which more than 20km^2 is below sea level,. The region is adjacent to the Hebei Plain towards the west, which is affected by the groundwater depression cone due to over-pumping in the Northern Plain. Within recent years, a series of subsidence centres have fast developed in the rapidly expanding towns of Wuqing, Xiqing, Jinnan, Jinghai and Ninghe.

In the Hebei Plain, subsidence started in the 1980s and 9 centres have formed in Cangzhou, Baoding, Hengshui, Renqiu, Nagong, Bazhou, Dacheng, Quzhou and Tanghai cities. Groundwater levels have quickly fallen by several metres to over 100m. Subsidence greater than 200mm had affected an area of 48,550 km^2 in the Hebei Plain in 1998. In Cangzhou city, the most severe subsidence zone in Hebei Plain, the total subsidence is over 2250mm, and 20 fractures, the longest of which is 4 km, have formed. This is because of variation in the thickness and nature of the superficial deposits in an area of uneven the bedrock topography. Dezhou city, in Shandong Province has suffered subsidence of 150-387mm that affects an area of 2037km^2. At the subsidence centre, the average annual increase since the late 1970s is 25–32mm/yr. In Jining city, Shandong Province, the total subsidence is 210mm and the area with more than 60mm of subsidence is 90km^2 where this is increasing at nearly 50mm/yr in the centre of the area.

In the Beijing city, located in the north of the Northern China Plain, the subsidence and hazard are less than in other regions, but the potential hazard should not be ignored, especially the effects on high-rise buildings and key facilities that are sensitive to ground movements.

Major Cities in the Fen-Wei River Graben

Six basins are arrayed obliquely in the Fen-Wei river graben, a zone of strong tectonic activity in China. Due to variable of bedrock topography and over pumping of groundwater, a series of fractures have accompanied subsidence. Three zones of subsidence and fractures have formed in Xi'an, Datong and Taiyuan City.

Subsidence and fracturing has been occurring for 40 years so that in Xi'an city, over 150km^2 of the area has suffered 100mm of subsidence and the maximum rate of subsidence is 300mm/a. Seven centres with subsidence greater than 2000mm have developed, where the maximum is 2.6m. Thirteen fractures are present in an area of 155 km^2 in the subsidence zone. The total length of fractures is 103km and their strike is about 70°—80°, spacing is 1-1.5km and the vertical displacement rate is 5-35mm/a and maximum 50mm/a.

In Taiyuan City, several subsidence centres have formed within region 40km long by 15km wide. In 1980, the area with 100mm subsidence was 108km^2, and the centre was located at Wujiabao. In 1990 the total amount of subsidence had increased from 819mm in 1980 to 2600mm and by 2002, it was 3700mm. Fractures 15.5km long and 200m wide are also present.

In Datong city, the subsidence started in the late 1970s and now the total amount 40-50mm with a maximum of 124mm and an average rate of 8—10mm/a. The subsidence region coincides with a groundwater depression cone. A fracture, 5km long, started in 1983, and then extended to 24km long in 1994. Over 10 fractures have been investigated, their total length is 34.5km.

SUBSIDENCE HAZARDS AND LOSS ASSESSMENT

Subsidence Hazards

Land subsidence due to excessive groundwater exploitation is a type of regional geological hazard that develops slowly and progresses to a disaster and that is difficult to control and entailing great losses. Rapidly growing urbanisation on low-lying coastal land is responsible for a number of severe problems. The area is in danger of flooding, particularly when storm or tidal surges occur, the frequency and intensity of which are rising. Settlements due to construction, damage to structures, and increased salinization of agricultural land are associated problems.

Subsidence has resulted in areas of land below sea level that are now present in the coastal region of Tianjin and the Hebei Plain that are vulnerable to the effects of storm surges. Four tidal surges that occurred respectivel in 1985, 1992, 1997 and 2003 in the region, caused damage or destruction of several stretches of sea wall as well as the port, oil field and fish ponds.

In the Yangtze Delta region, the function of flood control facilities and the flood discharge capability has been degraded so polluted water becomes trapped in the town area. At the river mouth saline water moves upstream reducing the water quality. In Suzhou city in the Yangtze Delta region, 24 buildings located in the fracture zone were damaged. In Xi'an city and Datong city, the pipelines, roads and bridges are often damaged ever year. The elevation data for the railway in Cangzhou shows the subsidence is over 1.2m, and there are problems with drainage.

In the Wenning Plain of Zhejiang province, the land is only 2.5–3.3m above sea level and the groundwater level is controlled at 1.9-2.1m below ground Due to over-pumping of groundwater, fields have become flooded during the rainy season so rice cannot be planted as usual.

2.2 Loss Assessment of subsidence

According to incomplete statistical data, total losses due to subsidence since the 1950s are assessed at 450•500 billions RMB(Chinese dollas in which the direct economic loss totals 35–40 billions RMB. The annual total losses are assessed at 9–10 billions RMB, and annual direct economic loss is 0.8–1.0 billions RMB.

Shanghai City has suffered the most severe loss in China. The total losses are assessed at 290 billions RMB from 1950s to 2001, and the direct losses 18.9 billions RMB, that is 6.5% of the total. With rapid geo-hazards, such as landslides and mudflows, deaths and direct losses are a much higher proportion of the total cost.

Tianjin has suffered one of the most severe losses due to subsidence hazards, when in 1992, a storm surge destroyed several of embankments and also caused damage to the port, warehouses, oil wells, causing losses of 0.4 billions RMB. The direct losses were approximately 10-14 billions RMB in total from 1985 to 1992, and the annual direct loss was 0.25-0.3 billions RMB.

COUNTERMEASURES ON SUBSIDENCE HAZARDS REDUCTION

In China, subsidence is rapidly developing and widely distributed, so the first job is to survey the nation-wide occurrence of subsidence, then to conduct the risk assessment and safety function geo-environmental zoning. The monitoring network is been established step-by-step. It consists of GPS and InSar-based surface monitoring and the borehole extensometer and groundwater-based ground monitoring. Special subsidence reduction measures need to be carried out to protect key facilities, such as the metropolitan zone in the Yangtze and in the Northern China plain, high-speed railway.

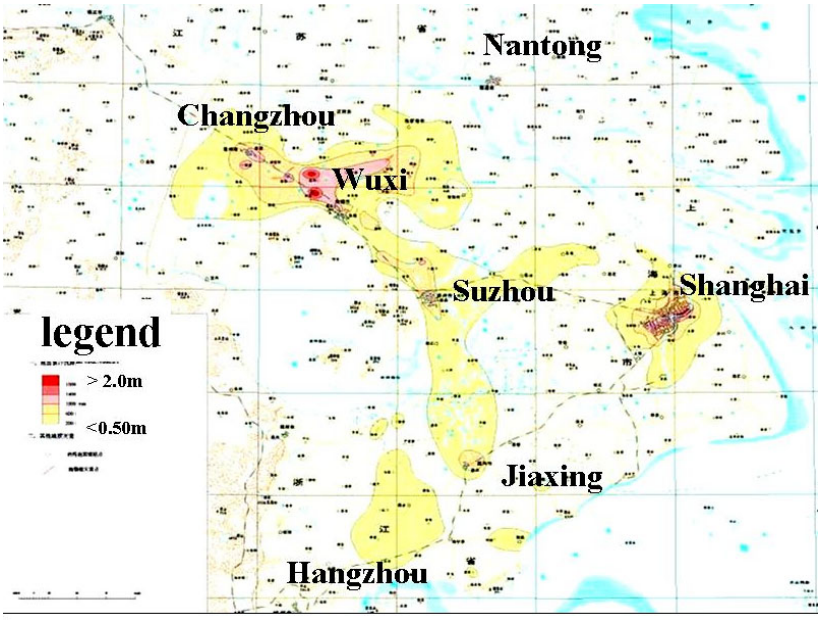

Figure 1. Subsidence in the Yangtze Delta

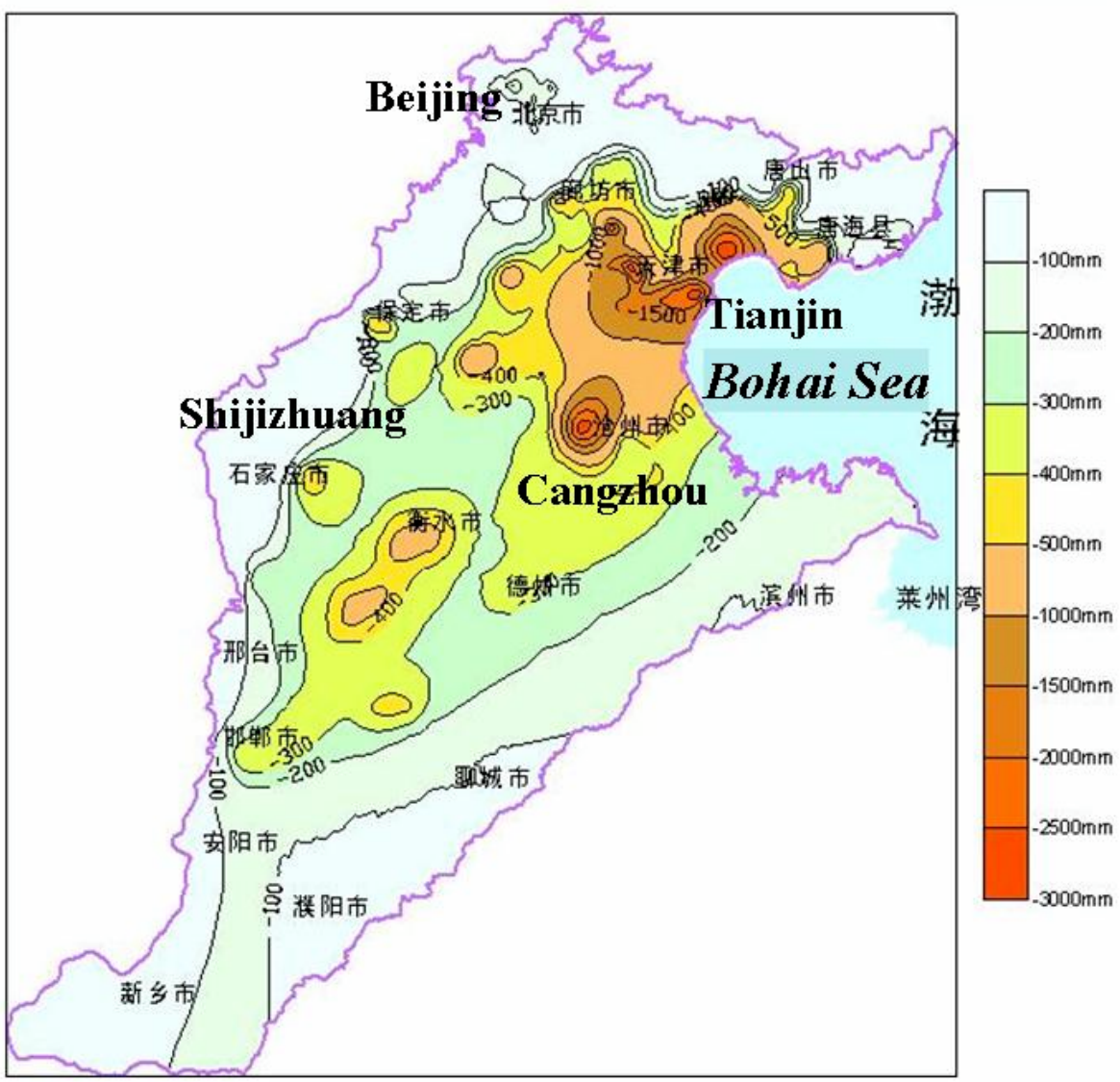

Figure 2. Subsidence in the Northern China Plain

The most effective means of subsidence reduction is to prohibit groundwater pumping. In the cities of Jiangsu Province and Zhejiang Province, groundwater levels rapidly decreased from 15m below ground level in the 1980s to over 80m in 1990s due to the surface water becoming polluted so that the deep aquifer with good quality of water was required. Since pumping stopped, in recent years the groundwater levels are rising, but supplying water from new source from far way would be very costly. Shallow groundwater could be used in the subsidence region for the increasing water cycle and reduce pollution at lower cost. In Suzhou city, the shallow groundwater is used and improved wells are increasing the amount of water extracted.

A comprehensive monitoring network coupled with an understanding of the ground conditions and subsidence mechanisms in Shanghai and Tianjin has enabled the pumping from difference aquifers to be optimised. The No.2 and No.3 confined aquifers were concentrically pumped in Shanghai before 1960s and caused problems. Since 1968, extraction from the above aquifers has have been limited and the No.4 and No.5 aquifer at 150m below the surface have been pumped. Until 2003, 79% of the previous amount of water extracted from the No.3 and the No.4 aquifer causes only few millimetres of subsidence at the same water supply rate. An aquifer restoration project is being tested in this subsidence region. This is by artificial recharge in which about 0.6 billion m^3 of water has been injected into the aquifer in Shanghai since 1966 that not only recovers the groundwater level, but also limits the subsidence.

CONCLUSION

Over 50 cities in China are threatened by land subsidence, including those in the delta region of the Yangtze River, the Northern-China Plain and the Fen-Wei River graben where urbanization is rapidly increasing. In Shanghai, the largest city of China, the subsidence rate within recent years is several millimetres per year. This is less than in past decades when the rate was several centimetres per year, which shows that prevention can be successful. Since this

change about 3000 buildings have been constructed. The subsidence has caused damage to railways; pipelines and especially to the magnetic suspension train and underground transport system (subway).

A comprehensive programme of counter measures is suggested over the next 10 to 15 years as follows: to survey Quaternary deposits and their structure, the aquifer and groundwater environment, bedrock/basement topography, geological structure and faulting, whilst also establishing a GIS-based data display platform; investigations of land subsidence occurrence and evolution, and conduct a risk assessment and function zoning and to complete the monitoring network covering subsidence zones. Additional measures include enforcement of prevention and limits to pumping as well as undertaking aquifer restoration and artificial recharge.

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