Research on the impact of urbanization on Climate and Ecological Environment of World Cultural Heritage Site– A case study of Fuling Mausoleum in Qing Dynasty

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Research Article

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Posted Date: September 12th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2042578/v1

Research on the impact of urbanization on Climate and Ecological Environment of World Cultural Heritage Site-- A case study of Fuling Mausoleum in Qing Dynasty

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Abstract

Taking the Fuling Mausoleum,a world cultural heritage, as the research object, this paper analyzes the impact of urbanization on the climate and ecological environment of the World Cultural Heritage site.Based on the Landsat series remote sensing image data and meteorological station data from 2005 to 2020, the spatial and temporal change characteristics of urban land in the region where the world cultural heritage located are characterized. The temporal and spatial change characteristics and influencing factors of climate change and habitat quality in the study area are quantitatively evaluated and analyzed by GIS technology and Habitat Quality module of InVEST model.The results show that: (1) the urban land in the area where Fuling Mausoleum is located shows a trend of expanding eastward and southward along the existing urban land from 2005 to 2020, and agricultural land and woodland to construction land are the main sources of new urban land, which is in line with the characteristics of urban development and changes in Shenyang in recent years.(2)During the study period, the temperature in the area where the Fuling Mausoleum was located showed a fluctuating upward trend, the average temperature increased by 0.15C / 10a, and the precipitation increased by 102mm/10a. At the same time, NDVI showed a significant negative correlation with the average temperature, and a positive correlation with precipitation as a whole.(3)From 2005 to 2020, the habitat quality of the Fuling Mausoleum heritage site showed an overall downward trend: among them, the average annual decline rate was 0.36% in the areas with high habitat quality levels, 0.14% in the middle regions, and 0.5% in the areas with low habitat quality levels. The heritage site is strongly disturbed by human factors, especially the degradation in the east of Qing Fuling is very obvious, but the distribution of the degraded area is relatively scattered. The low-value and non-degraded areas of habitat degradation index are mainly located in the heritage area and the eastern mountain region.

Keywords: Urbanization; World Cultural Heritage; Climate Change; Ecological Environment Quality; Fuling Mausoleum in Qing Dynasty

1 Introduction

Most of the world cultural heritages are located in the urban center or the suburbs. The increasingly frequent urban land expansion and urban renewal activities have greatly reduced the vegetation area around the world cultural heritage sites and significantly increased the impervious surface, which has seriously affected the climate and ecological environment of the world cultural heritage sites.The newly released National Strategy for adaptation to Climate change 2035 makes it clear that the degree of warming in Northeast China is greater than the national average, facing increased risks such as increased summer flooding, and it is particularly important to protect endangered cultural heritage threatened by climate change.Therefore, long-term, continuous and accurate monitoring of urban land use change, climate and ecological environment evolution of the World Cultural Heritage site can provide a scientific basis for heritage protection departments to promote the protection of World Cultural Heritage in an orderly manner.

Urbanization is an important feature to measure the development level of regional economy, society, culture and so on. While the process of urbanization promotes economic development, social progress and cultural prosperity, it also has a significant impact on the regional climatic environment and ecological environment(Qin Dahe et al.2021). At present, the research on the evolution of regional climate and ecological environment caused by urbanization is mainly focused on: collecting urban meteorological data to study the characteristics of urban heat island change and ecological environment change (Liu Yuche et al. 2013;Hicks et al.2010); using numerical simulation to study urban climate and eco-environmental effects (Song, X. S. et al.2011;Trusilova K et al.2008); based on urban remote sensing data to study the climate and eco-environmental effects of land use cover change (LUCC) (Ideki, O.and Weli, V. 2019;XIA Chuyu et al.2022;Li Yanan,Duo et al.2022;Li Shengpeng et al. 2020;Shi Xiaowei,Feng et al. 2021).In the above research, using meteorological data to analyze urban climate change and ecological effects is the most common method in the study of urban climate and ecological environment, and numerical simulation is also one of the methods in urban climate change and ecological evolution. In recent years, satellite remote sensing data have been widely used in the study of urban climate and ecological environment because of their high spatial resolution. In the context of the current high-quality development of urban economy, the urbanization process of heritage sites is highly spatio-temporal dynamic, and the dynamic monitoring of urban remote sensing based on sparse phase can not fully characterize the dynamics of urbanization around heritage sites. Continuous monitoring can directly and accurately reflect the change of urban land around the heritage site. In addition, most of the existing studies are limited to the analysis of the heritage building environment, and seldom involve the evolution of climate and ecological environment caused by the urbanization of the heritage site. Therefore, based on the Landsat series of remote sensing images from 2005 to 2020, this paper characterizes the spatio-temporal change of the urban land use in the Qingfu Tomb, the world cultural heritage, and evaluates the ecological environment quality of the heritage site based on the InVEST Habitat Quality model, and deeply discusses the impact of urbanization on the ecological environment of the heritage site.

2 Materials and Methods

2.1 Study Area

Fuling Mausoleum is located at the southern foot of Tianzhu Mountain in the eastern suburb of Shenyang, Dongling Park, near the Hun River.It is the mausoleum of Nurhachi, the emperor of the

Qing Dynasty. Located in the eastern suburbs of Shenyang,so it is also known as Dongling Mausoleum, which is one of the three mausoleums in Shengjing. The main body of the mausoleum is getting higher and higher from the south to the north, and then becomes wider and wider, covering an area of about 194800 square meters. As a sacrificial place for Qing emperors, Fuling Mausoleum is a well-preserved and distinctive imperial mausoleum complex in Qing Dynasty. It is a fine work of art and Chinese treasure carefully designed and built by ancient Chinese philosophers. In 1988, it was announced by the State Council as the third batch of national key cultural relics protection units. On July 1, 2004, it was listed as a World Heritage site by the United Nations Educational, Scientific and Cultural Organization (SHARP R,et al.2020).

Fuling Mausoleum and its existing environment are the study area of this paper (fig. 1). In recent years, the expanding city size has a significant impact on the climate and ecological environment of the heritage site. Climate change monitoring and eco-environmental quality assessment are particularly important as the basis of overall heritage protection.

Figure 1 Geographical location map of the study area.

2.2 Data Source

The data set mainly used in this paper includes Landsat series of remote sensing data, DEM, meteorological data and road traffic vector data, all of which are in WGS_1984 coordinate system. The Landsat and DEM data are derived from the Geospatial data Cloud of the Chinese Academy of Sciences (http://www.gscloud.cn/), which are the original data from Landsat series of remote sensing images and 30m resolution digital elevation data of GDEMV2 in the study area from 2005 to 2020. They are mainly used for land use change analysis in urban area and habitat quality assessment of heritage sites. The meteorological data are collected from the data of the World Weather "Reliable

Prognosis" website (rp5.ru). It is the daily mean temperature and precipitation statistical data of the meteorological stations near the study area from 2005 to 2020, which is mainly used for monitoring climate change in heritage sites. Road traffic vector data, including highways, national highways, provincial highways, county highways and railways, are derived from the National Geographic Information Resources Catalog Service system (http://www.webmap.cn), which is used to assess the habitat quality of heritage sites. Based on the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model Habitat Quality module to calculate the habitat quality of heritage sites, the required parameters come from the existing research results at home and abroad , as well as the scores of experts in related fields.

2.3 Research Methods

Extraction of urban land. The definition of urban land used in this paper is that non-vegetation man-made areas (such as towns, rural settlements, road traffic, etc.) dominate (more than 50%) pixels. After radiometric correction, cropping, atmospheric correction and other pre-processing of the original image data based on the ENVI platform, the Support Vector Machine (SVM) classification method is used to supervise the Land Use / Land Cover Change (LUCC) classification of the study area, according to the regional characteristics of the Fuling Mausoleum and the purpose of habitat quality evaluation. The types of land use / cover are divided into five types: agricultural land, forest land, urban land, other agricultural land and water, and the land use / cover map from 2005 to 2020 is obtained.

Monitoring the year of urbanization. The range of new urban land in the study period is obtained from 2005 to 2020 as the base year. Through the consistency test of the land use / cover data of this base year, the reliability of the new urban land use range is increased, thus the long-time series continuous change information of urban land in the study area is obtained and the spectral characteristics and time series information of Landsat long-time series images are mined deeply. The year detection method of urbanization of heritage sites is constructed to obtain the characteristics of urban land use pattern and urban expansion (or renewal) of the study area year by year from 2005 to 2020.

Figure 2 Verification of urbanization year detection based on visual interpretation of Landsat series remote sensing images from 2005 to 2020.(Band combination: near infrared-red-green band)

Figure 3 Results of urbanization year detection based on NDVI time series curve mutation point

By randomly selecting 50 verification sample points in the new urban land use area, the clear Landsat images from 2005 to 2020 are obtained in ENVI (with the sample points as the center, the network of 1km buffer radius is constructed), and supplemented by the available Google Earth high-resolution images and vegetation index curves, each sample point is visually interpreted one by one. According to the new urban land from different sources, the long time series curve of vegetation index is constructed, and the sudden change point is detected. Taking the geometric center sample point of the study area as an example, the year monitoring of urbanization at pixel level is obtained (figure 2) and the year of urbanization is verified by visual interpretation based on NDVI time series curve (figure 3).According to the Landsat images (Band: NIR-Red-Green) in figure 2 for a total of 15 years from 2005 to 2020, the pixel was covered by vegetation from 2005 to 2011, was reclaimed from 2012, and the new urban construction was completed in 2019, that is, the urbanization was completed. At the same time, according to the results of the mutation point detection based on the NDVI curve in figure 3, the pixel began to urbanize in 2012 and completed the urbanization transformation in 2019.

Climate change monitoring. In the climate change monitoring research based on land use and cover change, the meteorological data are collected from the daily average temperature and precipitation of the meteorological stations near the study area from 2005 to 2020. After removing the outliers and missing values, the annual mean temperature anomaly change and annual precipitation change in the study area are obtained, and the characteristics of NDVI and climate change are obtained by using time series analysis and other methods.

Habitat quality assessment. The InVEST model was jointly developed by Stanford University, the World Wildlife Fund and the Nature Conservancy (HILLARD E M et al.2017). The model has significant advantages in characterizing the spatio-temporal dynamic changes of regional ecosystem services and visualizing the evaluation results. The habitat quality (Habitat Quality) module of the model comprehensively considers the sensitivity of each land use type to threat factors and external threat intensity to evaluate the distribution of habitat quality in the study area, and measures biodiversity and ecosystem function according to the score of habitat quality. The model assumes that the habitat quality of each grid pixel is determined by its own land use type and its distance from the threat source, in which the calculation formula of habitat degradation (Bhagabati, N. K. et al.2014) is as follows:

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} (w_r / \sum_{r=1}^{R} w_r) r_y i_{rxy} \beta_x S_{jr} \quad (1)$$

In the formula, y is all the raster in the r map of the habitat threat source of the heritage site, and y_r is the number of raster pixels, w_r is the weight of different threat source, r_y is the intensity of threat source, i_{rxy} is the stress effect of threat source r in each grid y of habitat in the study area, β_x is the accessibility level of habitat grid x, and S_{jr} is the sensitivity of land use type j to threat source r. The values of these influencing factors range from 0 to 1. Among them, the stress effect of threat source r in the threat source grid y on the habitat in the habitat grid x tends to decline with the increase of distance, and the attenuation mode can be divided into linear attenuation and exponential attenuation (Wen Zhuyun et al. 2022). The calculation formula is as follows:

$$i_{rxy} = 1 - d_{xy} / d_{r\max} \quad (2)$$

$$i_{rxy} = \exp[-(2.99 / d_{r\max}) d_{xy}] \quad (3)$$

In the formula, d_{rxy} is the linear distance between the habitat grid x and the threat source grid y, and $d_{r\max}$ is the maximum distance of the threat source r. The periphery of the heritage area is greatly affected by urban expansion. Urban land and roads are extracted as threat sources to determine the relevant maximum stress distance, weight and attenuation type (Table 1).

Table 1 Threat factor weight

The formula for calculating the habitat quality index (et al.2017) is as follows:

$$Q_{xj} = H_j \left[1 - (Dxj^{z} / (Dxj^{z} + k^{z}) \right] \quad (4)$$

In the formula, Q_{xy} is the habitat quality of habitat grid x in land use type j, H_j is the habitat suitability corresponding to land cover type j, k is the semi-saturation constant (1/2 of the maximum value of D_{xj}), z is the default parameter of the model, with a value of 2.5. In this model, the higher the habitat suitability of different land use types (between 0 and 1), the closer to the natural ecosystem. The sensitivity of the natural landscape to the ecological threat source is larger (between 0 and 1), and the artificial landscape has strong anti-interference ability to the threat source.In this paper, based on the reference value of InVEST 3.11.0 and previous research results, the suitability of various types of habitats and sensitivity to stress factors are shown in Table 2. Based on the calculation of the habitat quality model in the area where Fuling Mausoleum is located, in order to statistics and compare the changing trend of habitat quality in the study area, the habitat quality values are divided into three grades: low , medium and high , corresponding to the habitat quality values of 0-0.50, 0.50-0.75, and 0.75-1, respectively.

Table 2 Sensitivity of land use types to ecological threat factors

3 Results and Discussion

3.1 Urban land use change of heritage site

The spatial distribution map of urban land from 2005 to 2020 (figure 4) shows the process of urbanization in the region since the Fuling Mausoleum was listed as a World Cultural Heritage site. In 2005, the urban land in Fuling Mausoleum was mainly distributed in the west of the study area, and the level of urbanization was low; in contrast, in 2020, the urban land in the study area increased significantly, mainly to the east of Dongling Park and to the south of the Hunhe River showing a trend of eastward and southward expansion along the existing urban land, in line with the characteristics of urban development and changes in Shenyang in recent years.

Figure 4 Spatial distribution of urban land from 2005 to 2020

Based on the results of remote sensing interpretation, the urbanization year of pixel level of new urban land in the heritage site is obtained, and the changing characteristics of urban land area and proportion time are obtained (Table 3): in 2005, the proportion of urban land in Fuling Mausoleum is 33.58%. Except for water bodies, the proportion of non-urban land is 62.40%; by 2020, the proportion of urban land in the study area will increase by 7.50%, and non-urban land will decrease significantly.

Table 3 Land use change from 2005 to 2020

In order to meet the needs of economic development and urban construction, the urban expansion in the heritage area is obvious, and the new urban land in the process of urbanization mainly comes from forest land and agricultural land (Table 4). From 2005 to 2020, the proportion of land conversion from various types of land to construction land was 51.51%, of which 17.40% was converted from agricultural land to construction land and 25.55% from forest land to construction land, which was the main source of new urban land. The conversion area from construction land to other land types accounts for 30.24%, which is smaller than the area transferred to construction land, and the change of water area in the region is not obvious.

Table 4 Transfer matrix of land use change from 2005 to 2020

3.2 Climate change monitoring at heritage sites

In recent years, the global average surface temperature shows an increasing trend, and the regional difference of precipitation is significant. In order to better study the changing trend of air temperature and precipitation in the heritage area, this paper collates and calculates the annual average temperature anomaly and annual precipitation in the study area from 2005 to 2020, as shown in figures 5 and 6. After 2014, the temperature in the study area showed a fluctuating rising trend, the average temperature increased by 0.15C / 10a, and the precipitation increased by 102mm/10a.

Figure 5 Variation map of annual mean temperature anomaly in the study area from 2005 to 2020

Figure 6 Variation of annual precipitation in the study area from 2005 to 2020(Data from "Reliable Prognosis" (rp5.ru))

Urbanization causes changes in surface vegetation, which in turn can have an impact on regional climate change within a radius of 10 km around the heritage site. Based on meteorological data and the above-mentioned interannual variation of NDVI, this paper analyzes the relationship between NDVI change and air temperature and precipitation. With the increase of NDVI value in the study area, the average temperature decreases, and the NDVI value decreases and the average temperature increases. The two show significantly opposite characteristics of change. This is because the change of NDVI mainly depends on urban construction or engineering construction, and has a significant negative correlation to the local air temperature in the study area.

Figure 7 Relationship between NDVI and temperature change in the study area from 2005 to 2020

On the whole, the vegetation area around the heritage site is obviously degraded due to the process of urbanization, such as the decrease of NDVI value and precipitation, and the improvement of vegetation evapotranspiration capacity due to the implementation of urban greening or ecological engineering, thus promoting the increase of regional precipitation. The change trend of NDVI and precipitation in the study area is consistent on the whole, and there is a positive correlation between NDVI and regional precipitation.

Figure 8 Relationship between NDVI and precipitation in the study area from 2005 to 2020

3.3 Habitat quality assessment of heritage sites

3.3.1 Temporal and spatial distribution of habitat quality

In order to characterize the impact of land use change on regional habitat quality in Fuling Mausoleum, ArcGIS was used to reclassify and classify the habitat quality results assessed by InVEST model in 2005 and 2020, and the spatial distribution map of habitat quality was obtained (figure 9). It can be seen from the picture that the habitat quality of Fuling Mausoleum in 2005 is a high-grade region, and different ecological quality grades are distributed in its surrounding areas. With the continuous development of cities in recent years, the construction land in the study area increased significantly in 2020, and the areas with low habitat quality showed a significant expansion trend. The habitat quality of Fuling Mausoleum is still high grade, and the habitat quality of the eastern part of Fuling Mausoleum is obviously decreased.

Figure 9 Spatial distribution map of habitat quality in the study area from 2005 to 2020

According to the statistics of the area changes of each habitat quality grade (Table 5), the areas where the heritage sites are located with high habitat quality levels decreased from 112.38 km^2 in 2005 to 97.08 km^2 in 2020, with an average annual decline rate of 0.36%. In the middle region, the habitat quality decreased from 74.59 km^2 to 68.76 km^2, with an average annual decline rate of 0.14%. The area with low habitat quality grade increased from 96.48 km^2 to 117.61 km^2, with an average annual increase rate of 0.5%. Due to man-made interference such as urban expansion and urban renewal, the eco-environmental quality of new urban land around Fuling Mausoleum and the south bank of the Hun River has declined significantly.

Table 5 Statistics of habitat quality grade area in the study area from 2005 to 2020

3.3.2 Spatio-temporal analysis of habitat degradation

It should be pointed out that the habitat degradation index of the site of Fuling Mausoleum reflects the degree to which the world cultural heritage is affected by human factors such as the process of urbanization, and to a certain extent, it can represent the changes of the ecological environment in the area where the heritage site is located. Combined with the spatial distribution map of land use types and habitat degradation distribution map of heritage sites, it can be concluded that the areas with high value of habitat degradation index are mainly distributed in urban land and surrounding areas, and are strongly disturbed by human factors. in particular, the degradation in the east of the heritage area is very obvious, but the distribution is scattered. The low value area of habitat degradation index is mainly located in the heritage area and the eastern mountain region, while the non-degradation area is mainly distributed in the eastern mountain region with high vegetation cover and far away from human disturbance.

Figure 10 Distribution map of habitat degradation from 2005 to 2020

4 Conclusion

According to the changes of urban land use and vegetation cover in the study area in 2005 and

2020, it can be concluded that:

(1) The change of urban land in the heritage site. Since the Qing Fu Mausoleum was listed as a world cultural heritage, the urbanization process of its region is remarkable. In 2005, the urban land in the area where Fuling Mausoleum is located is mainly distributed in the west of Fuling Mausoleum, and the level of urbanization is low; in 2020, the urban land in the study area is mainly distributed in the east of Dongling Park and south of the south bank of Hunhe River, showing a trend of eastward and southward expansion along the existing urban land, which is in line with the characteristics of urban development and changes in Shenyang in recent years. From 2005 to 2020, the proportion of land conversion from various types of land to construction land was 51.51%, of which 17.40% was converted from agricultural land to construction land and 25.55% from forest land to construction land, which was the main source of new urban land. The proportion of conversion area from construction land to other types of land is 30.24%, which is smaller than the area of construction land transferred to other types of land.

(2) Climate change monitoring of heritage sites. During the study period, especially after 2014, the regional air temperature in Qingfuling Institute showed a fluctuating upward trend, with the average temperature increasing by 0.15°C/10a and the precipitation increasing by 102mm/10a. Based on the interannual variation of NDVI of meteorological data and vegetation cover information in the study area, the relationship between NDVI change and temperature and precipitation change was analyzed. NDVI and average temperature showed a significant opposite change characteristics, that is, negative correlation. In general, it showed a consistent trend with precipitation, that is, a positive correlation.

(3) Assessment of habitat quality in heritage sites. In 2005, the habitat quality of Qingfuling was high grade, and different ecological quality levels were distributed in the surrounding areas. In 2020,

the area with low habitat quality in the study area showed a significant expansion trend, and the habitat quality in the area where Qingfuling was located was still high. From 2005 to 2020, the average annual rate of decline was 0.36% in the area with high habitat quality level, 0.14% in the area with medium habitat quality level, and 0.50% in the area with low habitat quality level. It is strongly disturbed by human factors, especially the degradation of the east of the heritage area is extremely obvious, but the distribution of the degraded area is relatively scattered. The low value of habitat degradation index and non-degradation area are mainly located in the heritage area and the eastern mountainous area.

This study mainly focuses on the local climate change and habitat quality change caused by urbanization in the site of Fuling Mausoleum, the world cultural heritage. The NDVI value of the study area shows a significant opposite to the average temperature, because the NDVI change mainly depends on urban construction or engineering construction. The vegetation area around the heritage site is obviously degraded due to the process of urbanization, such as the decrease of NDVI value and precipitation, and the improvement of vegetation evapotranspiration capacity due to the implementation of urban greening or ecological engineering, thus promoting the increase of regional precipitation.

The main reason for the decline of habitat quality is that the urban expansion makes the areas with lower habitat quality of heritage sites gradually radiate the periphery, at the same time, the areas with higher habitat quality become lower areas, and the process of urbanization in this region is significant, resulting in the expansion of threat sources. this leads to the degradation of habitat quality, the decline of habitat suitability and the decline of habitat quality. In addition, the population density of the area around the heritage is relatively large, the distribution of urban land is concentrated, the human disturbance is severe, the decline probability of habitat quality is large, the degree of habitat degradation is increasing, and the degraded area shows a trend of spatial expansion.

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Figures

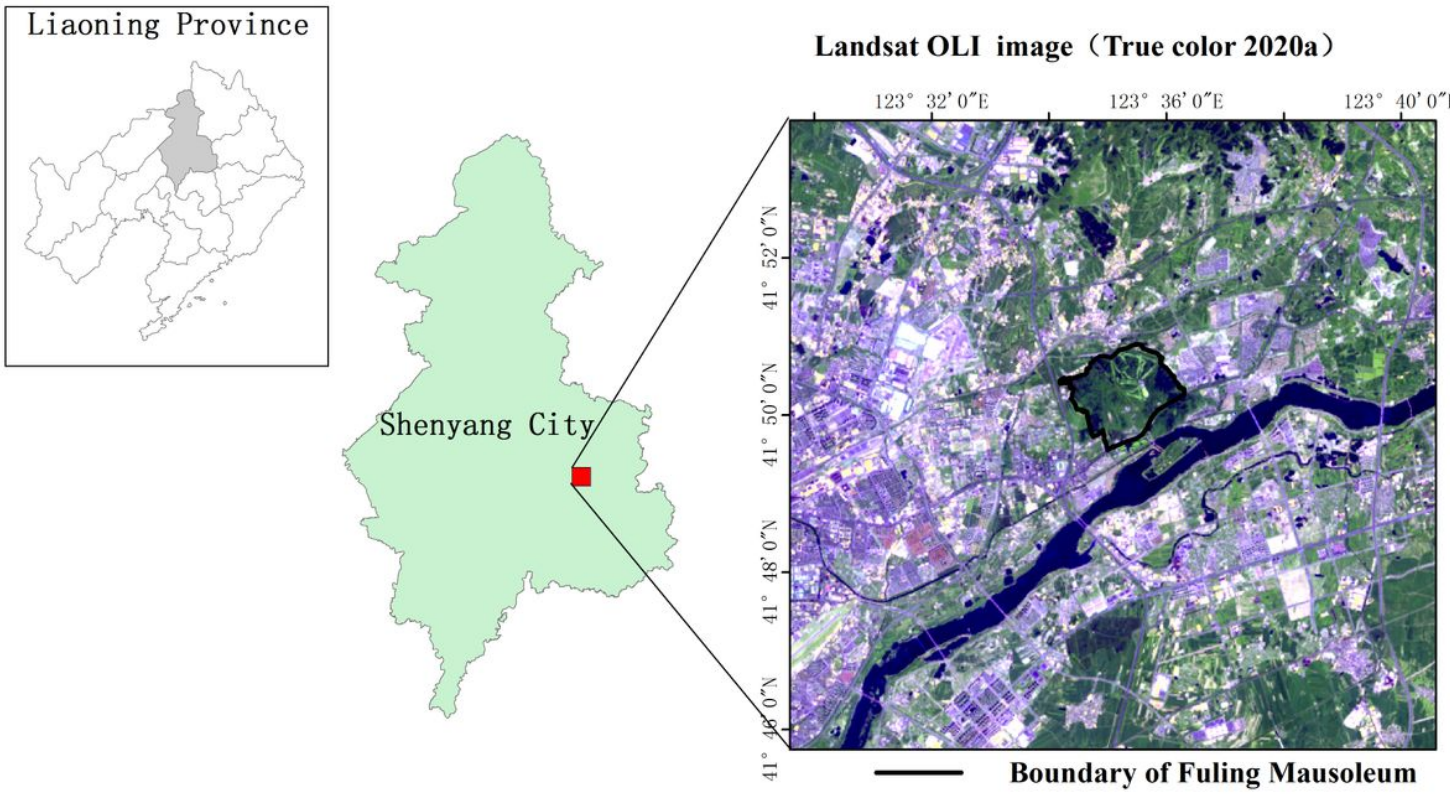

Figure 1

Geographical location map of the study area.

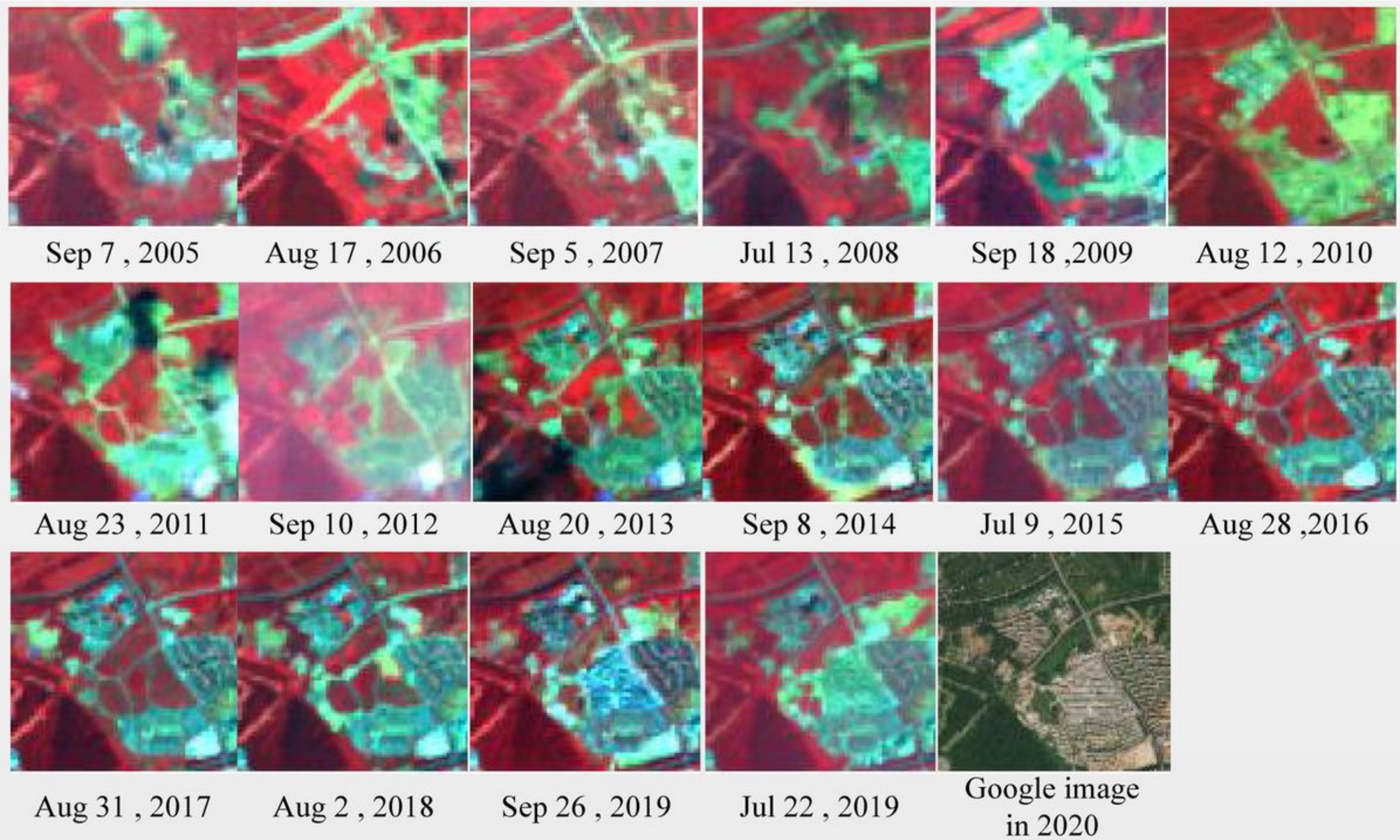

Figure 2

Verification of urbanization year detection based on visual interpretation of Landsat series remote sensing images from 2005 to 2020.(Band combination: near infrared-red-green band)

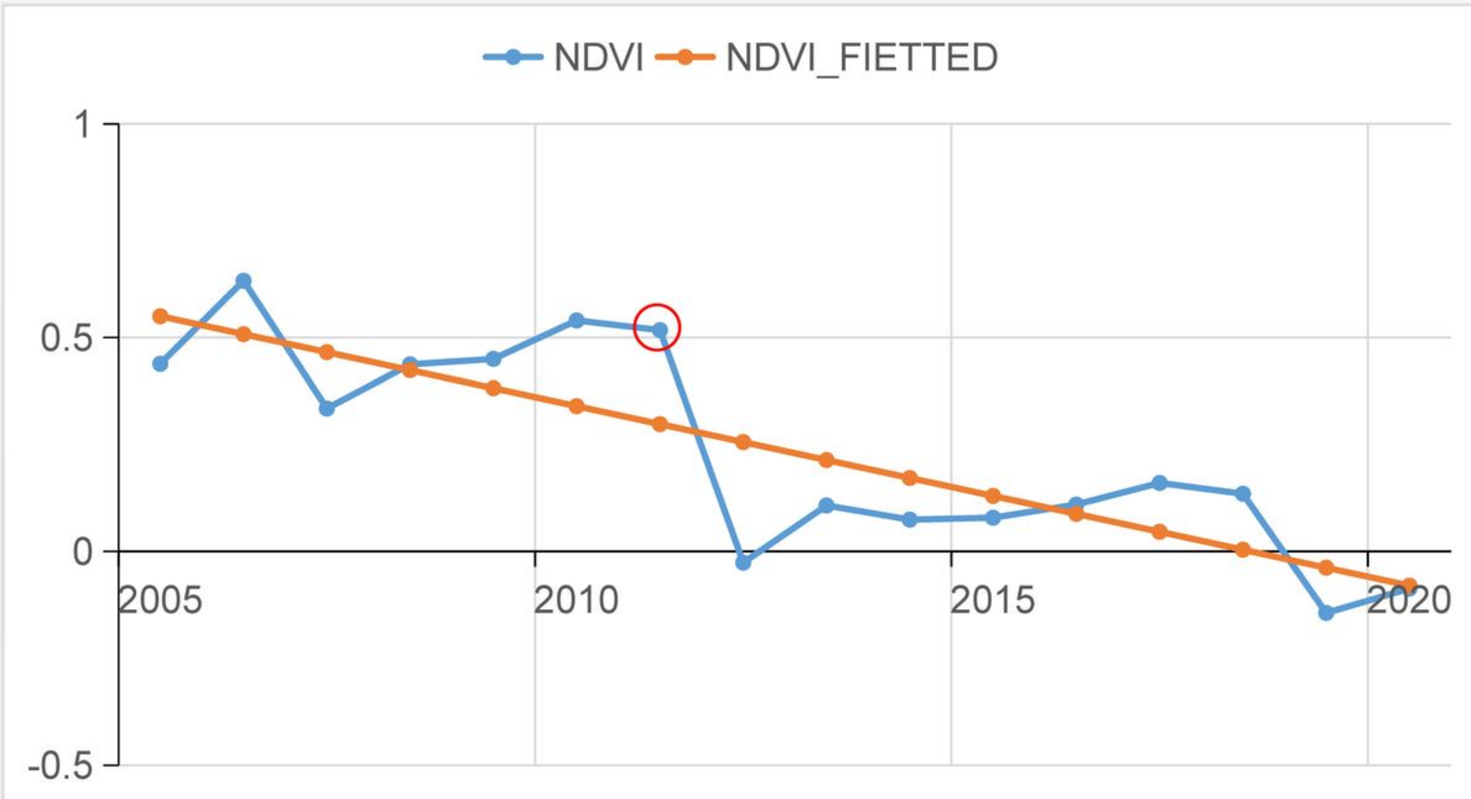

Figure 3

Results of urbanization year detection based on NDVI time series curve mutation point

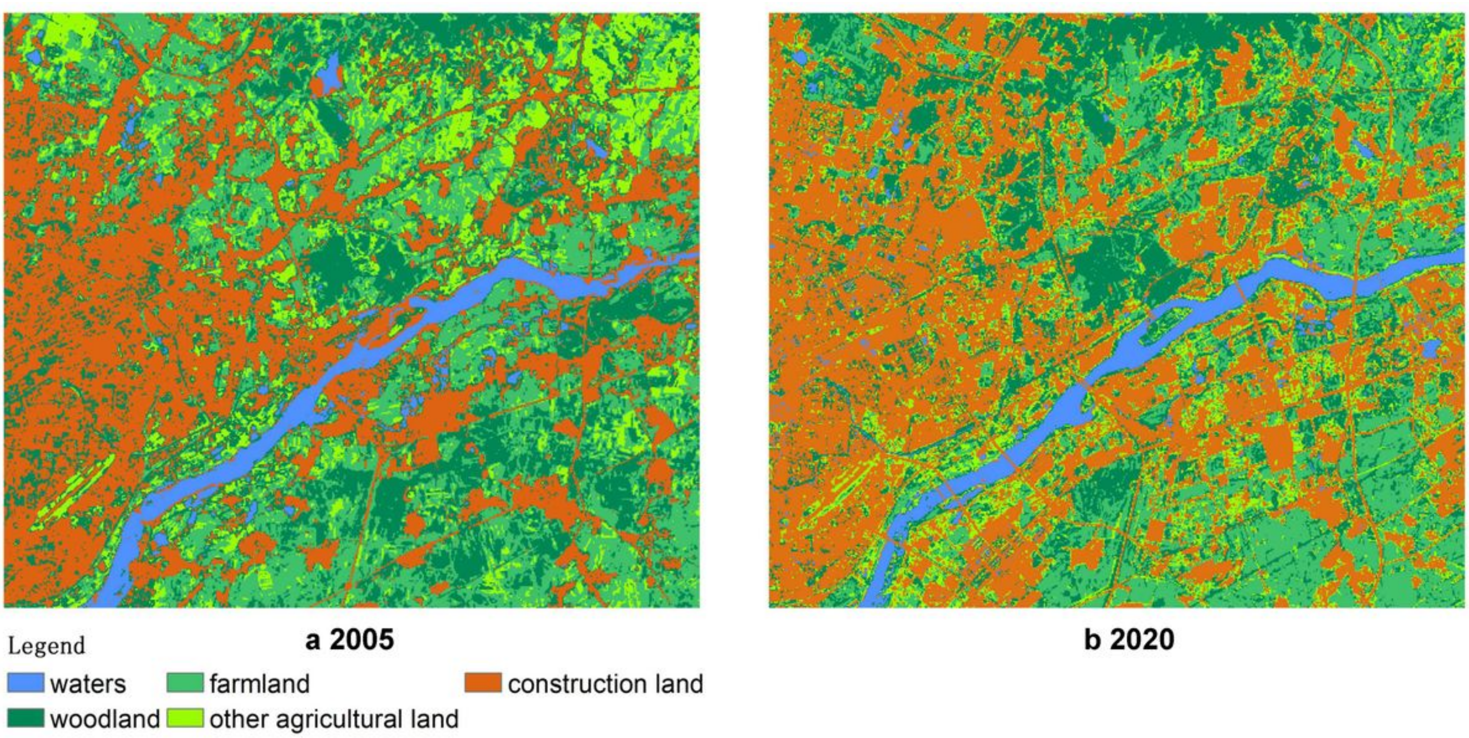

Figure 4

Spatial distribution of urban land from 2005 to 2020

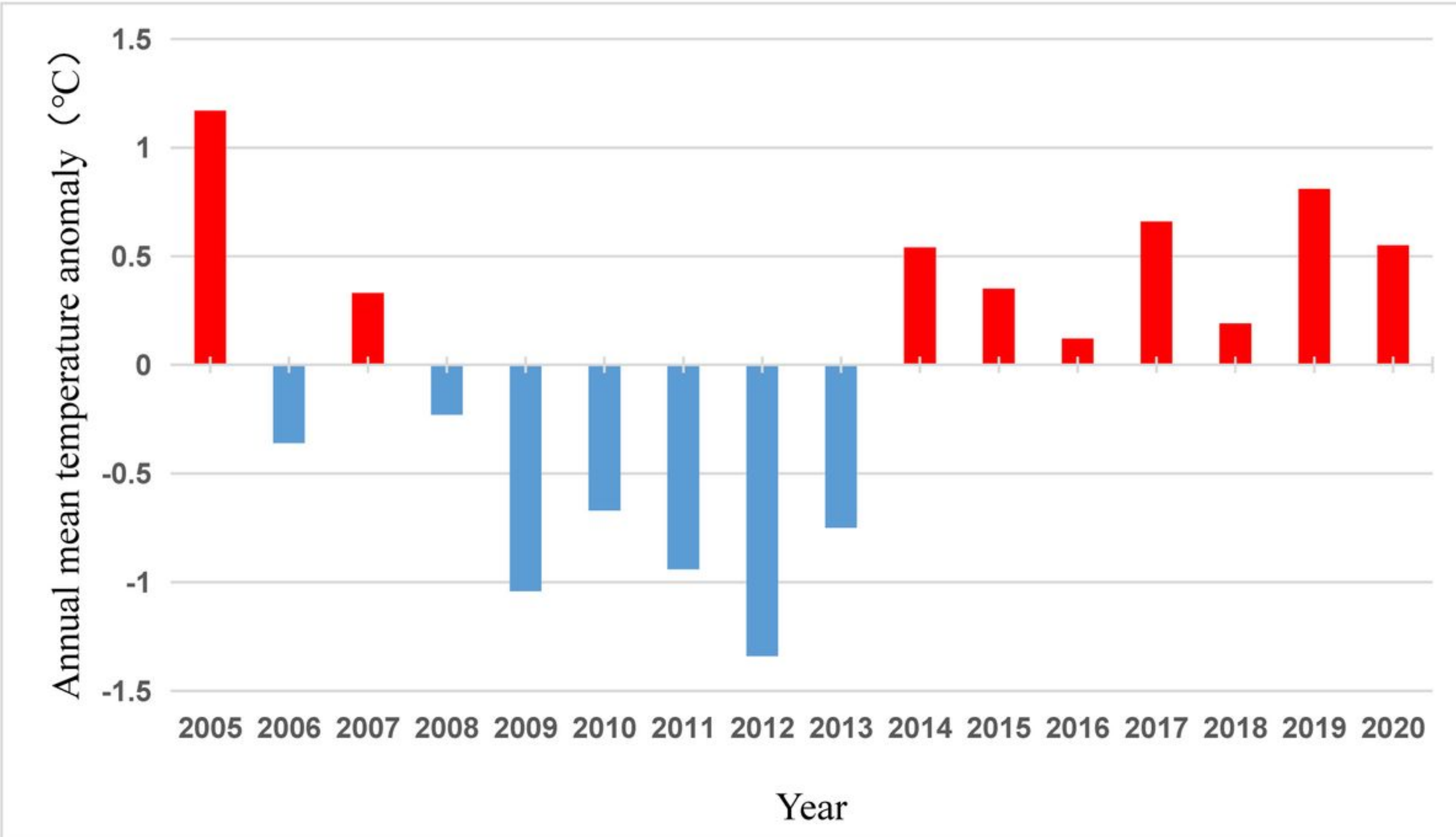

Figure 5

Variation map of annual mean temperature anomaly in the study area from 2005 to 2020

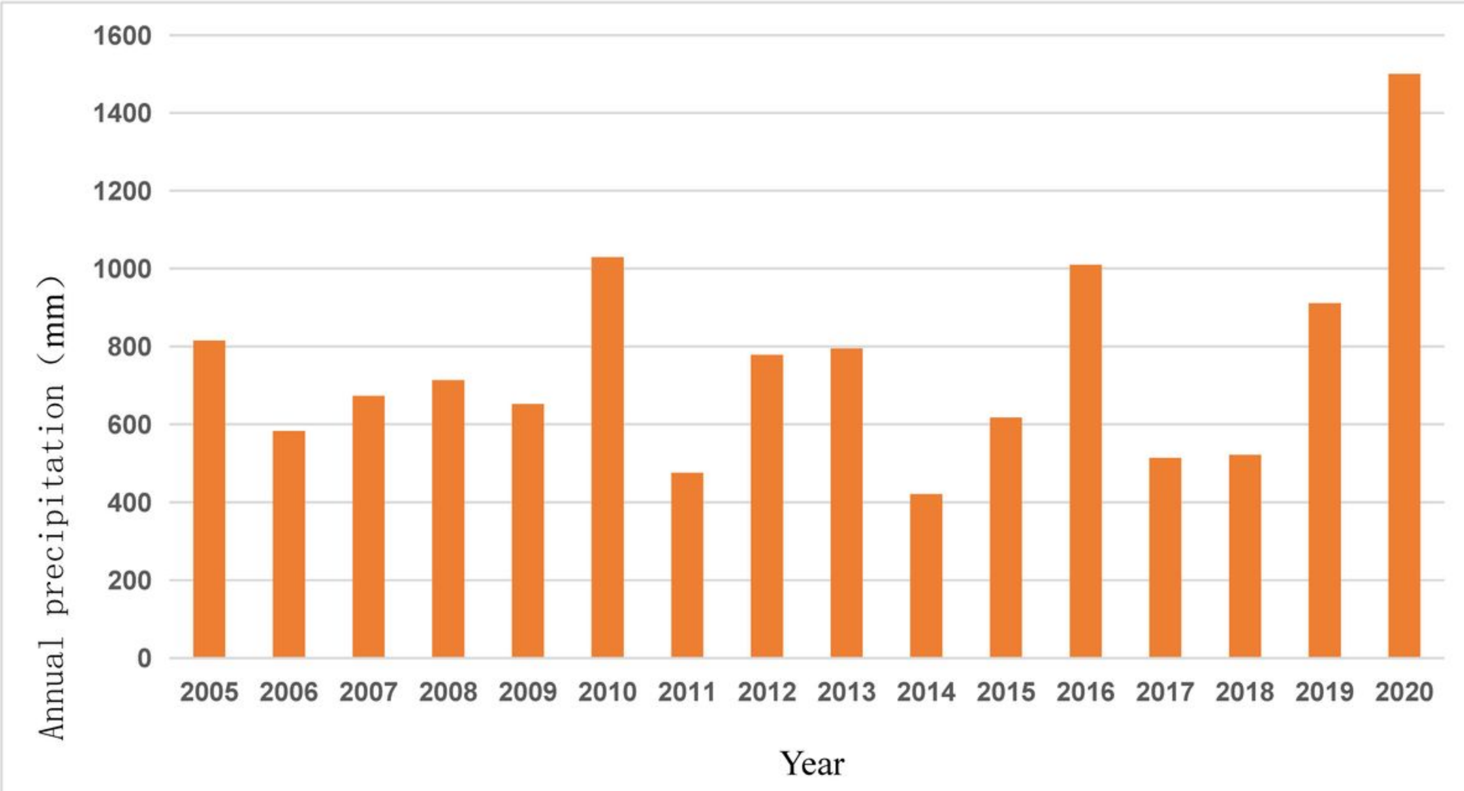

Figure 6

Variation of annual precipitation in the study area from 2005 to 2020(Data from "Reliable Prognosis" (rp5.ru))

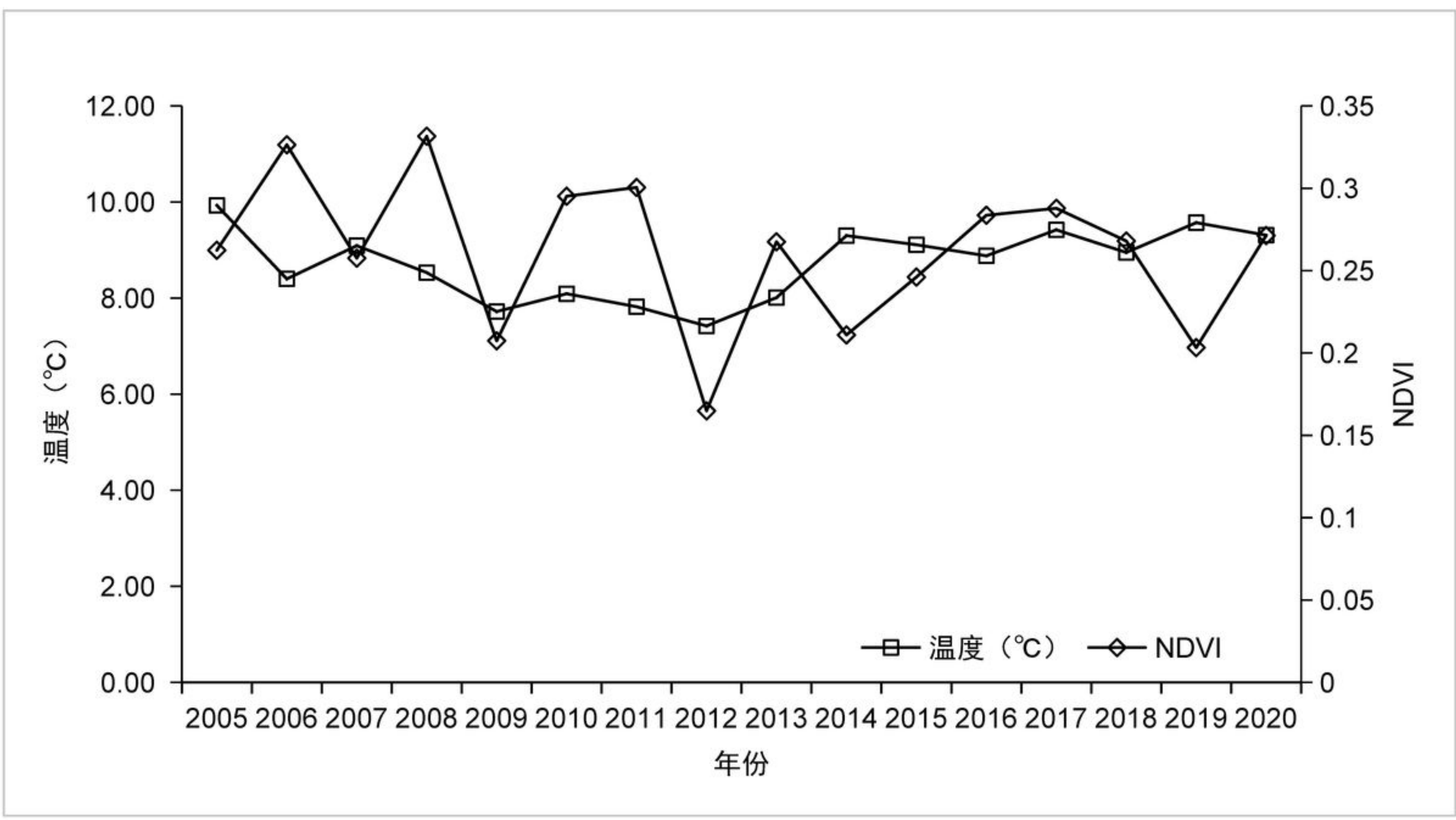

Figure 7

Relationship between NDVI and temperature change in the study area from 2005 to 2020

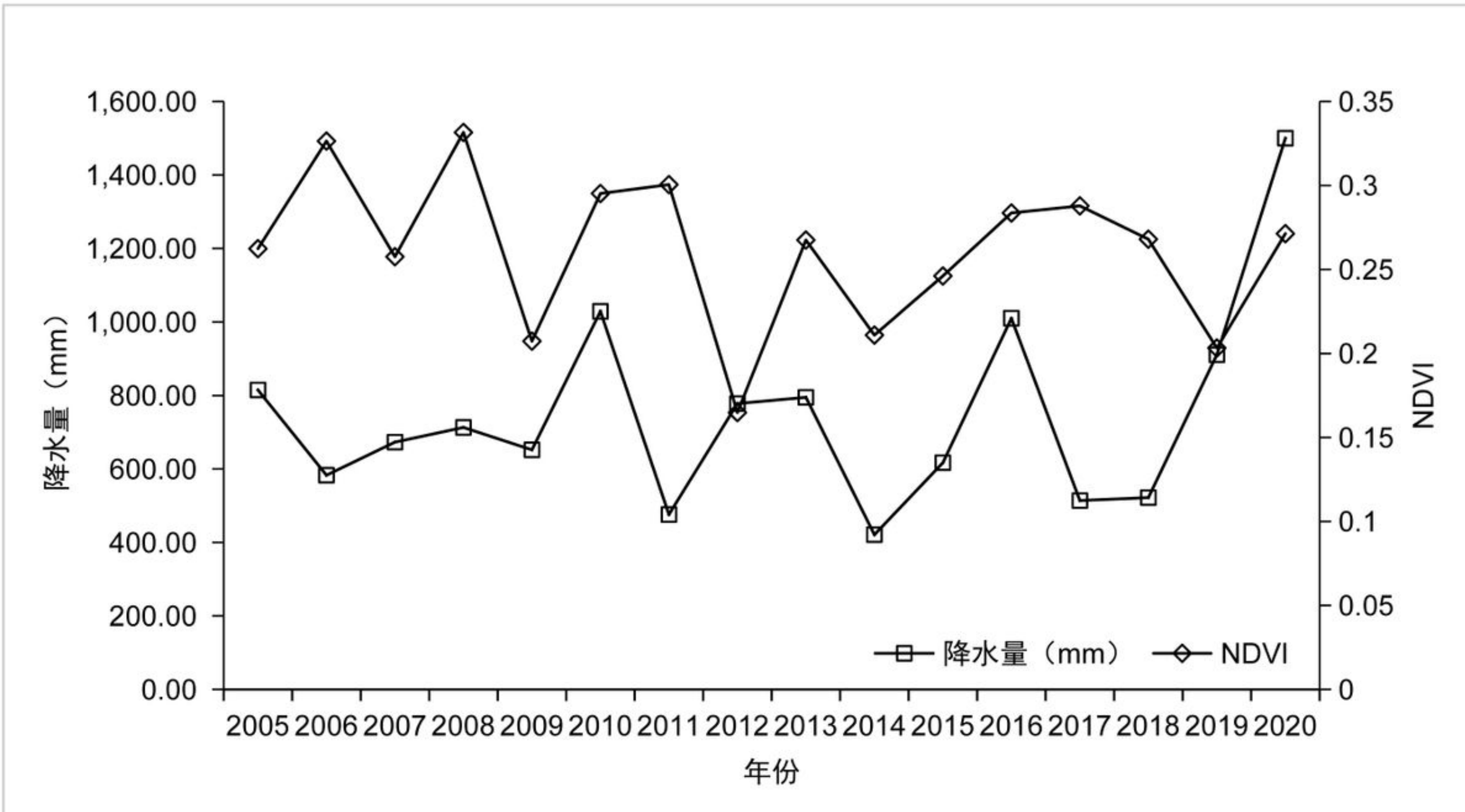

Figure 8

Relationship between NDVI and precipitation in the study area from 2005 to 2020

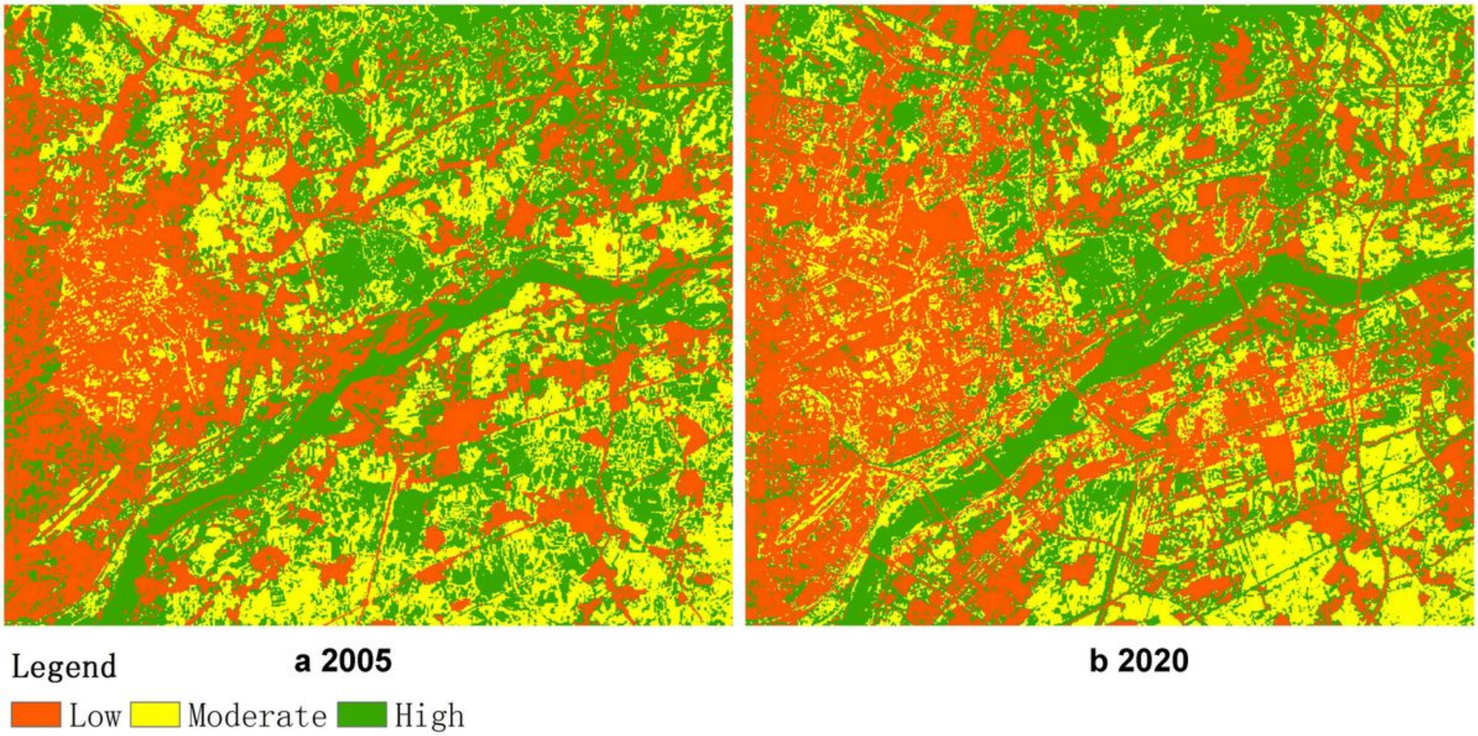

Figure 9

Spatial distribution map of habitat quality in the study area from 2005 to 2020

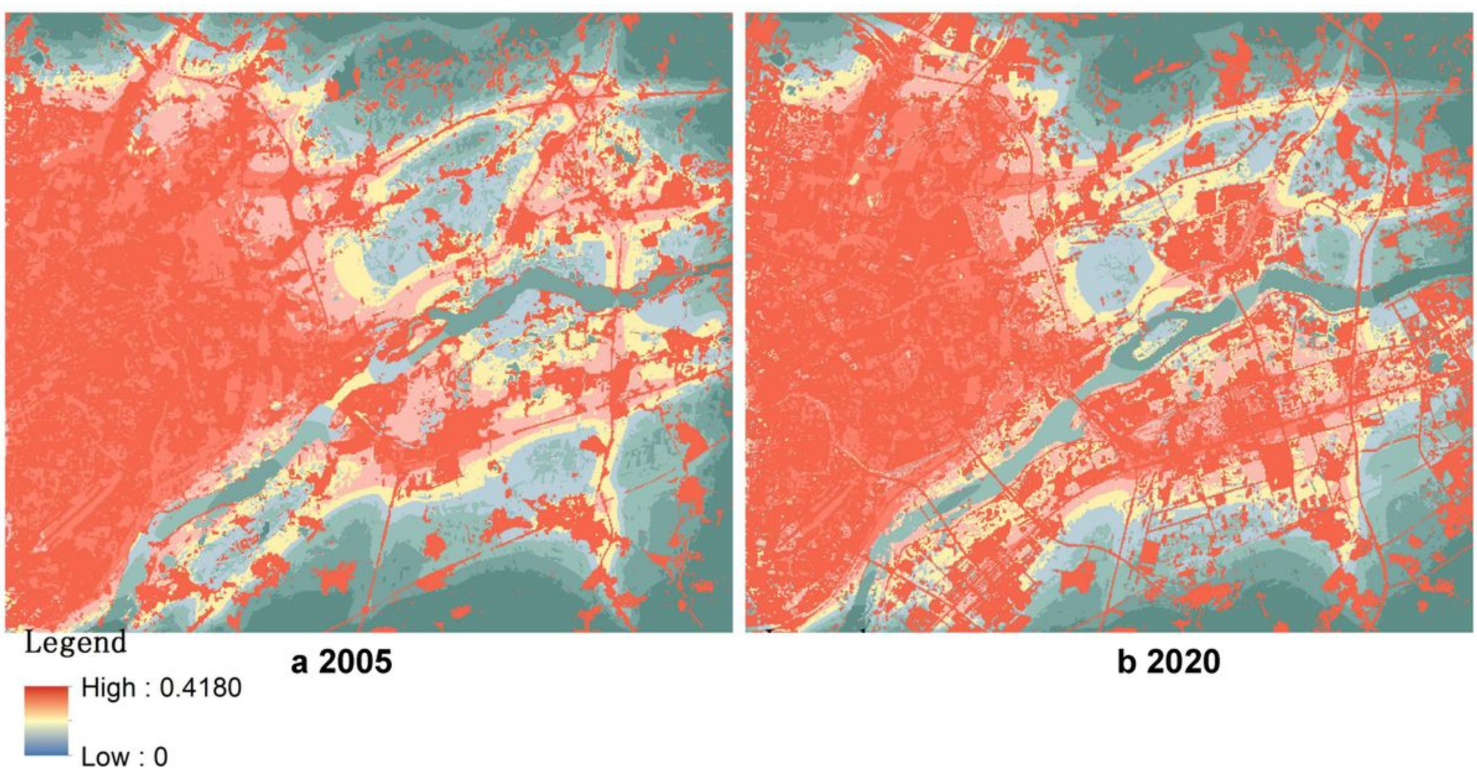

Figure 10

Distribution map of habitat degradation from 2005 to 2020

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.xlsx
- Table2.xlsx
- Table3.xlsx
- Table4.xlsx
- Table5.xlsx