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ORIGINAL ARTICLE

The effects of karst collapse on the environments in north China

He Keqiang · Guo Dong · Du Wen · Wang Ronglu

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Abstract In this paper, a systematic study was completed on the distribution features and origins of karst collapses in north China. There are 65 modern karst collapse areas with 1,416 karst collapse pits and 38 paleo–karst collapse areas with 3,654 paleo-collapse pillars. Modern karst collapses are mainly distributed in the plain region of the east Taihang and Yanshan Mountains and are concentrated in three zones from the west to the east in this region. The regional distribution features of karst collapses in north China are controlled by the boundary of the geological tectonics, condition of soluble rock and the extent of human activities. From the results, three-grade indices have been adopted to establish a classification scheme for karst collapse in north China. The effects of karst collapses on the environments in north China are summarized using a karst collapse classification scheme.

Keywords Karst collapse · Environment · Effect · Classification · North China

Introduction

In addition to the rapid economic development and construction that occurred in the developed karst area of the world during the 1950s to late 1970s, karst collapse became a serious environmental problem, especially in important mining areas. Typical areas of karst collapses and subsidence caused by drainage and over-pumping in the world include gold mining areas in South Africa, aluminum mining areas in north Ural of Russia, zinc and lead mining areas in the Guangdong province and Shuikou mountains of the Hunan province, coal mining areas in Kailuan, Liujiang Handan of the Hebei province, Zibo of the Shandong province, Taiyuan, Luan of the Shanxi province in China. Alterations in these regions have resulted in great damage to the environment and have drawn significant attention to the environmental-geology field throughout the world. During that time, except in the mining areas, karst collapses occurred in urban and rural areas as a result of groundwater over-pumping for industrial and agricultural purposes (He 2001; He et al. 2005; Troitzky 1993).

Between 1970s and 1980s, damage of the karst collapse to the environments became more serious due to rapid economic development and population increases throughout the world. The hallmark feature of this period is that karst collapse occurred widely, not only in mining areas, but also in many urban areas, railways, highways and karst reservoirs. As a result, karst collapse has become a serious geological hazard caused by heightened development efforts. Since then, karst collapses have been widely studied in the world. Since the 1980s, research on karst collapse has progressed significantly, especially with the development of new technology and methods such as GIS, GPS and RS (Hu 2001; Achari 1999).

In fact, the earliest research on karst collapse can be found in Russian, American and German literature. For example, A. B. Bapulofu established “the suffusion

H. Keqiang (✉) · G. Dong · D. Wen · W. Ronglu
Department of Civil Engineering,
Qingdao Technological University,
Qingdao, Shandong 266033,
People’s Republic of China
e-mail: keqianghe@sina.com

effect theory which is also the theory about karst collapse mechanism.'' A karst collapse, which occurred in Shanon, Missouri in 1922, was reported by Brige, an American geologist in the 1930s (Benson 1984; Troitzky 1993). The book, ''On Engineering Karst,'' was published by Tolmachev and Reuter in (1990). Alexander and V. Anikeev of Moscow State University also completed influential research on karst collapse (Chen 1994; Yuan 1994, 2002).

Classification of karst collapse was proposed for the first time by Gremer in 1941 (Sowers 1984; Sridharan and Jayadeva 1982). In view of the extensive occurrence and serious damage of karst collapse to the environment, the international symposium on ''Karst collapse and subsidence,'' with the participation of 13 countries, was held for the first time in Hanoverian, Germany in 1973. The main topics of the symposium were classified into four groups: (a) karst collapse and subsidence; (b) mechanisms of karst collapse and subsidence; (c) regional division for karst areas and exploration methods of underground cave locations and (d) engineering examples and engineering control measures. Another important international symposium on sustainable development in karst area with the participation of 21 countries was held in 2001 in Beijing, China. This symposium particularly emphasized problems of the ecosystem, resources, environment and sustainable development in karst areas and completed a systematic analysis on the origin, classification and evaluation of karst collapse (Lei and Jiang 2002).

This paper reveals the distribution features of karst collapses in north China and provides a systematic analysis on the damages of karst collapse on the environment.

Distribution of karst collapses in north China

Several factors such as rapid development, increasing water consumption in industry, agriculture and by the populace, extraction of underground water and drainage of groundwater for mine exploration purposes, have caused a large number of karst collapses and serious damage to the environment in the karst area. According to the literature, 16 countries have reported serious karst collapses throughout the world. China, with a karst collapse area of 3.63 million square kilometer, for example, is one of the countries where karst collapses occur commonly (Gao 2003).

The geographic area of north China covers 42°–33°29′44″ northern latitude and 126°11′26″–108°50′46″ east longitude. The area adjoins the Yellow River and east of north Wei River in the west, Pohai Sea in the east, Yanshan and Changbai Mountains in the north and Qinling and Funiushan Mountains and the north line of Huaihe River in the south, which includes several important economic zones of China, such as the provinces of Hebei, Shanx, Shangdong, Liaoning Peninsula and west Liaoning, Henna, the Wei River, Xuzhou, Huai River, Beijing, Tianjin and Tangshan. The total area of this region is 77,000 km^2. The carbonate strata, which has a total area of 469,397 km^2, occupies a total area of 60.6%. The vast carbonate strata area is just inferior to that of south China and is the second largest region in China. This provides the essential basis for the development of the modern karst collapse and paleo–karst collapse in the region. (Fig. 1)

According to elementary statistics, except the area of Shanghai city and the provinces of Ningxia and Xinjiang, there are 2,840 karst collapse areas and 32,000 karst collapse pits in 24 provinces throughout China. The most developed karst collapses are generally in the provinces of southern China such as Guangxi, Guizhou, Hunan, Jiangxi, Sichuan and Yunnan. The developed areas of karst collapse in north China are mainly distributed in the provinces of Hebei, Shandong, Henan, Shanxi, Liaoning, Jiangsu, Anhui and Beijing city. There are 65 modern karst collapse areas with 1,416 karst collapse pits and 38 paleo–karst collapse areas with 3,654 paleo-collapse pillars (Table 1; Fig. 2).

Distribution features of the karst region and karst collapse in north China (Fig. 2) indicate that the modern karst collapse is mainly distributed in the plain regions of east Taihang and Yanshan Mountains. The collapse is also concentrated in three zones from west to east within this region:

I. The zone of Taihang Mount.–Luliang Mount.–Yanshan Mount.

Zone I includes the north and west areas of Huabei Plain of north China, where the modern karst collapses and the paleo-pillars are both well developed.

II. Hilly area of Huabei plain.

Zone II includes the middle-south area of the Shandong province, the middle area of the Henan province, the south area of the Hebei province, Xuzhou–Huaihe River area of the Jiangsu province, where the modern karst collapses are well developed.

III. Hilly plain area of east Liaodong Peninsula–Jiaodong Peninsula.

Zone III includes the hilly plain area of east Liaoning peninsula and Jiaodong peninsula, where the modern karst collapses are relatively developed.

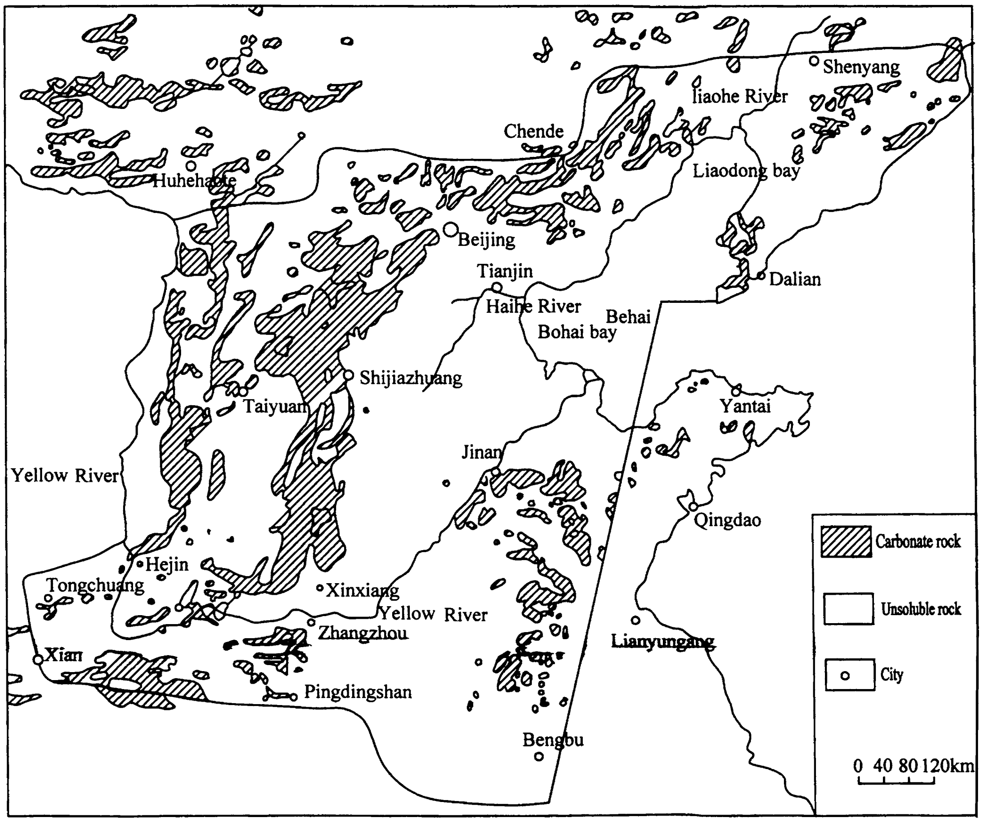

Fig. 1 Distribution of carbonate rock in north China

Table 1 Origin and classification of karst collapses in north China

Provinces of China	Origin of modern karst collapse								Origin of paleo–karst collapse		Sum total	
	Drainage and water bursting in mine extraction		Water pumping		Others		Subtotal		Collapse pillars			
	Areas	Pits	Areas	Pits	Areas	Pits	Areas	Pits	Areas	Pits	Areas	Pits
Liaoning	3	27	4	22	5	206	12	255	1	1	13	256
Hebei	7	24	2	306	3	123	12	453	8	214	20	667
Shanxi	5	5	–	–	–	–	5	5	19	3,402	24	3,407
Shandong	5	151	9	448	1	1	15	600	1	1	16	601
Henan	3	40	–	–	–	–	3	40	–	–	3	40
Shan'xi	1	1	–	–	1	6	2	7	1	1	3	8
Jiangsu	2	2	3	9	–	–	5	11	7	34	12	45
Anhui	7	32	2	11	–	–	9	43	1	1	10	44
Beijing	–	–	–	–	2	2	2	2	–	–	2	2
Total	33	282	20	796	12	338	65	1,416	38	3,654	103	5,070

The distribution of the modern karst collapses in north China is controlled by geological tectonics, condition of soluble rock and the extent of human activities. In zone II, the modern karst collapses are relatively concentrated, which are mainly associated with karst water exploitation and mine pit drainage for industrial and agricultural purposes along the Jinpu railway and specific cities.

Classification of karst collapse in north China

Research on karst collapse in north China dates back to more than 30 years ago and a great deal of data and research have been accumulated. The results of these studies objectively provide the beneficial condition of classification and further research on karst collapse. At present, a more reasonable principle and method of

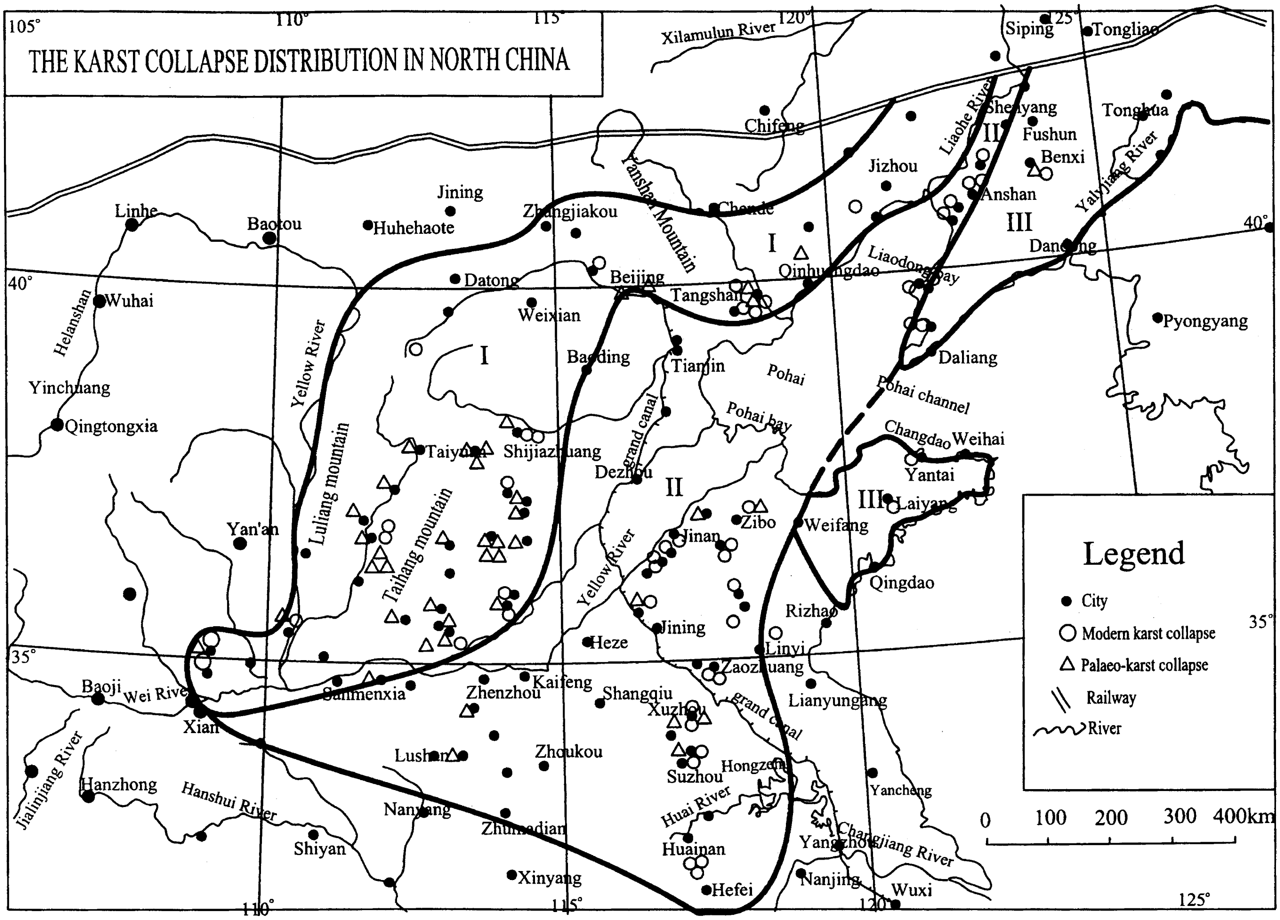

Fig. 2 The karst collapse distribution in north China

classification should be established to guide the investigation, prevention, control and predication of karst collapse. Thus, it can facilitate engineering construction in the karst area in north China and the development of karstology.

So far, there is no uniform principle and method for classification schemes of karst collapse. Different researchers have developed different classification schemes, but most classifications of karst collapse are generally based on a few factors. The various classification methods can be divided into two categories: one emphasizes the shape of karst collapse, such as circular, elliptical, elongated and irregular karst collapse, etc., and the other emphasizes the etiology of karst collapse such as mine drainage, over-pumping, etc. In fact, determining the method of karst collapse is very complicated and is generally the result of many different dynamic factors and mechanisms. Therefore, not only the strata of karst collapse, but other factors such as its origin, time of occurrence and shape features should all be taken into account in the classification scheme.

According to features of modern karst collapse and paleo–karst collapse in north China, the three-grade indices, which have been widely adopted in modern taxology, are used in the classification of karst collapse in north China.

Grade I

The modern karst collapse and paleo–karst collapse are divided in terms of karst collapse time of occurrence (Table 2).

Grade II

This classification is based on the origin and precipitating factors of karst collapse. It directly explains the essence and origin of karst collapse. It also describes the developed direction and tendency of collapse. A natural karst collapse, for example, refers to those induced by different natural factors, such as floodwater, rainstorm, gravity and earthquake. Karst collapse induced by human activities can be further divided into

Table 2 The scheme of classification of karst collapse in north China (Grade I)

Types	Karst collapse time of occurrence
Modern karst collapse	Occurred in the Quaternary period
Paleo–karst collapse (collapse pillars)	Occurred before the Quaternary period

drainage, over-pumping, water storage, load, vibration and seepage. All these factors are a result of different engineering activities (Table 3).

Grade III

This classification is based on the scale of karst collapse, which refers to the number of karst collapses in an area. The categories are as follows: great (more than 100), large (50–100), middle (10–50) and small (less than 10) (Table 4).

Table 4 The scheme of classification of karst collapse in north China (Grade III)

Types	Number of karst collapse pits
Great scale	>100
Large scale	50–100
Middle scale	10–49
Small scale	<10

Karst collapse damage to the environment in north China

Karst collapses, as a result of traffic, mine exploitation, urban construction and irrigation projects, have caused serious damage to the environment and led to severe geological hazards. Deterioration of ecologic environments, specifically ground and hydrogeological environments, has occurred. It also impacts the exploitation and utilization of various resources in the karst collapse area. Damages to ecological–geological environments are summarized in Fig. 3.

Effects of karst collapse on the rail transport system

The effects of karst collapse damage on the rail transport system has been disastrous. According to elementary statistics conducted by Dan Liu, Lizhong Yang and Jianxiu Wang in 1997, karst collapses have occurred in 60 sections and with more than 375 spots along the north China railway, resulting in travel cessation for more than 2,000 hours causing direct and indirect economic loses of several hundred million yuan. The roadbed of Changchun–Dalian railway, for example, collapsed in a very short time because the Quaternary aquifer was drained and the deep karst groundwater was overexploited leading to the formation of a deep groundwater drawdown cone. A karst collapse, which occurred at Taian station on the Jinpu railroad, caused the stationhouses and roadbed to crack because of karst groundwater over-pumping. Since 1976, over 20 karst collapses have occurred along the railway in north China, where the maximum diameter of the collapses has been up to 23 m. Drainage in neighboring mine areas has also induced ground subsidence along the railway resulting in serious damage to the environment. These two examples highlight the fact that areas where karst groundwater is over-pumped

Table 3 The scheme of classification of karst collapse in north China (Grade II)

Types	Sub-types	Origin and induced dynamic factor
Natural karst collapse	Flood karst collapse	Induced by the floods in an area near rivers or lakes
	Rainstorm karst collapse	Induced by the increasing soil weight and seepage forces caused by rainstorms
	Gravity karst collapse	Induced by falling rocks in underground caverns
	Earthquake karst collapse	Induced by the impact or liquefaction caused by the forces of earthquakes in strong earthquake areas
Karst collapse induced by human activities	Drainage karst collapse	Induced by drainage or water invasion in mining pits
	Over-pumping karst collapse	Induced by over-pumping groundwater
	Water storage karst collapse	Induced by the water storage of hydraulic engineering
	Vibration and load karst collapse	Induced by blast vibrations and increasing loads
	Leakage karst collapse	Induced by the leakage effect of reservoir water
	Others	Induced by other dynamic factors

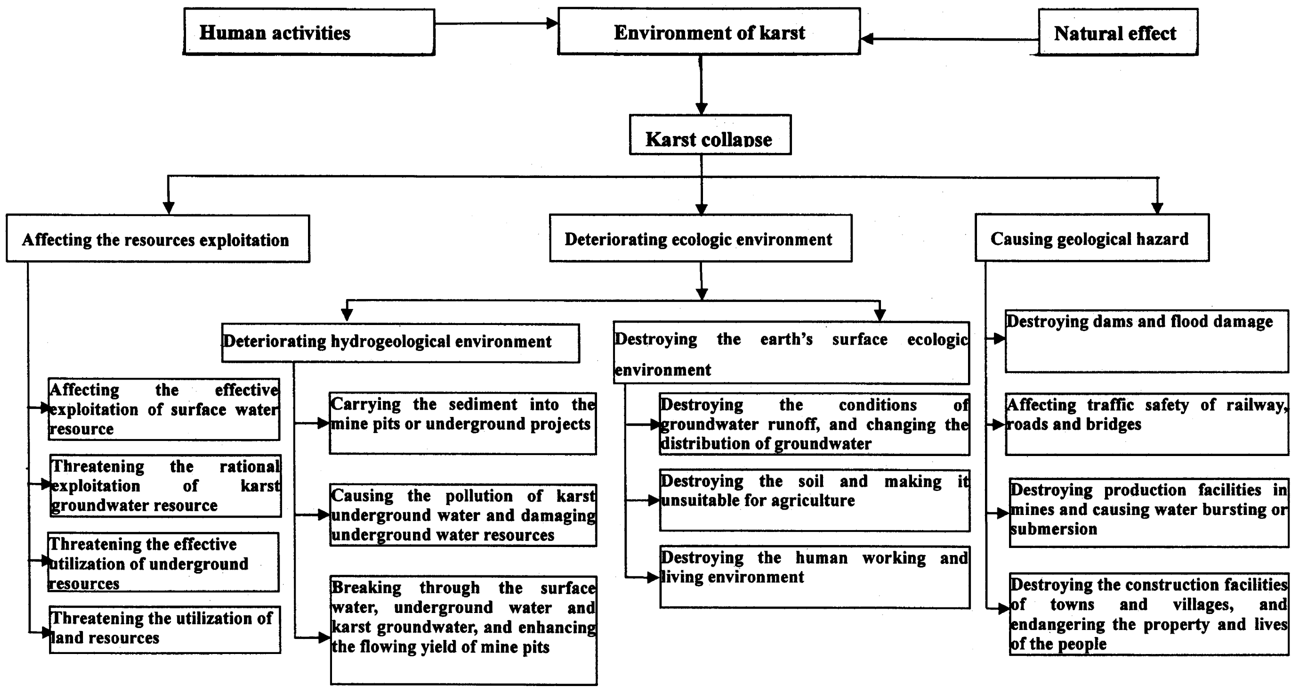

Fig. 3 Different types of karst collapse damages to the environment

tend to be well-developed areas that experience significant losses. Karst collapse induced by human activities is generally characterized by large scale, sudden events with significant damage.

Karst collapse precipitated environmental damage as a result of mine exploitation

Karst collapse as a result of mine exploitation tends to be characterized by severe damage. The coal strata from the Carboniferous period to the Triassic period, under which exists huge thick limestone strata from the Ordovician period, are distributed widely in the provinces of Hebei, Henan, Shanxi, Shandong, Liaoning, Jiangsu and Anhui, China. Because of the action of paleo–karst and the collapse of overlying strata, varying scales of karst collapse pillars have been well-developed and have become a special kind of karst collapse hazard in north China. These hazards easily promote the flooding of water from mine pits.

According to investigation results, 50 mines have been threatened by water invasion in 19 mine areas of the Shanxi province of China. Some mines have been totally destroyed by water invasion and loss of the paleo–karst pillars. The annual average economic loss in the Shandong province of China caused by karst collapse and water invasion is approximately 48 million RMB.

Water bursting induced by karst collapse pillars in the Kailuan mine field in Tangshan city of the Hebei province in China in 1984 submerged not only the mine pit but also its neighboring mine pit, Lujiatuo Coal Mine, in a very short time. The collapse also damaged the mines of Tangjiazhuang, Zhaogezhuang and Linxi.

The damage of karst collapse to the urban geological environment

Karst collapses have damaged many buildings, roads and public utilities and constituted a direct threat to the safety of urban construction and infrastructure in north China. In north China, areas that have suffered serious damage from karst collapses are the cities of Tangshan and Qinghuangdao, Taian, Zaozhuang, Zibo, Jining, Laiwu, Wafangdian, Anshan and Jinzhou, Xuzhou and Huaibe.

Tangshan is one of the cities which has suffered the most significant damage because of karst collapse in north China. According to the statistics, more than 138 karst collapses have occurred in the center of the city during the 1970s. The Tanshan earthquake caused 120 karst collapses producing very serious damage to the buildings and roads of Tangshang city.

The center area of Zaozhuang city in the Shandong province of China is a developed area that experienced karst collapse. There were 24 karst collapses in the 2 km^2 area surrounding the Shiliquan Water Supply Base from 1980 to 1982. Since that time (up until February 2001), 200 karst collapses have occurred in the 25 km^2 area surrounding Zaozhuang city.

Since 1984, ten karst collapses have occurred in Xuzhou city of Jiangsu province in China. In April 1992, seven collapsed pits caused about 224 rooms to be damaged.

Conclusions

Through the above analysis, the following conclusions can be drawn:

1. There are 65 modern karst collapse areas with a total of 1,416 collapse pits and 38 paleo–karst collapse areas with over 3,654 paleo–karst collapse pillars in north China.
2. Distribution features of the karst region and karst collapse in north China show that the modern karst collapse primarily occurs in the east plain region of the Taihang and Yanshan mountains, which are concentrated in three zones from west to east of this region: the zone of Taihang Mount.–Luliang Mount.–Yanshan Mount.; the hilly area of the Huabei Plain and the hilly plain area of east Liaodong Peninsula–Jiaodong Peninsula.
3. The distribution features of modern karst collapses in north China are controlled by the boundary of geological tectonics, soluble rocks in this region and the extent of human activities. Therefore, modern karst collapses are relatively concentrated in the basin and plain karst collapse areas of the Liaoning province, Shandong province, Xuzhou city and Huai River hill. These collapses were mainly due to karst groundwater over-pumping and dewatering of karst mine pits for industrial and agricultural means along the Jinpu railway and cities.
4. According to the features of modern karst collapse and paleo–karst collapse in north China, three-grade indices have been implement to establish the classification of karst collapses in north China.
5. Karst collapse not only causes severe geological hazards but also deteriorates the environment. Moreover, it can produce a serious threat to the exploitation and utilization of various resources in karst collapse areas.

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