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Original Research

Study on Ecological Environmental Change of Former Qing Architectural Heritage Area in Shenyang Based on Remote Sensing Ecological Index

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Abstract

The regional ecological environment on which architectural heritage depends is one of the most important external factors affecting the overall protection of architectural heritage. A rapid, accurate and objective understanding of the ecological conditions of the architectural heritage regions within the city limits where human disturbances are more frequent is of great practical significance for the study of the overall conservation and heritage of the architectural heritage areas. Based on the remote sensing monitoring data from 1995 to 2019, using the Remote Sensing Ecological Index (RSEI) as a visual index, this study systematically analyzed the spatio-temporal evolution of the ecological environment status of Former Qing architectural heritage area in Shenyang during the past 25 years. The results indicated that: (1) The average RSEI represented a fluctuating upward trend in early Qing era architectural heritage area and various heritage types. The average RSEI of ancient tombs showed a significant growth trend, while the ancient buildings showed a low-speed growth. (2) The ecological environment of Former Qing architectural heritage area in Shenyang has been continuously improved, and the overall ecological environment quality of ancient tombs has a significant improvement trend. The proportion of ecological environment improvement area in ancient buildings is lower than that in ancient tombs. The ecological environmental quality are obviously polarized in each architectural heritage area each year.

Keywords: architectural heritage, remote sensing ecological index (RSEI), remote sensing monitoring

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Introduction

Architectural heritage reflects the footprints of human civilization and social activities and also carries the history and culture of human beings for thousands years [1]. In the context of ecological civilization, it is particularly important to clarify the interrelationship between architectural heritage protection and natural ecological environment and to comprehensively carry out multi-scale and multidisciplinary research on the influencing factors of architectural heritage protection. As early as 1933, the Athens Charter issued by the International Conference on Modern Architecture (CIAM) proposed that while protecting the structure and characteristics of the architectural heritage from destruction, the external space of the city where the architectural heritage belongs should also be respected, especially the environment around the architectural heritage should be paid special attention to, mentioning technical or social issues such as atmospheric environment and living environment [2]. The "Recommendations on the Conservation of Historic Areas and their Contemporary Role" adopted by the 19th session of United Nations Education Scientific and Cultural Organization (UNESCO) put forward the concept of "historic areas and their surrounding environment" protection [3]. "Environment" means the environment, natural or artificial, that influences the dynamic and static methods of observing historical areas. Gustavo Giovannoni, an Italian expert in the restoration of monuments, clarified the relationship between architectural heritage and urban space and its environmental atmosphere [4, 5]. In March 1985, the European Convention on the Protection of Architectural Heritage adopted by the Council of Europe emphasized the relevance and organic connection between cultural heritage and the natural environment, and paid attention to the inseparable overall relationship between architectural heritage and the natural environment [6]. In 1999, the Charter of Vernacular Architectural Heritage adopted at the 12th Congress of ICOMOS adopted the concept of architectural heritage, which is more conducive to focusing on its environmental characteristics [7].

Most of the existing research focuse on the basic theories and methods of architectural heritage protection, as well as the economic value and social benefits of architectural heritage. Based on architecture, heritage science, ecology, cartography and other disciplines, quantitative research on the ecological environment status of architectural heritage areas needs to be in-depth. With the development of remote sensing information technology, many scholars take advantage of this advantage and try to use mathematical models or digital operations and other methods to evaluate ecological environment quality from an objective and quantitative perspective, and the research scale and scope are constantly expanding, solved the problems of relying on instrument field investigation and manual detection in the past, which were time-consuming, high cost and susceptible to interference by external factors. Based on long-term monitoring data of remote sensing image monitoring data, this paper applies spatial information technology to represent the continuous and gradual-change process of the ecological environment change in the region where Shenyang's former Qing architectural heritage is located. It intends to systematically analyze its external influencing factors and apply a remote sensing comprehensive ecological index (RSEI) based entirely on remote sensing information and integrating multiple index factors. Visual expression of the spatial and temporal dynamic change characteristics of the ecological environment of the architectural heritage area from 1995 to 2019, accurate monitoring and evaluation of the external environment of the architectural heritage area.

Material and Methods

Overview of Study Area

In terms of geomorphologic unit, Shenyang is located in the transition zone between Liaodong Mountain and Lower Liaohe Plain, and its geomorphological form is transformed from the low hilly area in the northeast to the wavy inclined plain area in front of the mountain, while the central and western areas are the vast and flat Lower Liaohe Plain, during which the geomorphological form is diverse and the topographic height difference changes greatly. With Hunhe River as the boundary, the north of Hunhe River wedges into the city from the northeast of Hadaring to the southwest, and the south of Hunhe River wedges into the city from the southeast of Qianshan to the northwest, forming a "Dongshan" pattern. Liaohe River as the boundary, north of the Liaohe Xiushui River, Liuhe River, Luoyang River from north to south into the Liaohe River; Liaohe River, Puhe River, Hunhe River from east to west converge in the western part of the city, forming a "west water" pattern [8].

As the city with the most existing Former Qing architectural heritage in Liaoning Province, there are 12 places in Shenyang, including 11 places in the downtown area of Shenyang and 1 place in Xinmin city. The research area of this paper selects the former Qing architectural heritage area in the central urban area of Shenyang (as shown in Fig. 1), which is divided according to the heritage types, including ancient tombs and ancient buildings. Among them, the ancient tombs include Qingfu Mausoleum and Qing Zhaoling Mausoleum; the ancient buildings include Shenyang Imperial Palace, Yongan Stone Bridge, Shengjing City site, Shisheng Temple, Cien Temple, South Mosque, North Pagoda Falun Temple, South Pagoda and East Pagoda [9].

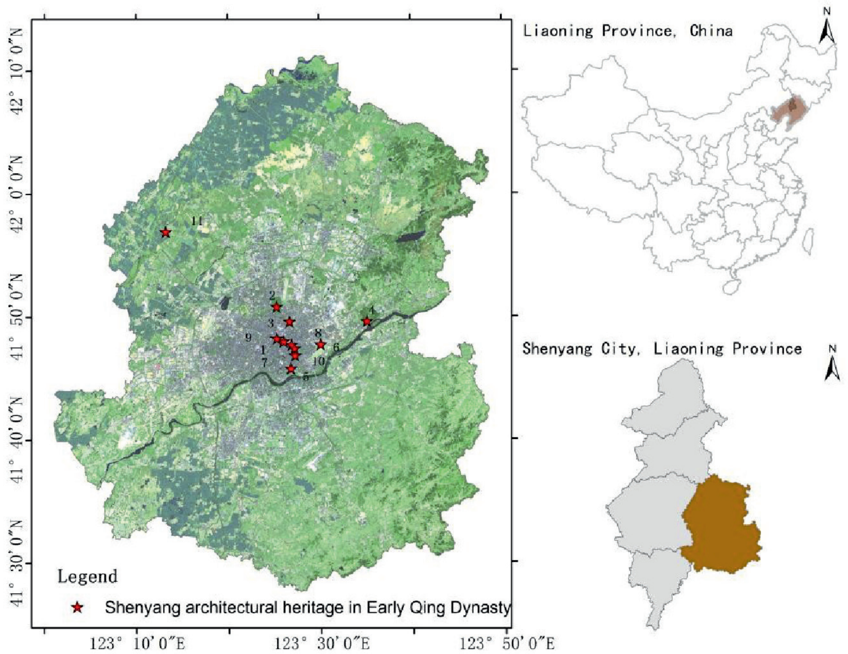

Fig. 1. Scope of the study area (1. The Imperial Palace of Shenyang, 2. Qingzhao mausoleum, 3. Shisheng Temple, 4. Fuling Mausoleum in Qing Dynasty, 5. South tower, 6. East tower, 7. Shengjing city site, 8. North Tower Falun Temple, 9. Halal South Temple, 10. Ci ‘en Temple, 11. Yong’an Stone Bridge).

Data Source and Study Methods

Data Source

The basic data source is the Landsat series remote images from 1995 to 2019 (Table 1), with a resolution of 30m. The time of image acquisition is roughly similar, which can ensure that vegetation, water and other ground objects maintain a stable state in similar seasons, and can ensure the accuracy of research results to a certain extent. The image with the least cloud cover is selected. The cloud cover of the six remote sensing images selected is relatively low, all below 5%, so as to improve the accuracy of data. Table 1 shows the basic characteristics of remote sensing images in the study area.

The secondary data include ASTER GDEM data with a resolution of 30 m and vector data on administrative boundaries.

In order to reduce the difference of remote sensing image data with different phases in terms of illumination, terrain and atmosphere, so as to ensure the accuracy of remote sensing image information extraction, this paper uses ENVI5.2 software to carry out radiometric calibration and atmospheric correction processing on the six periods of remote sensing images respectively, and uses radiometric calibration to convert the gray value of pixels into radiation brightness value. The FLAASH model was used for atmospheric correction, and the Band Math tool was used to convert the results of atmospheric correction into reflectivity data. The nearest neighbor pixel method and quadratic

Table 1. Basic characteristics of remote sensing images in the study area.

Sequence Number	Date acquired	Orbital Number	Satellite Name	Sensor Type	Average Cloud Cover
1	1995-09-04	p119r31	LANDSAT 5	TM	0.50
2	2002-09-15	p119r31	LANDSAT 7(SLC-on)	ETM+	0
3	2006-09-18	p119r31	LANDSAT 5	TM	0
4	2010-09-29	p119r31	LANDSAT 5	TM	0
5	2014-09-08	p119r31	LANDSAT 8	OLI_TIRS	0.28
6	2019-09-22	p119r31	LANDSAT 8	OLI_TIRS	0.02

Data source:Geospatial Data Cloud, Chinese Academy of Sciences (http://www.gscloud.cn/)

polynomial are used to register the six periods of remote sensing images, so that the root-mean-square error is controlled within 0.5 pixels. Finally, the vector boundary of Shenyang central city is used to cut the six periods of remote sensing image data, and the remote sensing image data of Former Qing architectural heritage area in Shenyang is obtained.

Remote Sensing Ecological Index (RSEI) Model

In the analysis of the external ecological environment of the former Qing architectural heritage area in Shenyang, humidity, greenness, dryness and heat have the greatest impact on the ecological environment. According to the four indicators that have the greatest impact on the ecological environment, the environment is systematically evaluated. Through principal component analysis and normalization, the remote sensing ecological index (RSEI) is generated and the ecological environment status is comprehensively evaluated. Based on Landsat series remote images, indexes of greenness, humidity, dryness and heat were extracted to measure the quality of their ecological environment, and remote sensing ecological index (RSEI) was constructed. The formula is as follows [10]:

$$RSEI = f(G，W, T, D) \tag{1}$$

Its definition based on remote sensing is as follows:

$$RSEI = f(NDVI, Wet, NDBSI, LST) \tag{2}$$

Where: G is green, W is humidity, T is heat, and D is dryness; NDVI is the vegetation index, Wet is the humidity component, NDBSI is the building and bare soil index, and LST is the surface temperature.

(1) Humidity index

As an effective data compression and redundancy reduction technique, Tassels cap transformation is widely used in ecological monitoring. Since the humidity component is closely related to the humidity of vegetation and soil, the humidity index in this study is represented by the humidity component Wet, and its expression is as follows [11]:

$$Wet_{TM} = 0.0315\times\rho_{Bule} + 0.2021\times\rho_{Green} + 0.3102\times\rho_{Red} + 0.1594\rho_{NIR} - 0.6806\rho_{SWIR1} - 0.6109\rho_{SWIR2} \tag{3}$$

$$Wet_{ETM+} = 0.2626\times\rho_{Bule} + 0.2141\times\rho_{Green} + 0.0926\times\rho_{Red} + 0.0656\rho_{NIR} - 0.7629\rho_{SWIR1} - 0.5388\rho_{SWIR2} \tag{4}$$

$$Wet_{OLI} = 0.1511\times\rho_{Bule} + 0.1973\times\rho_{Green} + 0.3183\times\rho_{Red} + 0.3407\rho_{NIR} - 0.7117\rho_{SWIR1} - 0.4559\rho_{SWIR2} \tag{5}$$

Where: ρ_{Blue}, ρ_{Green}, $|\rho_{Red}$, ρ_{NIR}, ρ_{BSWIR1}, ρ_{BSWIR2} respectively represents the reflectance of blue-green, red, blue, near-infrared, shortwave infrared 1 and shortwave infrared 2 bands of sensor TM, ETM+ and OLI images after radiation calibration. WET_{TM}, WET_{ETM+}, WET_{OLI} represents the humidity component of Landsat 5, Landsat 7 and Landsat 8.

(2) Greenness index

Normalized Vegetation index (NDVI) is the most widely used vegetation index, which not only reflects the background influence of plant canopy, but also relates to vegetation cover. Because it can better reflect vegetation growth, it is selected as the greenness index, and its expression is as follows [12]:

$$NDVI = (\rho_{NIR} - \rho_{Red})/(\rho_{NIR} + \rho_{Red}) \tag{6}$$

(3) Dryness index

The index-based build-up index (IBI) is chosen as the construction index representing the dryness index. However, bare soil will also cause the "dryness" of the surface in the environment, so the dryness index (NDBSI) can be synthesized by the two, namely, the construction index (IBI) and soil index (SI) synthesis, so its expression is as follows [13]:

$$SI = [(\rho_{SWIR1} + \rho_{Red}) - (\rho_{Blue} + \rho_{NIR})]/[(\rho_{SWIR1} + \rho_{Red}) + (\rho_{Blue} + \rho_{NIR})] \tag{7}$$

$$IBI = \frac{\{2\rho_{SWIR1}/(\rho_{SWIR1} + \rho_{NIR}) - [\rho_{NIR}/(\rho_{NIR} + \rho_{Red}) + \rho_{Green}/(\rho_{Green} + \rho_{SWIR1})]\}}{\{2\rho_{SWIR1}/(\rho_{SWIR1} + \rho_{NIR}) + [\rho_{NIR}/(\rho_{NIR} + \rho_{Red}) + \rho_{Green}/(\rho_{Green} + \rho_{SWIR1})]\}} \tag{8}$$

$$NDBSI = (IBI + SI)/2 \tag{9}$$

(4) Heat index

The surface temperature, which represents the heat index, can be calculated using the Landsat user manual model, as well as the newly revised calibration parameters such as Chander et al. [14]:

$$L = \text{gain} \times D_N + b\text{ias} \tag{10}$$

$$T = K_2 / \ln \quad K_1 / L + 1 \tag{11}$$

Where: L is the radiation value of TM thermal infrared band at the sensor; gain, bias and DN respectively represent the gain value of thermal infrared band, the bias value of thermal infrared band and the gray value of pixel. K_1 and K_2 are the calibration parameters; T is the temperature at the sensor.

The temperature T obtained by equation (9) can be converted to the surface temperature by the surface specific emissivity. So the heat expression is as follows [15]:

$$LST = T / \ 1 + (\lambda T / \rho)\ln\varepsilon) \tag{12}$$

Where: LST stands for heat index; λ is the central wavelength of thermal infrared band; $\rho = 1.438\times10^{-2}$m·k; ε is the surface emissivity.

(5) Construction of remote sensing ecological index model.

The ecological index should be in the form of a single index, and the comprehensive impact of each index on the environment can be obtained through the analysis of the index. Due to the inconsistency of dimensions of the four different indexes in this study, the weight imbalance between the coefficients will be caused if the principal components analysis (PCA) is carried out directly. Therefore, normalization processing should be carried out before the PCA, and their dimensions should be unified to 0~1. Make the principal component analysis in the same dimension. The commonly used normalization formula is as follows [16]:

$$N_{I_i} = (I_i - I_{min})/(I_{max} - I_{min}) \quad (13)$$

Where: N_{I_i} is an index value after normalization; I_i is the value of this index in pixel i; I_{max} is the maximum value of this index. I_{min} is the minimum value of this indicator. After the normalization of the four indexes; PCI is further calculated to generate remote sensing ecological index (RSEI) [17], and the initial ecological index ($RSEI_0$) can be obtained by further subtracting PCI from 1, and its formula is as follows:

$$RSEI_0 = 1 - \{PC1[f(NDVI, Wet, NDSI, LST)]\} \quad (14)$$

In order to facilitate the dimensional unification and mutual comparison of indicators, $RSEI_0$ can also be normalized, and its formula is as follows:

$$RSEI = \frac{RSEI_0 - RSEI_{0\_min}}{RSEI_{0\_max} - RSEI_{0\_min}} \quad (15)$$

The obtained RSEI is the established remote sensing ecological index, and the higher the value, the better the ecological environment, and the worse the ecological environment.

Results and Discussion

Temporal Characteristics of the Ecological Environment in the Architectural Heritage Area

From 1995 to 2019, the change trend of remote sensing ecological environment status in the central urban area of Shenyang, the former Qing architectural heritage area and each heritage type area is shown in Fig. 2. The ecological environment status in the central urban area tends to be stable as a whole, and the average RSEI decreases slightly, with an average annual rate of decline of 0.0045. The highest RSEI value is 0.493 in 1995, and the lowest RSEI value is 0.464 in 2014, with the largest increase from 2006 to 2010. The main reason was that the vegetation index increased from 0.438 to 0.476, an increase of 8.54%. The average RSEI decreased due to the obvious increase of surface temperature during 2010-2014.

Based on the changes of the average RSEI in Shenyang's former Qing architectural heritage areas, ancient tombs, ancient buildings and other heritage types, the following conclusions are drawn:

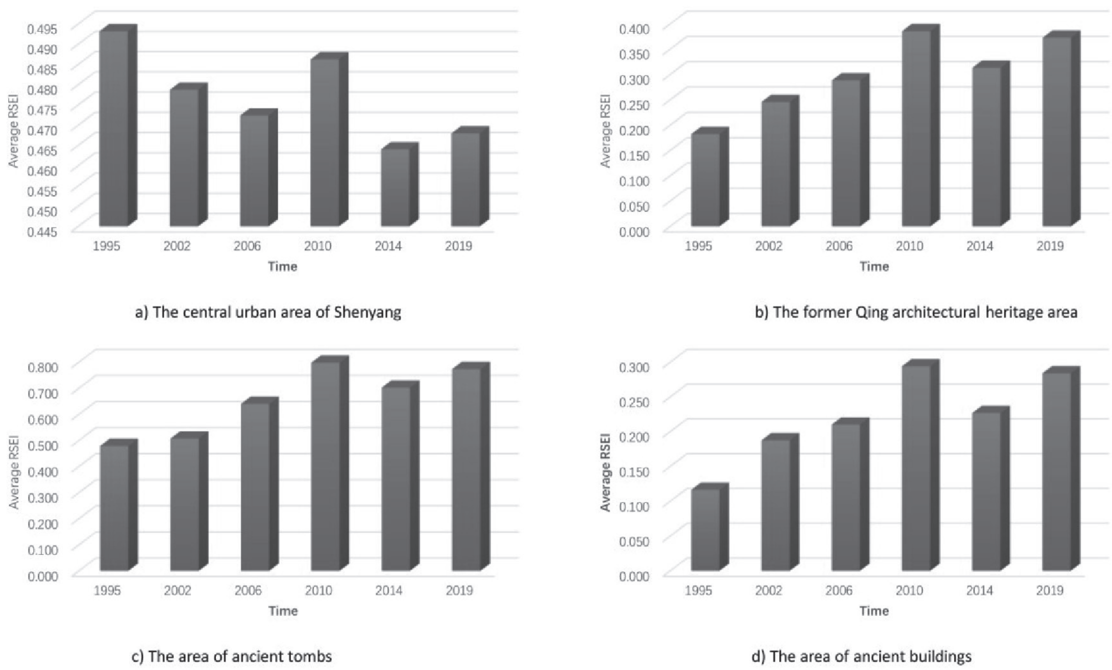

Fig. 2. Temporal changes of remote sensing ecological environment status in the central urban area of Shenyang and the former Qing architectural heritage area.

(1) From 1995 to 2019, the average value of RSEI in each period of the former Qing architectural heritage area was significantly lower than that in the central urban area, but its change trend was stable and rising, increasing from 0.182 in 1995 to 0.373 in 2019, with an average annual growth rate of 0.0358, indicating that the ecological environment of the architectural heritage area showed a slight improvement trend as a whole.

(2) In the past 25 years, the external ecological environment of ancient tombs has been at a good level, and the average annual growth rate of RSEI is 0.0633, the highest average RSEI value is 0.798 in 2010, and the lowest RSEI value is 0.479 in 1995, among which the growth rate is the largest from 2006 to 2010, indicating that the external ecological environment of the region where the ancient tombs are located is better. The main reason is that the vegetation condition of Qingfu Mausoleum and Qingzhao Mausoleum is better, and it was listed as World Cultural Heritage in 2004, and the protection level is higher.

(3) The average RSEI of ancient buildings increased from 0.116 in 1995 to 0.284 in 2019, with an average annual growth rate of 0.0297, which was significantly lower than the average RSEI of ancient tombs. The average RSEI showed a low-speed growth trend, indicating that the regional ecological environment of ancient buildings, including Shenyang Imperial Palace, Shisheng Temple, etc., needed to be improved. The reason is that the ancient buildings located in the central city are located in the old city, the original ecological environment is poor, and there are frequent human disturbance, resulting in the average increase of RSEI is much smaller than that of the ancient tomb area.

Spatial Differentiation of Ecological Environment in the Architectural Heritage Area

Remote sensing change detection is an effective way to extract the change of image pixel spectral values in different periods, and analyze and determine the characteristics and processes of surface changes quantitatively, monitor and evaluate the changes of various features caused by the change of features over time in remote sensing images. In order to obtain the ecological environment changes of the former Qing architectural heritage area in Shenyang from 1995 to 2019, the difference of RSEI index in two periods of the heritage area was calculated, and the difference results were used to judge the ecological environment changes of the former Qing architectural heritage area in Shenyang. In this paper, the difference of the ecological environment quality in the central urban area of Shenyang and the former Qing architectural heritage area is detected, and green represents the area of ecological quality improvement, red represents the area of ecological quality decline, yellow represents the area of ecological quality unchanged.

The spatial change trend of the average value of RSEI in the central urban area of Shenyang, the former Qing architectural heritage area and each heritage type area was visualized (Fig. 3), and the following rules were obtained:

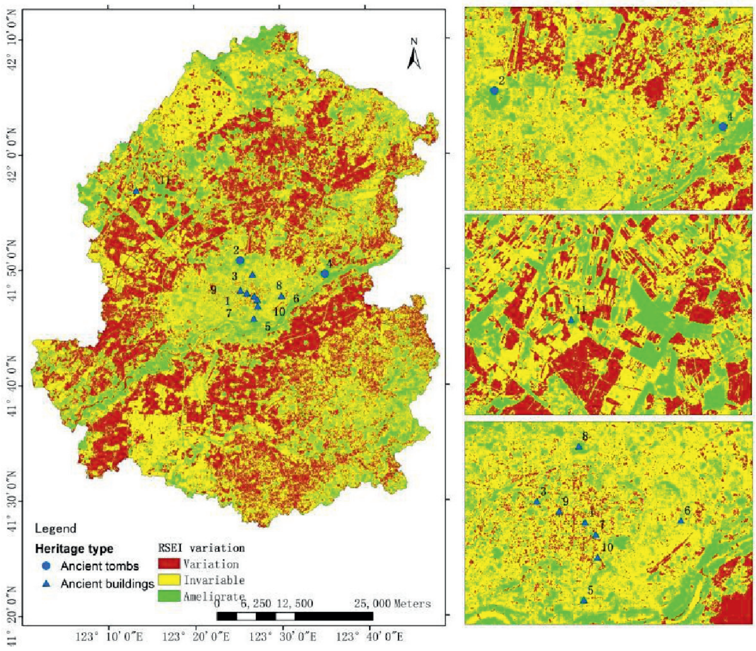

Fig. 3. Spatial differentiation of remote sensing ecological environment in Shenyang's former Qing architectural heritage area (1. The Imperial Palace of Shenyang, 2. Qingzhao mausoleum, 3. Shisheng Temple, 4. Fuling Mausoleum in Qing Dynasty, 5. South tower, 6. East tower, 7. Shengjing city site, 8. North Tower Falun Temple, 9. Halal South Temple, 10. Ci 'en Temple, 11. Yong'an Stone Bridge).

(1) From 1995 to 2019, the decrease of the average RSEI in the central urban area accounted for 50.14% of the total area, indicating that the overall ecological environment quality of the downtown area in Shenyang showed a slight decline, which was mainly distributed in the urban expansion and infrastructure construction areas.

(2) In the past 25 years, the average RSEI increase area of the former Qing architectural heritage area accounted for 59.62% of the total area, indicating that the ecological environment quality of the architectural heritage area mainly showed an improvement trend, and the improvement area proportion was significantly higher than the overall level of the central urban area.

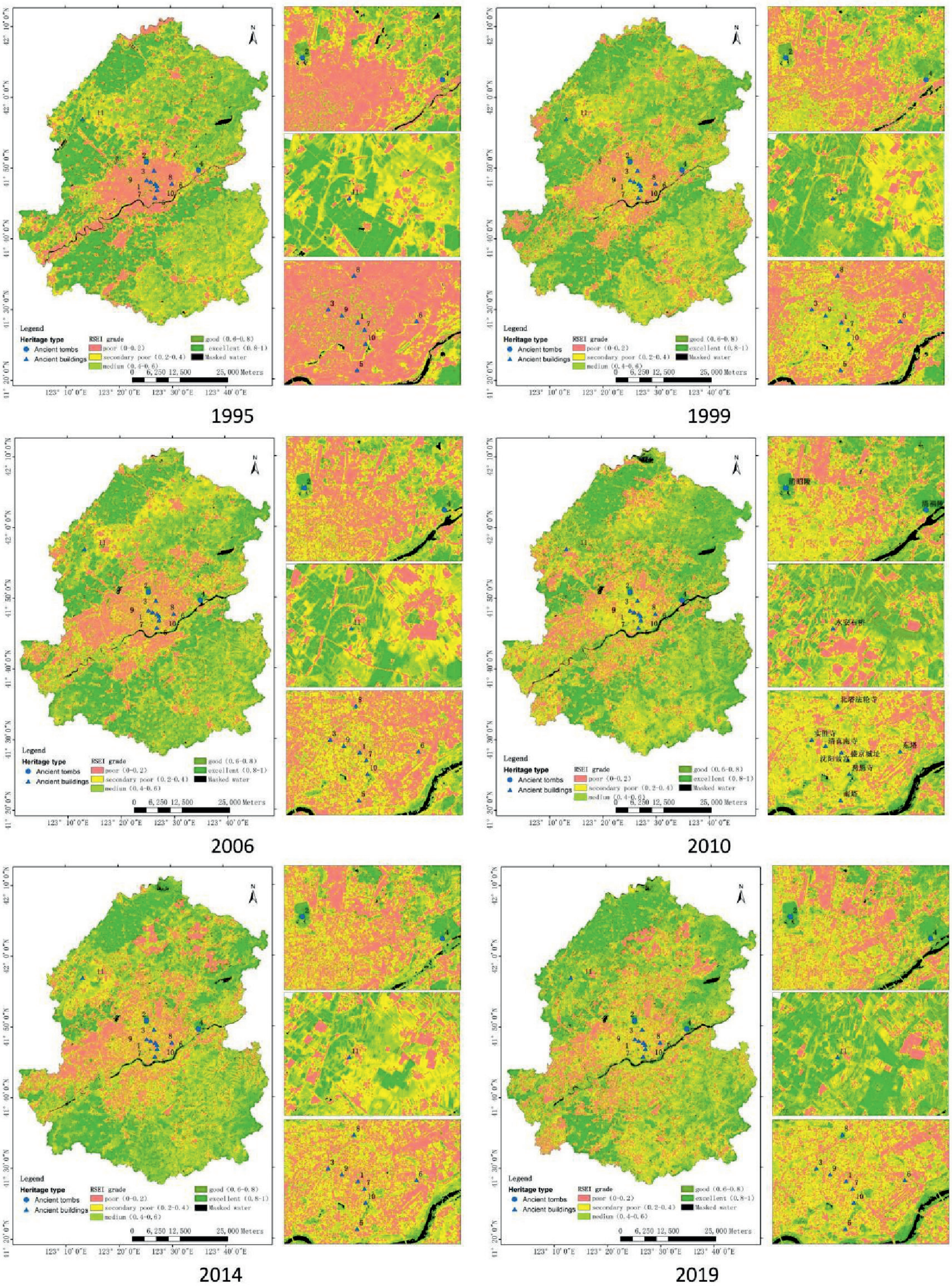

Fig. 4. RSEI image of the study area from 1995 to 2019 (1. The Imperial Palace of Shenyang, 2. Qingzhao mausoleum, 3. Shisheng Temple, 4. Fuling Mausoleum in Qing Dynasty, 5. South tower, 6. East tower, 7. Shengjing city site, 8. North Tower Falun Temple, 9. Halal South Temple, 10. Ci ‘en Temple, 11. Yong’an Stone Bridge).

(3) From 1995 to 2019, the external ecological environment of all types of architectural heritage areas showed a trend of continuous improvement. Among them, the improvement of ecological environment quality of ancient tombs accounted for a relatively high proportion, reaching 88.14%; The improvement area of the ancient buildings was 53.16%, and the improvement area is lower than that of ancient tombs. It can be concluded that the more areas of architectural heritage areas that improve the quality of the ecological environment, the better the quality of the regional ecological environment.

(4) The trend of ecological environment change in all architectural heritage areas is basically the same. In order to evaluate the RSEI more accurately, the RSEI of the former Qing heritage area in Shenyang were divided into grades with an interval of 0.2. They represent poor (0~0.2), secondary poor (0.2~0.4), medium (0.4~0.6), good (0.6~0.8) and excellent (0.8~1), which are divided into 5 grades. As can be seen from Fig. 4: in 1995, the ecological environment status of all architectural heritage areas was mainly at the medium level or below, among which the ecological environment status of Qingzhao Mausoleum and Fuling Mausoleum was at the medium level, and the ecological environment status of other heritage areas was below the poor level. In 2002, the ecological environment status of all architectural heritage areas was good or below, among which the ecological environment status of Fuling Mausoleum, Ci 'en Temple, South Pagoda and other heritage areas was significantly improved, while the ecological environment status of other heritage areas was not significantly changed. In 2006, except for the significant improvement of ecological environment in the region where the Qingzhao Mausoleum is located, the mean value of RSEI in each architectural heritage area did not change significantly compared with the previous period. In 2010, the ecological environment status of all architectural heritage areas changed significantly, and the ecological environment status levels showed significant polarization. Among them, the ecological environment status of Fuling Mausoleum and Qingzhao Mausoleum was excellent, the ecological environment status of Ci 'en Temple was medium, and the other heritage areas were poor. Due to urban expansion and other reasons, the ecological environment of Yong'an Stone Bridge has deteriorated significantly.

In 2014, the average value of RSEI in each architectural heritage area was decreased slightly than that of the previous period, among which, the ecological environment quality of Shenyang Imperial Palace, Shisheng Temple, South Mosque and Ci 'en Temple weakened significantly. In 2019, the ecological environment quality of Yong'an Stone Bridge and Qingzhao Mausoleum in the region has improved significantly, and the ecological environment status of Fuling Mausoleum and Qingzhao Mausoleum was excellent, that of Yong'an Stone Bridge was medium, that of Shenyang Imperial Palace was poor, and that of other heritage areas was poor.

Conclusions

In this paper, taking the former Qing architectural heritage area in Shenyang as the research object and the remote sensing images from 1995 to 2019 as the data source, it visually analyzes the spatio-temporal evolution characteristics of the ecological environment quality in the architectural heritage area, in order to provide a theoretical basis for the overall protection of the architectural heritage. The results show that:

(1) Characteristics of time changes in the ecological environment of architectural heritage areas. In the past 25 years, the overall quality of the ecological environment in the central urban area of Shenyang showed a steady trend, and the average RSEI showed a slight downward trend. The ecological environment quality of the former Qing architectural heritage area and each heritage type showed a fluctuating upward trend. Among them, the average RSEI of each period in the former Qing architectural heritage area was significantly lower than that of the central urban area, but its changing trend was stable and rising, and the whole showed a slightly improved trend. The overall ecological environment quality of ancient tombs is good, and the RSEI average value of ancient buildings shows a low-speed growth trend, indicating that the ecological environment status of ancient buildings in the region, including Shenyang Imperial Palace and Shisheng Temple, needs to be improved.

(2) Spatial differentiation of the ecological environment in the architectural heritage area. From 1995 to 2019, the average RSEI in the central urban area decreased by 50.14% of the total area, and the overall ecological environment quality showed a slight downward trend. The increase of RSEI in the former Qing architectural heritage area is significantly higher than that of the central urban area, indicating that the ecological environment of the architectural heritage area was continuously improved. In all types of architectural heritage areas, the overall quality of the ecological environment of ancient tombs is above the medium level, and that of ancient buildings is below the poor level. The variation trend of the mean value of RSEI in all architectural heritage areas is basically the same, and the ecological environment quality is clearly differentiated, and the ecological environment quality still needs to be improved.

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Conflict of Interest

The authors declare no conflict of interest.

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