Geomorphological indicators of karst environmental disturbance in the mountainous region of Jinan City, North China

Jiamei Guo, Rong Jia, Shanzhong Qi*
School of Geography and Environment, Shandong Normal University, Jinan, Shandong Province, 250358, China
*Corresponding author’s e-mail: shzhqi@sdnu.edu.cn

Abstract. As one of cities located in the karst region of North China, Jinan City is a karst region that is heavily urbanized in recent years, but no study has been undertaken to monitor the disturbance of karst environment. To effectively address the threats and the disturbance to karst region in the city, this study proposes hierarchal and standardized environmental disturbance indicators as a tool to monitor regional impacts and strengthen more protection of the karst mountainous areas in North China. The geomorphological indicators of karst disturbance in Jinan City of North China include quarrying or mining, and flooding and storm-water drainage (human-built surface structure indirect effect).

1. Introduction
China is a mountainous country and the karst mountainous geological area is about $3.44\times10^6$ km$^2$ which accounts for 25% of the world’s carbonate rock[1-2]. These karst mountainous geological regions in China include the southern area and northern area[3]. The main karst region in northern China is make up by Hebei, Shandong, Henan and Shanxi provinces and Beijing, Tianjin, Jinan, Xuzhou, and Yangquan cities[4-5], where the karstification is less developed compared with the more humid areas in South China Region[6]. In recent years, the karst mountainous areas of northern China have been become urban areas owing to the rapid development of urban sprawl, thereby disturbing the environment and resource of karst regions under effects of climate change and a large degree of the social-economic development in these areas, thereby resulting in the changes of karst environment and landscape in the urban mountainous regions of North China[7].

Many studies have been conducted in the karst mountainous region of South China to assess and monitor rocky desertification processes[8] or geological hazards[9] in order to understand desertification-related ecological problems, and the afforestation and reforestation projects in the karst regions of southwest China in order to combat desertification and improve the ecological environment[10]. However, studies on karst environment disturbance in the karst mountainous regions of China are scarce, especially in North China. As one of cities located in the karst region of North China, Jinan City has experienced extensive urbanization, especially in its southern karst region. At present, Jinan’s karst mountainous area is undergone widespread karst disturbance[11-12]. Although many studies and investigations on the spring protection have been done in Jinan City[13-15], no study has been studied monitoring the disturbance of karst environment. In order to effectively address the threats and the disturbance to karst region in Jinan City, the objectives of this study are (1) to detect karst environmental disturbance in the Jinan’s southern mountainous region, and (2) to assess...
its impacts on environmental change; further, to outline some disturbance geomorphological indicators of karst environment change in the study area.

2. Background of Jinan City

Jinan City is located between 116°49’–117°14’ E and 36°32’–36°51’ N, and located within Shandong province to the north of Taishan Mountain and south of the Yellow River. It is one of cities located in the karst region of northern China. Jinan City is famous for its fractured-karst springs, and its karst mountainous region mainly lies in the southern part of Jinan City, covering the area of more than 1367 km². Jinan City has a typical warm-temperate, semi-humid, continental monsoon climate and well-defined seasons. The mean annual temperature is 14°C, and the average mean precipitation 650–700 mm[12].

3. Karst environmental disturbance induced by urban expansion in Jinan City

Jinan’s southern area has made remarkable urbanization, where the spatial pattern of its land use has been profoundly transformed by rapid urbanization. Jinan City has expanded its total area to 8117 km²[12], of which the areal extent of built-up area has increased from 23.2 km² in 1948 to more than 447 km² in 2016 (Figure 1).

![Figure 1. Expansion of Jinan’s urban area from 1948 to 2016.](image)

A land use map was acquired from Landsat images of the study area in 1986 and 2017 and it indicated that the total area of urban/built-up land, unused land, and grassland increased but farmland, forestland, and water decreased from 1986 to 2017, respectively (Figure 2). During the study period, the increase in urban/built-up land’s total area of was up from 65.5 km² in 1986 to 196.3 km² in 2017, the area of unused land increased from 1.2 km² in 1986 to 19.9 km² in 2017, and the area of grassland increased from 270.1 km² in 1986 to 283.9 km² in 2017, respectively. But the farmland’s total area of was down from 616.1 km² in 1986 to 478.9 km² in 2017, forestland area decreased from 395.7 km² in 1986 to 376.8 km² in 2017, and water decreased from 16.2 km² in 1986 to 14.1 km² in 2017, respectively. Although their areas decreased, farmland and forestland were still the main type of land use in the Jinan’s karst southern region during the period of 1986—2017. Moreover, urban/built-up land and barren land were also main land use type from 1986 to 2017 owing to urbanization in the study area (Figure 2).
Figure 2. Landscape change and area of different types of land-use during the period of 1986—2017.

On the other hand, the urban hills are facing changes in Jinan City resulted from the mass construction of market housing and excessive real estate investment in the Jinan’s southern region within the city (Figure 3). The destruction and landscape change of hills resulted from urban expansion in the karst mountainous region of Jinan City were described in detail by Qi & Zhang[11] and Xu et al.[12], respectively. These disturbances have resulted in the serious natural hazards in the study area and in turn have been threatening the health and safety of Jinan’s karst mountainous regions.
Figure 3. Real estate development resulted from urban expansion and landscape change in the Jinan’s karst southern region.

4. Disturbance indicators of karst environmental change in Jinan City
The disturbance indicators of karst environmental change in Jinan City have been determined in geomorphological indicators. Considerations on karst environmental change are critically important in determining the magnitude and signs of disturbance. The interactions of humans, soil, land, and water are causing environmental conditions in the Jinan’s karst southern region to deteriorate and are resulting in the karst environmental disturbance in the Jinan City. The degree and severity of karst environmental change could be determined by such surface landforms geomorphological indicators in the karst mountainous region of Jinan City, including quarrying/mining, flooding and storm-water drainage (human-built surface structure indirect effect).

The documented findings in this study not only indicate the impacts of urbanization and changes in surface landforms on the disturbance of karst environment in Jinan City and their consequences, but also provide some guide for future integrated environmental management in the similar karst regions of North China.

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