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LANDSCAPE CHANGE OF LAND USE IN THE KARST REGION OF JINAN CITY, NORTH CHINA

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Highlights

- In recent years, the karst mountainous areas of North China have heavily experienced rapid urbanization which has profoundly changed the landscape pattern of land use in these areas.
- Jinan city belonging to the karst mountainous area of North China has being experienced rapid urban expansion in the recent years, thus inducing land use change.
- Studying landscape pattern of land use changes induced by urbanization would have implicational significance to urban planning and sustainability in the karst mountainous areas of North China.

Abstract. With the rapid development of urbanization, land use change has occurred in most karst mountain regions of North China over the last decade, so studying landscape pattern changes induced by urbanization would have implicational significance to regional planning and sustainability. Based on RS, GIS, and field investigation, land use change induced by urbanization in Jinan city belonging to the karst mountainous area of North China was analyzed over 30 years from 1987 to 2018, and further the landscape response of these changes was explored. The results indicate that (1) the most obvious changes have occurred in both urban/built-up land area and cropland area with rapid urbanization development in Jinan's karst area, and the former increased by 246.4 km^2 but the latter decreased by 343.3 km^2 from 1987 to 2018; (2) landscape pattern of land use is profoundly changed by quick urbanization in the period from 2000 to 2018, but does not siginificently from 1987 to 2000; and (3) in the monitoring period, the cropland's shape inclines to fragmentation and regularization, and the shapes of urban/built-up land and barren land have become increasingly distinct from the patch class level; from patch landscape level, the artificial landscape type (urban/built-up land) is increasingly dominant but the natural landscape type (grassland) is decreasingly dominant, thereby resulting in the disturbance of urban karst environment of Jinan city. Therefore, a protection policy should be taken to achieve strong urban karst sustainable development of North China.

Keywords: land use change, urban sprawl, landscape response, karst mountain area, Jinan city.

Introduction

Land use/land cover changes (LUCC) are the most direct manifestation of the interaction between natural environment and human activities (Roth et al., 2016) affecting the surface of the Earth, further causing the dynamic changes of landscape in spatial and temporal scales (Shi et al., 2004). Landscape changes are thought to be the most profoundly human-induced impacts on the Earth's ecological system (Aman et al., 2021), especially in the whole ecosystem of karst mountainous region, which have been undergoing irreversible landscape damage, environmental hazards, and land degradation owing to irrational human activities (Qi & Zhang, 2011; Parise & Pascali, 2003; Huang et al., 2008; Sauro, 2006). Karst covering the Earth worldwide has reached 15% (Jiang & Yan, 2010). Because of their unique ecosystem structure, karst areas are easily disturbed by human activities (Sauro, 1993 and 2006; Brion et al., 2011; Guo et al., 2015; Grimmeisen et al., 2016; Wu et al., 2018; Lang & Song, 2019), thereby causing karst irreversible landscape change and environmental hazards (Xu et al., 2012; Zhang et al., 2018). Karst landscapes have been partially or totally disturbed by extensive urban expansion, thereby inducing the changes between land use and fragile geological karst environment from temporal and spatial patterns (Andriani & Walsh, 2009; Sauro, 2006). The China's karst geological areas, with covering estimated area of 3.44×10^6 km^2, could consist of

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the Southwest region of China and North region of China (Lu, 1986). Numerous studies have been conducted in the Southwest karst region of China on environmental degradation (Huang et al., 2008, 2012), sustainable development (Tong et al., 2018), or influences of rapid urbanization or the pattern change of land use on flood events (Li et al., 2021) and ecosystem health of fragile karst environment (Zhao et al., 2021), but the North karst region of China has been given little attention. In recent years, the urbanization process has been accelerating in the karst areas of North China, and has profoundly changed the landscape pattern of land use in these areas. In particular, water and land resources of the typical karst areas in cities have been degraded greatly in terms of quality and quantity, and the landscape has also been damaged beyond recovery (Zhao et al., 2009; Kang et al., 2011), thereby resulting in the disturbance of the environment in the karst areas of the city (Philip & Kaya, 2005), further bringing the potential environmental hazards to the urban sustainable development (Qi & Zhang, 2011).

Belonging to one of the China's northern karst mountainous areas and well known for its fractured karst springs, Jinan city is in the stage of rapid urban expansion and is faced with considerable landscape pattern change of land use and ecological environmental protection (Qi et al., 2020; Liu et al., 2022), particularly in its karst mountain region. Meanwhile, the karst urban mountain area is currently faced with many environmental problems (Qi & Zhang, 2011), landscape change of urban hills (Xu et al., 2012), and ecological risks (Qi et al., 2020). Although many studies and investigations have been done in the last forty years in the Jinan's karst area (Li, 1985; Li & Kang, 1999; Wu et al., 2010; Gao et al., 2020), the most have mainly concentrated on the purpose of karst spring protection. However, the karst landscape disturbance resulted from land use change in the study area has received little attention, although the issue on land use change has been reported in Jinan city (Qi et al., 2020). So, the present study is to detect land use change through GIS and three Landsat TM images of 1987, 2000, and 2018, and to evaluate its landscape response to the karst ecosystem of from 1987 to 2018 which would have implicational significance to urban planning and sustainability.

1. Materials and methods

1.1. Study area

As the capital of Shandong, Jinan city is located in the China's northern karst region (116°49′–117°14′ E, 36°32′–36°51′ N), and its southern part is a karst urban mountain area which covers more than 2,269 km^2, locally known as Jinan- Springs-Field (JSF) and taken this region as the study area (Figure 1). The JSF belongs to the typical warm-temperate, semi-humid, continental monsoon climate and well-defined seasons. The mean annual temperature in JSF is 14 °C; the average mean precipitation is 650–700 mm (Xu et al., 2012).

1.2. Data and methods

To assess land use change in the study area from 1987 to 2018 using remote-sensing data, we obtained raw imagery (bands 5, 4, and 3) from the Institute of Remote Sensing Application (IRSA), Chinese Academy of Sciences, and then converted the raw imagery to maps of categories by using methods that Li et al. (2004) and Liu et al. (2005) described in detail. We interpreted and analyzed three thematic mapper images (taken in 1987, 2000, and 2018) at a spatial resolution of 30 meter by using geographical information systems (GIS) (Enaruvbe & Pontius, 2015; Pontius et al., 2013, 2017). Then we used the maximum likelihood classifier technique image classification, and acquired a total of 113 training sites from Google Earth for better interpretation (Sabr et al., 2016). Images were classified

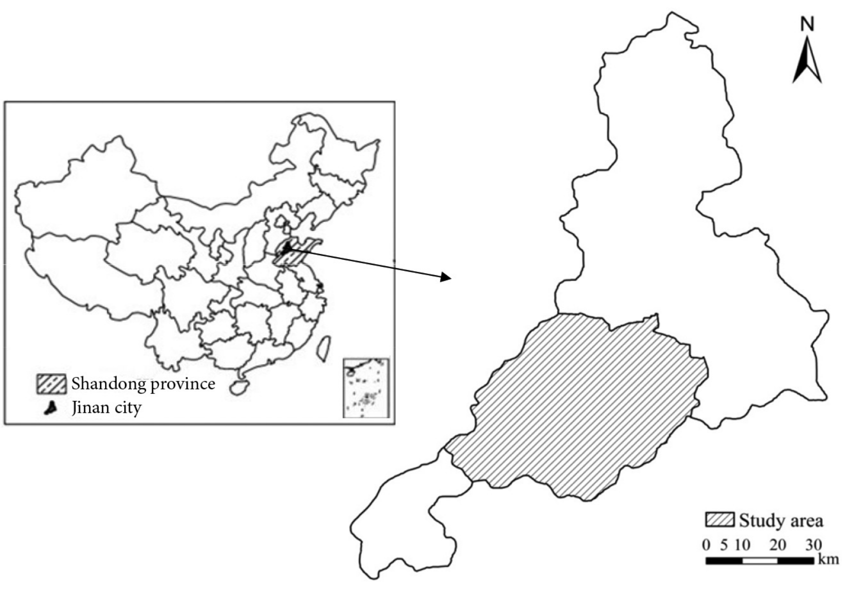

Figure 1. Location of the study area

into six land use types, namely cropland, forestland, grassland, water, urban/built-up land, and barren land which were listed in the Resources and Environmental Database Center of the Chinese Academy of Sciences (http://www.resdc.cn/). To evaluate the classification accuracy we collected total 134 sampling points for all images by GPS coordinates in the study area, and the kappa coefficient is above 0.85, indicating that this dataset meet this study needs (Chen et al., 2016). The ArcView software and its spatial analysis module were used to calculate the transition matrixes and define the transition of land use types in the JSF (Quan et al., 2018). Moreover, we carried out field investigation passing through the whole JSF to evaluate the landscape response of land use change.

1.3. Analysis of landscape pattern

Landscape change analysis can reflect effectively land use spatial pattern its impacts on landscape ecology based on geometrical features (Jin et al., 2020; Yang et al., 2020; Aman et al., 2021). Usually, landscape patterns have been analyzed by landscape metrics (McGarigal & Marks, 1995), which are classified into the three levels, namely patch, class, and landscape to quantify many aspects of landscape pattern, such as the fragmentation, heterogeneity, and connectivity (Cabral & Costa, 2017). To comprehensively detect the urbanization on landscape patterns in the JSF of Jinan city, 6 frequently used landscape-level metrics (Schindler et al., 2008; Plexida et al., 2014; Feng & Liu, 2015; Niesterowicz & Stepinski, 2016; Aman et al., 2021) were chosen in the study, that is, Patch Density (PD), Largest Patch Index (LPI), and Mean Patch Fractal Dimension (FRAC-MN) (from the patch class scale); and Contagion Index (CONTAG), Shannon's Diversity Index (SHDI), and Shannon's Evenness Index (SHEI) (from the patch landscape scale) (Table 1). All of above indices are calculated by the software of FRAGSTATS 4.2 (http://www.umass.edu/landeco/research/fragstats/fragstats.html).

2. Results and discussion

2.1. Land use change

With the rapid urbanization and civilization development in Jinan city, the temporal–spatial patterns of land use have been profoundly transformed in JSF (Figure 2), which could effectively lead to landscape pattern changes (Zhang & Wang, 2018; Dadashpoor et al., 2019). Generally speaking, land use changes in the JSF of Jinan city have occurred over 30 years. From 1987 to 2018, the forestland

Table 1. Brief description of each index for landscape pattern analysis

Scale	Index	Index interpretation
Class scale	Patch Density (*PD*): $PD = \frac{n_i}{A} \times 10\,000 \times 100 \;\; (PD > 0)$	It reflects the degree of fragmentation of patch. The larger the PD, the higher the fragmentation, the greater the degree of spatial heterogeneity
	Largest Patch Index (*LPI*): $LPI = \frac{\max_{i=1}^{n}(a_i)}{A} \times 100 \;\; (0 < LPI \le 100)$	It stands for the percentage of large patches in the whole landscape, and can indicate the landscape advantage of a certain area. The larger the value, the more obvious the advantage
	Mean Patch Fractal Dimension (*FRAC-MN*): $FRAC = \frac{2\ln(0.25 p_i)}{\ln(a_i)}$	It can reflect the complexity of the spatial shape of the patch and the complexity of the landscape spatial pattern, indicating the extent to which the landscape is affected by humans
Landscape scale	Contagion Index (*CONTAG*): $CONTAG = \left\{ 1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[p_i\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]\cdot\left[\text{In} p_i\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)} \right\} \cdot 100$ $(0 \le CONTAG \le 100)$	It describes the trend of extension or aggregation for different types of landscape patches. This indicator contains spatial information and values between 0 and 100
	Shannon's Diversity Index (*SHDI*): $SHDI = -\sum_{i=1}^{m}[P_i \times In(P_i)]$	It represents the richness and complexity of the types of land use landscape, reflecting the number of patch types and the change in the proportion of each patch type in the entire landscape. The larger the value, the more uniform the proportion of each type of plaque in the landscape
	Shannon's Evenness Index (*SHEI*): $SHEI = \frac{H}{H_{\max}} \quad SHEI = -\sum_{i=1}^{m}[P_i \times In(P_i)] \Big/ In(m)$ $(0 \le SHEI \le 1)$	It reflects the uniform landscape distribution of patches and is negatively related to the index of dominance

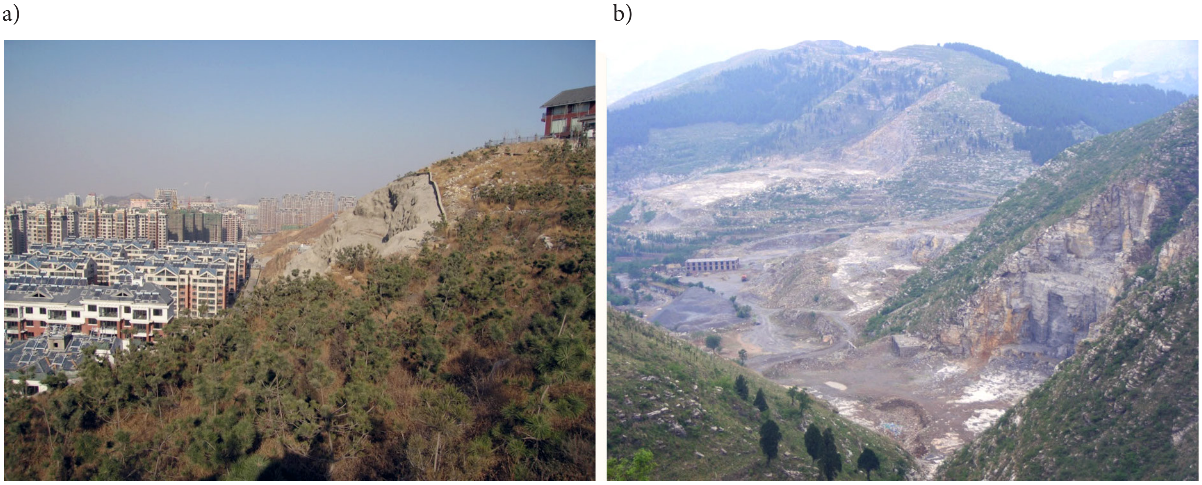

Figure 2. Large landscape change resulted from urbanization in the study area

area increased by 68.7 km^2; the urban/built-up land area increased by 246.4 km^2; the total water area increased by 3.5 km^2; and the total barren land area increased by 60.53 km^2, respectively (Tables 2 and 3). These changes demonstrate a trend of quick growing in the JSF. However, the total cropland area decreased by 343.3 km^2 from 1987 to 2018 (Table 3). In gross terms, 177.45, 241.81, and 59.69 km^2 were respectively converted into forestland, urban/built-up land, and grassland. The other less loss to cropland was changed into both water (14.78 km^2) and barren land (12.71 km^2). Anyway, although its area decreased (net decreasing by 343.3 km^2), cropland is still main land use landscape during the period of 1987–2018.

In addition, due to urban expansion, the decentralization of people and jobs from urban centers to suburbs are being obvious in the Jinan's karst area, thereby resulting in the substantial increase of urban/built-up land and barren land along with the relative increase of forestland and water (Table 3 and Figure 3). The large growth of barren land area was mainly derived from cropland (12.71 km^2), from forestland (20.99 km^2) and from grassland (25.15 km^2), respectively. The relative growth of forestland area was mainly derived from cropland (117.45 km^2) and from grassland (117.58 km^2), respectively. Moreover, the area increase of water mainly converted by cropland (14.78 km^2), grassland (1.08 km^2), and urban/built-up land (1.42 km^2), respectively.

Table 2. Area and proportion of various land use type in the JSF during 1987–2018

Type	1987		2000		2018	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Cropland	1143.2	50.36	1113.7	49.06	799.9	35.24
Forestland	562.1	24.76	562.1	24.76	630.8	27.79
Grassland	362.6	15.97	362.5	15.97	326.8	14.39
Water	23.4	1.03	23.6	1.04	26.9	1.19
Urban/built-up land	177.4	7.82	206.8	9.11	423.77	18.67
Barren land	1.27	0.06	1.27	0.06	61.8	2.72
Total	2269.97	100	2269.97	100	2269.97	100

Table 3. Transition matrix of land-use type during 1987–2018 (km^2)

1987	2018							
	Cropland	Forestland	Grassland	Water	Urban/ built-up land	Barren land	Decrease	Net change
Cropland	–	177.45	59.69	14.78	241.81	12.71	506.4	–343.3
Forestland	48.60	–	147.05	0.75	20.90	20.99	238.3	+68.7
Grassland	83.08	117.58	–	1.08	17.61	25.15	244.50	-35.81
Water	7.18	4.24	0.40		2.71	0.05	14.58	+3.47
Urban/built-up land	24.10	7.71	1.46	1.42	–	2.34	37.03	+246.42
Barren land	0.16	0.03	0.09	0.02	0.42	–	0.72	+60.52
Increase	163.1	307.0	208.6	18.1	283.5	61.2	1041.5	–

The direct driving force for increase of barren land mainly was rapid urbanization in the JSF. In the studied period, land clearing for construction has caused a large amount of land degradation and construction wasteland increase (Figure 2b). However, the mass construction of market housing and excessive real estate investment in the Jinan's karst region also causes the area increase of forestland and water. Additionally, the obvious decrease of cropland area was mainly changed into the urban/built-up land from 1987 to 2018. All of these changes could result in many environmental problems in the Jinan's karst mountain area.

Due to urbanization in JFS of Jinan city, environmental degradation of karst ecosystem occurred in the study area. For example, the urban hills of Jinan city were damaged, which were described in detail by Qi and Zhang (2011). Furthermore, many rapid flood passages were filled in for building, resulting in the likelihood of triggering more floods in future in JFS of Jinan city (Xu et al., 2012). Further, the dominance of artificial landscape type (e.g. urban/built-up land) is increasing, but the natural landscape type (grassland) is decreasing in the studied period (Tables 2 and 3). The whole landscape indicates that the tendency of fragmentation is deepening in the JSF.

On the other hand, land use change can show two obvious phases, namely the periods 1987–2000 and 2000–2018 (Figure 3). During 1987–2000, the process of urban expansion was slower and showed no apparent effect to landscape change of land use, indicating that only two land use types was changed, that is, cropland decrease and urban /built-up land increase (Table 2 and Figure 3). However, the rapid urban expansion has greatly affected land use change during 2000–2018, and all six land use types in the JSF have changed (Table 2 and Figure 3), showing that forestland, water, urban /built-up land and barren land increased but cropland and grassland decreased. General changes of landscape are shown by change in various cover types. During 1987–2018, the areas of forestland, urban /built-up land, water, and barren land have increased in the Jinan's karst region (Tables 2 and 3).

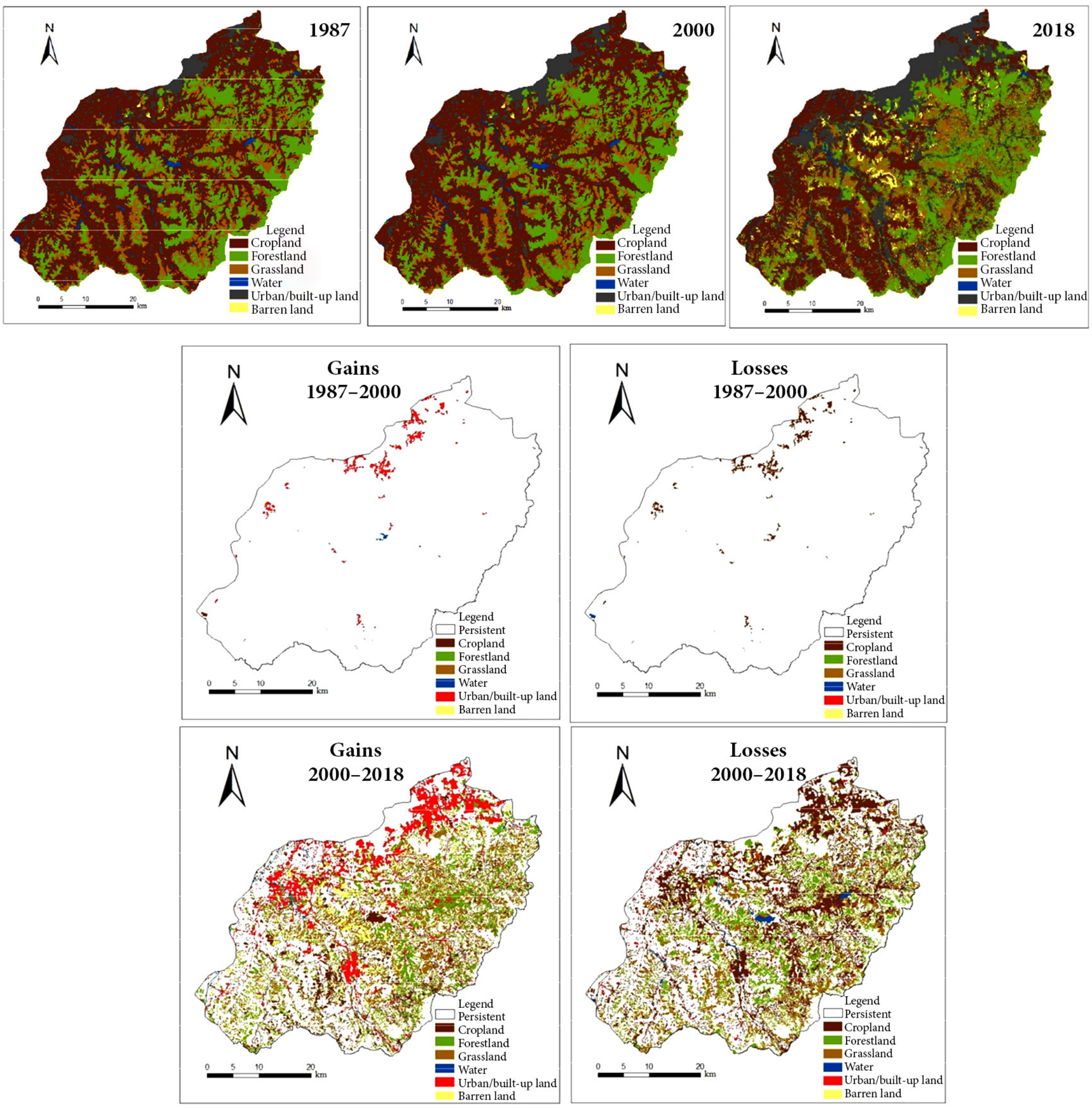

Figure 3. Spatiotemporal landscape change of land use in the JSF from 1987 to 2018

Table 4. Landscape change of land use type in the JSF in different time points 1987, 2000 and 2018

Index	Year	Cropland	Forestland	Grassland	Water	Urban/built-up land	Barren land
PD (patches/km^2)	1987	0.0	0.2	0.2	0.0	0.3	0.0
	2000	0.0	0.2	0.2	0.0	0.3	0.0
	2018	4.9	4.4	3. 9	0.4	1.3	1.5
LPI	1987	38.1	2.4	0.8	0.1	1.6	0.0
	2000	37.3	2.4	0.8	0.2	2.7	0.0
	2018	8.0	5.7	1.0	0.1	13.5	0.2
FRAC-MN	1987	1.099	1.087	1.114	1.080	1.045	1.066
	2000	1.099	1.087	1.115	1.079	1.045	1.066
	2018	1.079	1.083	1.080	1.099	1.070	1.089

2.2. Response of landscape change to land use

2.2.1. Landscape response from patch class level

The dynamic landscape of each type in the JSF in different time points 1987, 2000 and 2018 is shown in Table 4 and Figure 3.

Table 4 and Figure 3 indicate that the cropland shape tends to fragmentation and regularization. In spite of the decline of LPI in the JSF, cropland is the main land use type with the largest area in all six types, thereby becoming the main landscape in the JSF. Also, the cropland shape is becoming fragmentation resulting from its addition of PD and area reduction. On the other hand, both the cropland changed into urban/built-up land as well as more stringent management for cropland than before have indicated that the cropland shape is showing a tendency of complexity and regularization. This result is resulted from the decline of FRAC-MN. Additionally, urban/built-up land has being become active, and its degree of fragmentation and activity is the highest within whole land use landscape in the JSF that is shown through the higher LPI in all six types, especially from 2000 to 2018. This result indicates that the landscape type of urban/built-up land is also the main landscape type in the JSF with the rapid development of urbanization.

2.2.2. Response from patch landscape level

The rise of SHDI and SHEI during1987-2018 indicates that cropland and grassland have been reduced, but forestland has increased, which was mainly converted by both cropland (177.45 km^2) and grassland (117.58 km^2) (Table 3); the rare landscape types (e.g. urban/built-up land and barren land) show an expanding trend (Table 5). Moreover, the decline of CONTAG value shows that the fragmentation of whole landscape in the JSF is obviously increasing. The reason is that natural landscape is decreasing and becoming the artificial landscape for the next stage, then becoming main landscape for the next stage with the development of rapid urban expansion in the JSF.

Table 5. Dynamic landscape of JSF in different time points 1987, 2000 and 2018

Year	CONTAG	SHDI	SHEI
1987	60.80	1.23	0.69
2000	60.13	1.26	0.70
2018	46.12	1.46	0.82

Conclusions and recommendations

From 1987 to 2018, landscape change of land use has obviously occurred in the JSF. Urban/built-up land and barren land respectively increased by 246.37 and 60.53 km^2, but cropland decreased by 343.3 km^2 in the study area. Owing to rapid urbanization, obvious spatial differences in land use change occurred from 1987 to 2018 in the JSF. The historic or prehistoric human interaction with karst mountainous environments and modern development could result in widespread the disturbance of karst environments owing to rapid urbanization in karst region, thereby impacting both surface and sub-surface features (e.g. the Three Gorges Dam Project in China).

Additionally, the cropland's shape inclines to fragmentation and regularization from the patch class level, and the shapes of urban/built-up land and barren land have become increasingly distinct. On the other hand, the forestland coverage and water area occur slightly increasing. Moreover, for the response from patch landscape level, the artificial landscape type (urban/built-up land) is increasingly dominant because of the landscape patches expansion, but the natural landscape type (grassland) is decreasingly dominant. Whole landscape indicates that the tendency of fragmentation is deepening in the JSF owing to rapid urbanization in recent years. This study mainly indicates that a top priority in the relationship between fragile karst environment ecosystem and urban ecosystem in North China should be considerate in future decades.

For this purpose, some policy recommendations are drawn for long-term sustainable development of karst area in Jinan city of North China. On the one hand, anthropogenic disturbances should be continued to be controlled in the karst mountainous area of Jinan city to protect the forestland landscape and maintain the resilience of karst ecosystem. Although the forestland area in the JSF has increased by 68.7 km^2 from 1987 to 2018, the urban/built-up land area and barren land area also respectively increased by 246.42 km^2 and 60.52 km^2 from 1987 to 2018, showing an increase in urbanization influence. So, decision-makers should give a top priority in protecting the integrity of the forestland ecosystem in the karst area of Jinan city. On the other hand, during the process of urban sprawl from 1987 to 2018, a lot of contiguous patches of cropland, forestland and grassland were encroached by urban/built-up land or barren land, thereby resulting in a stronger artificial landscape in the Jinan's karst area. Therefore, decision-makers of urban development should take such rational and sustainable strategies as retaining large patches of grassland and forestland with equal distribution in this area.

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Conflict of interest

The authors declare no conflict of interests.

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