Construction and application research of ecological evaluation platform based on Cesium

Yao Fu, Guize Luan, Jingzhi Cai, Yuchen Li and Fei Zhao

ABSTRACT

In this study, Sentinel 2A and Landsat series remote sensing images were used to determine the weights of vegetation coverage, humidity, dryness and heat by using the principal component analysis method. The remote sensing ecological index evaluation model was used to evaluate the ecology of the Fuxian Lake area from 2013 to 2018. Environmental quality in the study area is monitored and analyzed. By developing a unified organization and management module of spatio-temporal data in the collaborative production of multi-source heterogeneous data, the mapping relationship between data and parameters is established. The 3D-web data integration decision platform is constructed. Based on the Cesium engine real-time rendering and interactive visualization network 3D platform, real-time calculation and visualization of the ecological evaluation of the Fuxian Lake area between 2013 and 2018 is realized. The ecological environment of the study area continued to deteriorate from 2013 to 2015, improved slightly in 2016, and improved significantly in 2017–2018. The platform has the functions of searching, selecting the base map, measuring on the map, and positioning the coordinates, which can achieve the real-time ecological analysis function and show the change process of the ecological environment and natural resources.

Key words | data decision platform, ecological analysis function, map service, remote sensing ecological index

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HIGHLIGHTS

- Remote sensing data were used to determine the weights of RSEI by using the principal component analysis method.
- Environmental quality is monitored and analyzed.
- The 3D-web data integration decision platform is constructed.
- A real-time rendering and interactive visualization network 3D platform based on the Cesium engine is constructed.
- The platform has many functions.

INTRODUCTION

At present, the relationship between human activities and the ecological environment is getting closer and closer. Human activities have caused profound changes and influences on

the ecological environment and ecosystem, and the resulting contradictions among population, resources and environment are becoming increasingly prominent. Therefore, the study of ecological security is of great significance for understanding the status of ecological security and for making relevant ecological environment decisions. At present, China's ecological environment deterioration tendency has

not been effectively controlled in general. Although there has been partial improvement in recent years, the degree of governance is still far from recovering the serious consequences caused by ecological damage. With the proposal of national ecological civilization construction, the implementation of a sustainable development strategy of harmonious coexistence between humans and nature, and the rapid development of science and technology informatization levels in recent years, society is in urgent need of the introduction of new technologies and the application of new technologies in the improvement and protection of the ecological environment (Mitrović 2015). The formation and development of an ecosystem will be affected by multiple factors, and a single ecological factor cannot objectively and comprehensively reflect the changes of its ecological environment (Song & Xue 2016). Therefore, it is particularly important to analyze the comprehensive effects of multiple ecological factors and comprehensively evaluate the regional ecological environment. In recent years, a new remote sensing ecological index (*RSEI*) has been proposed. It is completely based on remote sensing information, which can directly represent regional ecological quality, intuitively reflect multiple indicators of the ecological environment, and realize rapid monitoring and evaluation of the regional ecological environment, with certain practical significance and high practical reference value (Lintao *et al.* 2014). At present, the application of *RSEI* is mainly limited to calculating green degree, dryness degree, humidity and heat indexes respectively through the information values of different bands of remote sensing images, and then synthesizing these indexes to finally reflect the changes of ecological environment in the study area from some angles. Some scholars have used a feature inversion technology and improved remote sensing ecological index to predict the ecological change caused by population growth in the Xiongan new area (Xu *et al.* 2018, 2019). Some scholars have made a comparative analysis of the remote sensing ecological index (*RSEI*) and ecological index (*EI*), and found that *RSEI* can reflect changes in ecological environment quality more effectively than *EI* (Shan *et al.* 2019). However, at present, most research based on *RSEI* can only evaluate the regional ecological quality by calculating the data of various indicators. There is no corresponding ecological evaluation platform that has been built, and this cannot be visualized in real time.

In the digital city stage, the main task is to build a digital spatial information-sharing platform. The platform design of this stage focuses on the sharing of basic spatial data. The platform design is based on a distributed spatial database, and the data provides online services through a Web service mode. With the development of smart city construction, the space–time data integration platform based on the data center, data warehouse or virtual view gradually appears, and finally develops into a space–time data cloud platform. However, due to the complex characteristics of space–time data, the space–time data cloud platform developed at present mainly focuses on technical implementation, while the research on the management, scheduling and visual analysis of massive space–time data is still in its initial stage. Cesium is a Javascript library that can display a 3D Earth and map across platforms and browsers. It supports 2D, 2.5D and 3D map expansion and dynamically displays data based on the timeline, providing good data visualization support (Birowosuto *et al.* 2007; De Paor *et al.* 2016). Therefore, the innovation of this study is to quantify the change system of the ecological environment in the research area from 2013 to 2018 for the first time and display its development process. So from the temporal characteristics of spatio-temporal data, this study adopts the open source web 3D map engine Cesium for development, fully considering remote sensing data, temperature, atmospheric data, soil data such as a data integration model, built with multi-source and heterogeneous data, the unity of the multi-dimensional space–time big data organization and management, and geographic space and time large-scale data calculation, a unified framework of time and space in visual display and the integrated service function of the ecological data integration processing platform, used to show changes in the ecological environment.

CONSTRUCTION OF ECOLOGICAL EVALUATION PLATFORM BASED ON CESIUM

Overall design

In order to realize the real-time extraction, query and analysis of ecological information, as well as the integration and decision analysis of massive real-time monitoring data, the holographic transformation of the ecosystem from static to dynamic is realized. In this study, a real-time rendering

and interactive visualization network 3D platform based on the Cesium engine was constructed to realize the dynamic visualization of heterogeneous spatiotemporal data. Cesium supports dynamic geospatial visualization and has very high performance and precision. In view of this, this study chose Cesium as the basic engine of the network 3D data integration platform. The overall design of this module is shown in Figure 1. The platform has added a layer control module, geographic data management module, search query module, graph calculation module and coordinate positioning module. Based on the Cesium engine, user interaction functions such as *RSEI* index calculation, ecological decision evaluation and ecological environment evaluation can be realized. The whole platform adopts the Java language, Hadoop architecture for distributed integration computing, and Cesium engine for data integration visualization analysis in the front end.

The platform constructed in this study has improved the basic functions of Cesium, facilitating the rapid construction of the Cesium map project and its agile development, being reusable, supporting various configurations, and being suitable for ecological analysis. The platform integrates the leading open source to gallery, visualization, libraries, research and development of Web browser browsing using a three-dimensional Earth, without any plug-ins, provides a new big data visualization, real-time streaming data visualization function, through the platform can be realized fast on the browser and the mobile terminal is beautiful, smooth map plotting and spatial analysis. The core content of the platform construction is to build a Cesium-based network 3D data integration decision-making platform. Firstly, a unified organization and management module of space–time data is developed in the collaborative production of multi-source heterogeneous data

to realize preliminary data integration. In the target matching module, the network structure and parameters of the SOM neural network are determined, and the mapping relationship between data and parameters is established to facilitate the continuous matching and fusion of data. Finally, in the data fusion module, a convenient interface for data editing is provided to realize efficient dynamic visualization and decision analysis.

Ecological evaluation decision function

The Fuxian Lake, ranging from $24°21'26''$N to $24°38'06''$N and $102°49'10''$E to $102°57'26''$E, is located in Yuxi city, the central area of the Yunnan Province. It is the largest deep-water freshwater lake in China and the largest lake at the source of the Pearl River, which is related to the Nanpanjiang river system (Li *et al.* 2017). The hills around Fuxian Lake are mainly distributed in the north and east, with shallow depressions in the middle and a river flowing from the eastern boundary. Fuxian Lake is a mid-narrow faulted lake formed under the influence of a tectonic basin. Its deepest point in the north reaches about 156.8 m and its maximum width reaches 11.5 km. The narrowest region is 3.2 km in the middle (Chen *et al.* 2019). More than 120 rivers flow into this lake, at least 56 of which are seasonal streams. The climatic conditions are the subtropical and semi-humid monsoon climate of Central Asia. Annual rainfall is about 943 mm, with 80%–90% concentrated in the monsoon season. The average temperature is about 15.5 °C (Cui *et al.* 2008; Zeng & Wu 2009). Seventy-five percent of the population live in the north of the Fuxian Lake area and the daily lives of the residents, cause local environment deterioration, therefore parts of northern basin range are included in the study area, in order to avoid the study area and nebula
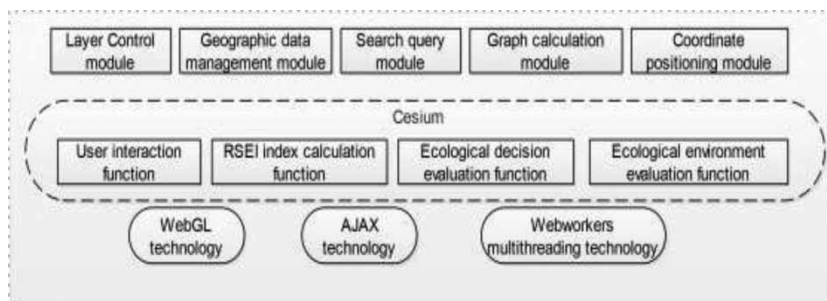

Figure 1 | Overall design of the Cesium module.

near Dianchi watershed river basin ecological environment affect the results of the study, according to the hydrological model based on DEM data extraction basin range. The Fuxian Lake Basin in the study area is shown in Figure 2.

To understand the evolution process of Fuxian Lake area's ecological environment, it is necessary to evaluate its ecological environment quality. Firstly, ecological security evaluation units should be determined, including vegetation coverage, water temperature, air humidity, soil dryness, heat and other indicators. To understand these environmental indicators, we need to get corresponding data and adopt appropriate methods to process them. In this study, Sentinel 2A and Landsat series remote sensing image data were used. The atmospheric environmental quality can be used, the humidity data calculated by the shore vegetation coverage and soil environmental quality and soil dryness heat index according to evaluation, and finally all the data entries are collected in the database.

Remote sensing technology is widely used in the land ecological security-related evaluation model, which has a specific way for realizing the quantitative description of ecological security. It can serve people's livelihood with the evaluation and analysis of regional ecological security, and put forward feasible Suggestions on ecological environment protection,

governance and scientific development on the basis of evaluation. The remote sensing ecological index is a new ecological index used to comprehensively reflect the current situation of a regional ecological environment. The index is coupled with four indexes, namely, greenness, humidity, heat and dryness, which can be directly judged by human beings. It is completely based on remote sensing information technology, which reduces the subjectivity in practical application and the difficulty of index extraction. It can not only achieve quantitative evaluation of the ecological environment in the study area, but also visualize the evaluation results, and optimize the evaluation results to a certain extent. The technical flow chart of calculating the remote sensing ecological index is shown in Figure 3. In this study, Landsat8 data from 2013 to 2018 and Sentinel 2A remote sensing data from 2016 to 2018 were mainly used to control the cloud cover below 20%. Data preprocessing includes band synthesis, radiometric calibration and atmospheric correction, followed by calculation and extraction of the four indexes. The calculation results are normalized first, followed by principal component analysis, and finally the *RSEI* value is obtained.

The normalized difference vegetation index (*NDVI*) is an important index used to detect plant growth status, vegetation coverage, leaf area index and other biochemical and physical properties of vegetation, and has been widely used in remote sensing monitoring of vegetation (Ren *et al.* 2017). The calculation of *NDVI* is shown in Equation (1), where *NIR* is near infrared band (band 8 in Sentinel data) and *R* is red band (band 4 in Sentinel data). The green index reflects the vegetation coverage of the study area. *Fv* is calculated by using the mixed pixel decomposition method, which roughly divides the landscape into water body, vegetation and buildings. The specific calculation formula is shown in Equation (2). In this study, *NDVIveg* = 0.70 and *NDVIsoil* = 0.00, and when *NDVI* of a pixel is greater than 0.70, the value of *Fv* is 1. When *NDVI* of a pixel is less than 0.00, the value of *Fv* is 0. Therefore, the vegetation coverage was used to replace the green index in this study.

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \tag{1}$$

$$
\begin{aligned}
Fv = &(NDVI\ GT\ 0.7) * 1 + (NDVI\ LT\ 0.05) * 0 \\
&+ (NDVI\ GE\ 0.05\ and\ NDVI\ LE\ 0.7) * \\
&((NDVI - 0.05)/(0.7 - 0.05))
\end{aligned}
\tag{2}
$$

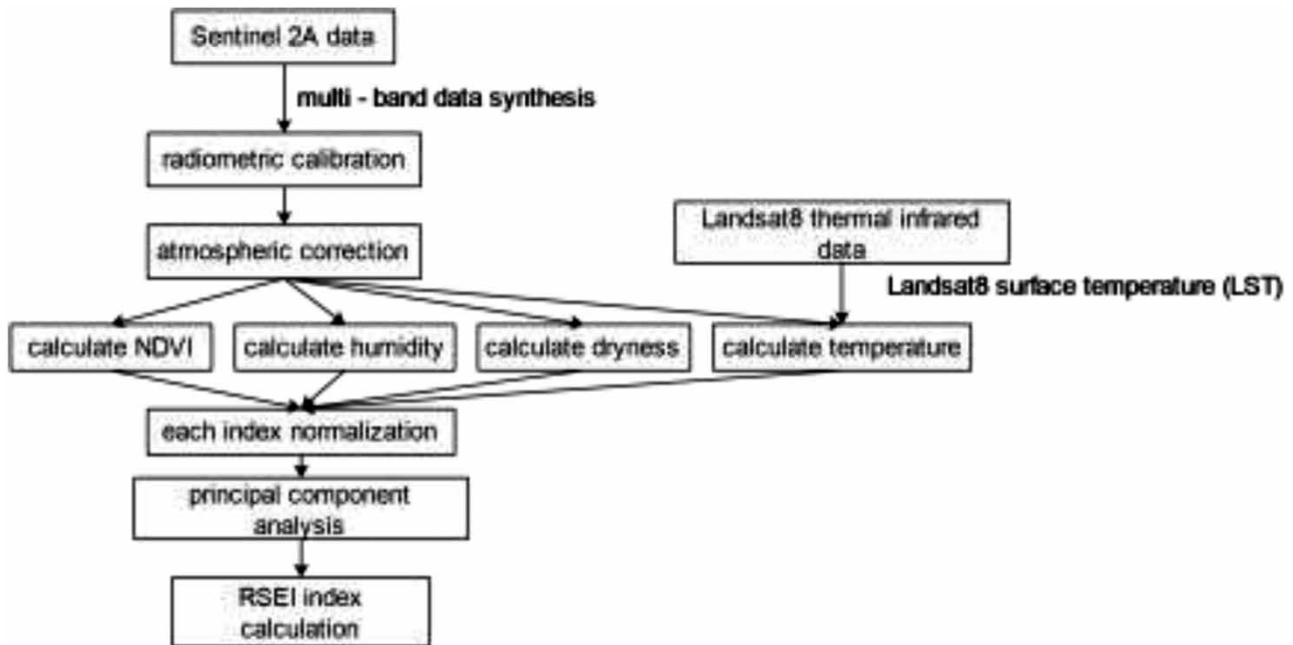**Figure 2** │ Schematic diagram of study area.

Figure 3 | Technical flow chart.

Taking remote sensing data in 2013 as an example, the green index diagram is shown in Figure 4(a). The components of brightness, greenness and humidity obtained by remote sensing hat transformation have been widely used in ecological environment monitoring. Among them, the component of humidity reflects the humidity of the water body, soil and vegetation and is closely related to the ecological environment. Therefore, the index of humidity is represented by the component of humidity. Due to the different types of sensors, the parameters vary accordingly. This research adopts the Tasselled Cap–Wetness formula published by the Index Database website, which
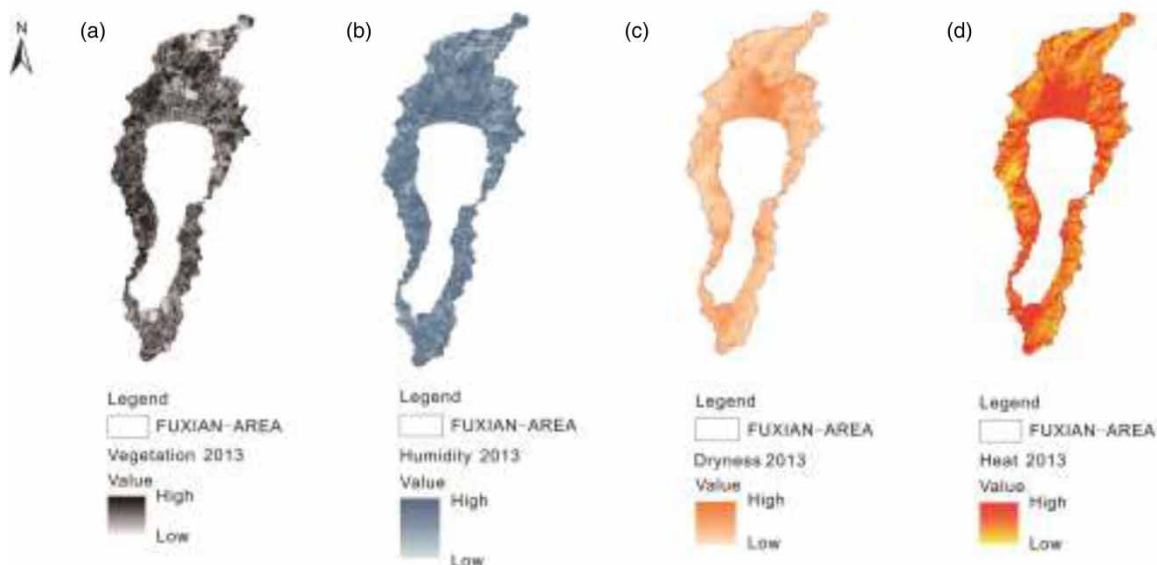

Figure 4 | (a) The green index diagram, (b) the humidity index diagram, (c) the dryness index diagram, (d) the heat index diagram).

calculates the moisture component of the Sentinel 2A data. As shown in Equation (3), each coefficient corresponds to the reflectance of each band of Sentinel 2A 2, 3, 4, 8, 11 and 12:

$$0.1509 * B2 + 0.1973 * B3 + 0.3279 * B4$$
$$+ 0.3406 * B8 - 0.7112 * B11 - 0.4572 * B12 \quad (3)$$

Taking remote sensing data in 2013 as an example, the humidity index diagram is shown in Figure 4(b). The index of dryness is generally represented by the bare earth SI, but in the regional environment, there are quite a number of lands for construction, and they also cause the surface of the earth to be 'dry', so the dryness index can be made of a synthesis, namely the synthesis of bare soil index SI IBI Equation (4) and building index Equation (5); ρ_2, ρ_3, ρ_4, ρ_8, ρ_{11} are respectively the sentinel 2A data 2, 3, 4, 8, 11 band reflectance, and the dryness index (NDSI) is as shown in Equation (6), and the higher the value, the drier it is. Taking remote sensing data in 2013 as an example, the dryness index diagram is shown in Figure 4(c).

$$I = \frac{(\rho11 + \rho4) - (\rho8 + \rho2)}{(\rho11 + \rho4) + (\rho8 + \rho2)} \quad (4)$$

$$IBI = \frac{2\rho11/(\rho11 + \rho8) - [\rho8/(\rho8 + \rho4) + \rho3/(\rho3 + \rho11)]}{2\rho11/(\rho11 + \rho8) + [\rho8/(\rho8 + \rho4) + \rho3/(\rho3 + \rho11)]} \quad (5)$$

$$NDSI = \frac{(SI + IBI)}{2} \quad (6)$$

Finally, the Landsat8 surface inversion tool is used to represent the heat index with surface temperature (*LST*). Since Sentinel 2A data does not have thermal infrared bands, the thermal infrared bands of Landsat8 images acquired at the same time were used to calculate the temperature, and the temperature results obtained with a resolution of 30 m were resampled to 10 m, so as to match the Sentinel 2A 10 m spatial resolution and improve the discrimination degree of the surface thermal environment. Finally, Landsat8 TIRS data was used to calculate the surface temperature. In this study, the Landsat8 surface inversion tool based on an atmospheric correction method was directly used, and the surface temperature (*LST*) was used to represent the heat index

(Zorer *et al.* 2011; Yao & Li 2019). By input using image information such as time, latitude and longitude, and model parameters, it and can calculate the band business, atmospheric transmission, effective bandpass upwelling radiance, effective bandpass downwelling radiance, and the resulting surface temperature traffic as the index of heat. Taking remote sensing data in 2013 as an example, the heat index diagram is shown in Figure 4(d).

APPLICATION EXAMPLE

Basic function

This study encapsulates the initialization of the map and initializes the map according to the configuration content by passing in JSON configuration information. In specific applications, some of the related parameters and layers are different in map initialization, and other functions are similar. According to need, different configuration information is modified or used. The configuration information is loaded as a JSON format file. The configuration file can be a static JSON file, and can also be loaded on the server dynamically according to user permissions to dynamically return data. Moreover, the platform supports the loading of almost all types of base maps in the current market, including ArcGIS services, Gaode, Google, world map and other online maps.

The basic functions of the platform constructed in this study include a query function, map configuration and layer control, measurement, coordinate positioning, marking, bookmark, map comparison, particle effect, flight tour, plotting, printing, etc. With specific functions such as the search function, by searching keywords it is possible to get place names with keywords and their location information. The function of measurement and plotting as shown in Figure 5 can calculate the spatial distance and ground distance (the distance measured according to the land's surface undulation, different from the mathematical linear distance in space) between the stored points or self-plotting points in the database, as well as the function of calculating area, angle, height, etc. The coordinate positioning function can locate the coordinate points on the map according to the user-input longitude, latitude and height information.
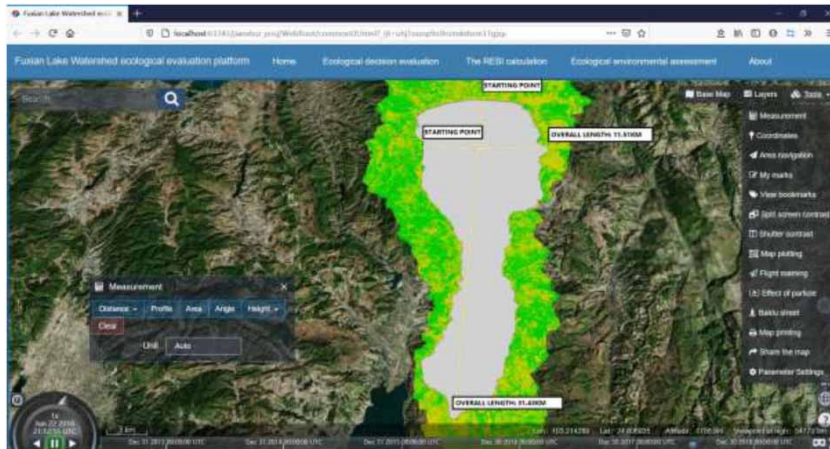
Figure 5 | Sample measurement function.

Map contrast features include layer split contrast and shutter contrast. The platform also builds a timeline, allowing users to view the ecological environment evaluation charts of different periods by dragging the timeline.

Ecological analysis function

Through the calculation in the section 'Ecological evaluation decision function' the four index values of green degree, humidity, heat and dryness can be obtained, and then the four indexes are normalized and analyzed by principal component analysis. Principal component analysis (PCA), based on the original data characteristics of the four indexes, automatically and objectively determines the weight value to realize the transformation of a variety of single indexes so as to be coupled into a comprehensive index, which avoids subjective arbitrariness, and the process is relatively simple. Because this study mainly analyzes the surrounding areas of Fuxian lake, the ecological environment change does not include the aquatic environment change. The load distribution on large bodies of water can affect PCA, and so in order to avoid water impact analysis results in the final analysis, the NDWI water index is used to mask information on the Fuxian Lake water body, and NDWI images are generated that highlight the waters (Puttinaovarat *et al.* 2015). Finally, the remote sensing ecological index was obtained. In this study, based on the calculated remote sensing ecological index, the ecological

Table 1 | Calculation results of RSEI from 2013 to 2018

	2013	2014	2015	2016	2017	2018
RSEI	0.616	0.601	0.574	0.594	0.692	0.725

environment assessment analysis of the Fuxian Lake Basin in the long time series from 2013 to 2018 was carried out. The average calculation results of *RSEI* are shown in Table 1. The ecological environment of the study area continued to deteriorate from 2013 to 2015, improved slightly in 2016, and improved significantly in 2017–2018.

The *RSEI* result values of each grid were divided into five grades with equal intervals: poor (0.00–0.2), relatively poor (0.2–0.4), medium (0.4–0.6), good (0.6–0.8), and excellent (0.8–1.0), as the evaluation criteria for the ecological environment. As shown in Figure 6, the left side of the split screen shows the ecological evaluation results of the region in June 2013, while the right side of the split screen shows the ecological evaluation results of the region in June 2018. The green part shows good ecological environment, the yellow part shows medium ecological environment, and the red part shows poor ecological environment. It can be seen that in 2013, the overall ecological environment around the lake was medium, and the ecological environment around some residential areas was poor. In 2018, after a long period of treatment, the ecological environment of the vegetation-covered area around the lake was good, the ecological environment
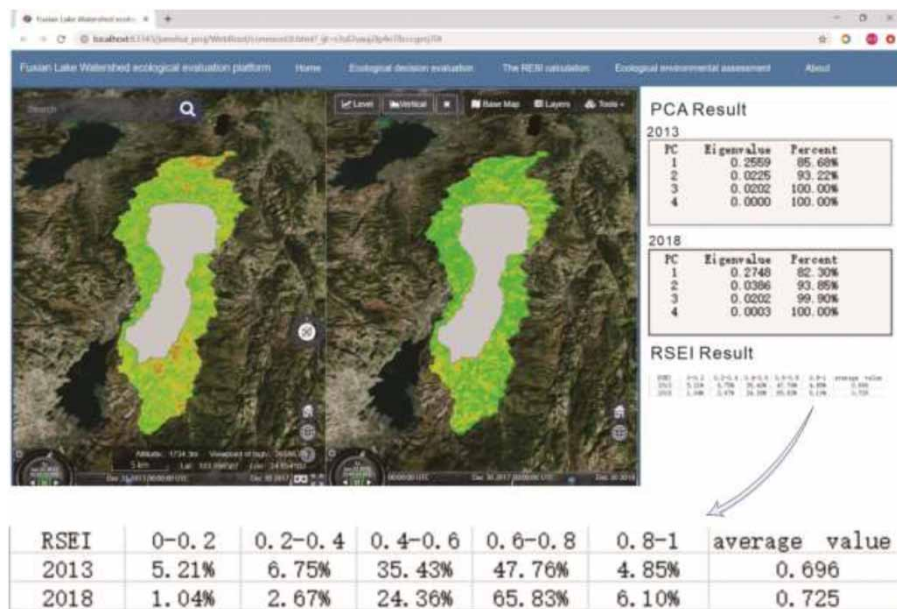
RSEI	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1	average value
2013	5.21%	6.75%	35.43%	47.76%	4.85%	0.696
2018	1.04%	2.67%	24.36%	65.83%	6.10%	0.725

Figure 6 | Split screen comparison of ecological evaluation. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2020.253.

around the residential areas was medium, and the ecological environment of very few residential areas was poor. Since 2017, five major projects have been carried out in the Fuxian Lake Basin, including mountain forest expansion, land adjustment and water conservation, pollution control and river control, lake management and water conservation, and habitat restoration. Therefore, the results of ecological environment assessment are consistent with the actual situation, which also proves that the ecological protection and restoration project targeted at Fuxian Lake Basin is successful.

DISCUSSION AND CONCLUSION

In this study, a real-time rendering and interactive visualization network 3D platform based on the Cesium engine is constructed. The server can load a Google satellite map, DEM elevation map, and world map annotation. Based on Fuxian Lake Basin, this study can realize some real-time ecological analysis functions, which can display the change process of the ecological environment and natural resources, such as ecological environment quality evaluation, water color change, vegetation coverage area change and evaluation, etc. Search, navigation, distance

measurement and other functions are realized. This design supports switching between different remote sensing data sources. Based on the existing geographic information data set, it contains an information window, which can conduct real-time ecological evaluation and display evaluation information, etc. According to the mean value of the RSEI index, this study quantitatively evaluates the ecological environment in the study area and presents the dynamic changes of the ecological environment over time. The research requires data to be standardized and weighted by principal component analysis. On the whole, the regional ecological environment quality with higher vegetation coverage rate is better, while the regional ecological environment quality that is greatly affected by human activities is worse. The results show that the ecological environment of the study area deteriorated from 2013 to 2015, improved slightly in 2016, and improved significantly in 2017–2018. The results are consistent with the actual situation and more accurate. For the first time, the change system of the ecological environment in the study area from 2013 to 2018 was quantified and its dynamics was displayed. The Cesium engine-based real-time rendering and interactive 3D visualization network platform was built, and also a multi-source, heterogeneous, multi-dimensional space–time unified organization with management of big data, geographical space and time

large-scale data calculation, a unified framework of time and space of visual display and integrated service function of ecological data integration platform, which has realized the heterogeneous dynamic visualization and decision analysis of spatio-temporal data and is used to show the changes of ecological environment. However, this system can only analyze the existing data, and cannot realize the real-time monitoring function of any remote sensing data.

ACKNOWLEDGEMENTS

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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