LONG-TERM ECOLOGICAL ENVIRONMENT CHANGE MONITORING IN SCALE OF CITY ALONG CHINA-EUROPE RAILWAY EXPRESS WITH A REMOTE SENSING-BASED ECOLOGICAL INDEX (RSEI): A CASE STUDY IN WARSAW, POLAND

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ABSTRACT:

The China-Europe Railway Express (CER-Express) has developed rapidly since its opening, but little attention has been paid to the long-term ecological environment changes along its route, especially in scale of city. This paper studies the long-term changes of cities along the route before and after the opening of CER-Express. Based on the Google Earth Engine platform, we apply the RSEI model for the cities along the route before and after the opening of the CER-Express from 2010 to 2020. Taking Warsaw, Poland as an example, quantitative analysis is carried out regarding its ecological environment changes and the reasons for these changes are discussed. Experimental results show that the mean values of RSEI between 0.6 and 0.8 before the opening, but declined significantly after the opening, and changed steadily in the later stage. This preliminary research can provide theoretical basis for cities along the CER-Express, protect to the sustainable development of CER-Express and response to the call of Goal 15 of the Sustainable Development Goals (SDGs).

1. INTRODUCTION

As a core component of the One Belt One Road initiative (Zhao et al., 2020), the China-Europe Railway Express (CER-Express) is regarded as a key infrastructure for freight train services between China and Europe, as well as countries and regions along the route. Since its first opening in 2011, the CER-Express has expanded to 168 cities in 23 European countries, which greatly promotes economic development and cultural exchanges along the express (Liu, Gu, Liu, & Wang, 2021). However, continuous railway operations may have negative effect on areas around the route, arising ecological problems, e.g., vegetation degradation, environmental pollution, deforestation, biodiversity (Radziemska et al., 2021). It is necessary to assess the ecological development status of the areas along CER-Express in detail in order to support sustainable development.

The rapid development of the CER-Express has attracted many researches (Zhongzhen, Yu, & Lee, 2020) in China-Europe trade, multimodal transportation, etc. But little attention has been paid to the local ecological environment along the route. There are some problems of eco-environment in scale of country or continent along the One Belt One Road due to the development of the infrastructure, e.g., the increase of greenhouse gas emissions, the intensification of ecological destruction (Ascensão et al., 2018). Although the CER-Express has improved the trade convenience from China to Europe (Zhongzhen et al., 2020), the carbon emissions generated during its transportation have an impact on social benefits (Li et al., 2019). Environmental degradation has occurred in railway-intensive countries (Ma et al., 2021). However, previous studies focus on large-scale monitoring, such as continents, countries. Degradation has yet not been discussed in detail along the route areas at a fine scale.

A number of remote sensing satellite image-based methods have been widely used for long-time series environmental change monitoring (Chen, Chuvieco, & Wang, 2021) with the great progress of the Earth Observing Technology in recent years. Various ecological indicators have been created to quantify eco-environment status, including the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and other indicators to evaluate changes in vegetation ecosystems (Qi, Jia, Liu, & Liu, 2019), the Land Surface Temperature Index (LST) to monitor the urban thermal environment (Algretawee, Rayburg, & Neave, 2019), etc. However, most of them are aiming at a certain ecological-related theme, making it difficult to explain the joint impact of multiple factors on the eco-environment and reflect the ecological environment status comprehensively. Therefore, comprehensive indicators are developed. The Ecological Index (EI) is widely used to evaluate the ecological environment quality of watersheds and cities (Liang, Wang, Fang, & Sun, 2019). The U.S. Environmental Protection Agency (EPA) uses the Environmental Quality Index (EQI) (Messer, Jagai, Rappazzo, & Lobdell, 2014) to investigate environmental status in all counties, etc. Although these indicators can reflect more features related to ecological status, there are still some challenges for data acquisition, indicator construction etc. Such as relying on statistical data, setting the weights of different indicators. The RSEI method is proposed by Hanqiu Xu (Xu, 2013). It is a remote sensing ecological index entirely based on remote sensing image information, which can provide a reliable assessment of regional eco-environmental changes and has been widely used in different scales (Wang, Zhao, & Wu, 2020). It provides the possibility to quantify the ecological environmental changes in cities along the CER-Express over a long period.

The main purpose of this study is to analyze the long-term ecological environment changes of cities along the CER-Express.

In this paper, Warsaw is taken as the study area. The Landsat 7 and Landsat 8 imageries are used to calculate the RSEI values from 2010 to 2020 based on the Google Earth Engine platform. Based on above RSEI maps, firstly, we use the box diagram to reflect the distribution of the RSEI value such as mean, median, minimum, maximum in the study area from 2010 to 2020. Secondly, the histogram of area distribution of different grades of RSEI to reflect the area proportional changes of each ecological level. In addition, the difference distribution maps of RSEI to reflect the distribution of ecological changes in the study area before and after the opening of the CER-Express, respectively. Our study can provide a reference for studying the eco-environment status in cities along the CER-Express. It can call on people to protect the sustainable development of CER-Express.

The rest of this paper is organized as follows: Section 2 presents the study area and data. Section 3 introduces the construction of the RSEI model. Experimental results will be interpreted in Section 4. Section 5 discusses the validity of the RSEI model. Section 6 draws the conclusion and outlooks future research.

2. REMOTE SENSING-BASED ECOLOGICAL INDEX

The RSEI is composed of four indicators, i.e., Normalized Difference Vegetation Index (NDVI), Wetness (WET), Land Surface Temperature (LST), and Normalized Difference Built-up and Soil Index (NDBSI), which represent four ecological factors directly related to human survival (Wang et al., 2020), namely, greenness, humidity, heat, and dryness, respectively. The formula of these remote sensing indices mentioned above is listed in Table 1.

In order to obtain the weight of each index objectively and automatically, these four indicators are coupled by Principal Component Analysis (PCA) method. In addition, a Modified Normalized Difference Water Index (MNDWI) is used to mask the water body to make the Wetness better represent the land surface humidity (Hu & Xu, 2018). The RSEI can be expressed as the formula (1).

$$RSEI=f(NDVI, WET, LST, NDBSI) \quad (1)$$

It is necessary to normalize the values of all indicators within [0, 1] before PCA is performed as a unit. Otherwise, the weight of indicators will be unbalanced. The normalization method of the indicator is shown in formula (2).

$$Index_i=(I_i-I_{min})/(I_{max}-I_{min}) \quad (2)$$

Where $Index_i$, I_i, I_{min}, and I_{max} represent the normalized result value, the original value, global minimum value, and global maximum value of the ecological index, respectively. After the normalization of these indicators, we calculate PCi as shown in formula (3), i.e., each principal component of the four indicators (NDVI, WET, LST, NDBSI).

$$PCi=f(NDVI, WET, LST, NDBSI) \quad (3)$$

The four component indicators obtained above are coupled by PCA, and the first principal component (PC1) is used to build the RSEI. In order to make the large value represent the good eco-environment, 1 can be used to minus PC1 to get the initial ecological index $RSEI_0$ as usually expressed the formula (4).

$$RSEI_0=1-PC1 \quad (4)$$

The RSEI is calculated from $RSEI_0$ by using the normalization method and the range of the RSEI result is [0, 1]. Finally, a higher RSEI value indicates a better ecological quality and a lower RSEI value indicates a poor ecological quality.

Table 1. NDVI, WET, LST, NDBSI, MNDWI calculation method.

Index	Formula
NDVI	$(B_{nir}-B_{red})/(B_{nir}+B_{red})$
WET	$\beta_1 B_{blue}+\beta_2 B_{green}+\beta_3 B_{red}+\beta_4 B_{nir} - \beta_5 B_{swir1}-\beta_6 B_{swir2}$
LST	Statistical mono-window model, SWM
NDBSI	$NDBSI=(SI+IBI)/2$
MNDWI	$(B_{green}-B_{swir1})/(B_{green}+B_{swir1})$

Note: *B* represents the Band of the Landsat image; The index calculation in Table 1 cites the literature (Hu & Xu, 2018; Wang et al., 2020; Xu, 2013).

3. ANALYSIS OF ECOLOGICAL ENVIRONMENT CHANGES BASED ON LONG TIME SERIES OF REMOTE SENSING

3.1 Study area

Warsaw is the capital city of Województwo mazowieckie Province, Poland. It is located in the central part of Poland. The Vistula River is the largest river in Poland and flows through the city. It can be seen from the Shuttle Radar Topography Mission (SRTM) Digital Elevation map with a spatial resolution of 30m on the right side of Fig.1 that the terrain is relatively flat on the whole in this area. Since the first train of the CER-Express "Su-Man-Europe" (Network, 2017) arrived at Warsaw in 2013 and 90% CER-Express passed through this city (Bai, 2020), which makes this study more representative. Consequently, the study on the eco-environment change monitoring in scale of city along CER-Express is meaningful. In this study, the buffer zone of 2 kilometers on both sides of the CER-Express in Warsaw, Poland is selected as our study area, that is the total width is 4 kilometers (Fig.1).

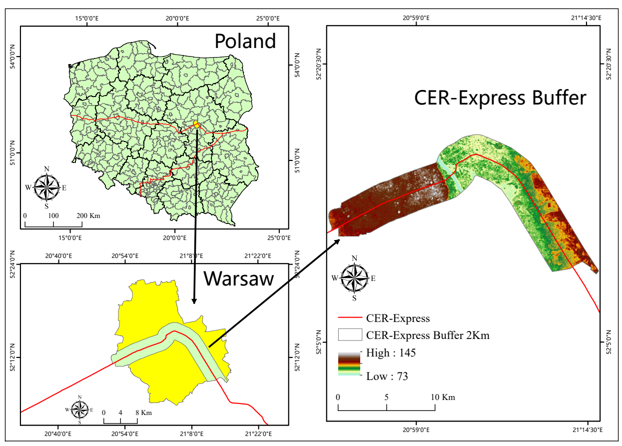

Fig.1. The location of the study area.

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3.2 Data

In this study, Landsat 7 and Landsat 8 imageries with a spatial resolution of 30m are acquired from the Google Earth Engine (GEE) platform. All imageries are surface reflectance (SR) images after geometric correction, radiometric correction, and atmospheric correction. We collect imageries from 2010 to 2020 of this study area to produce the RSEI distribution maps on this platform.

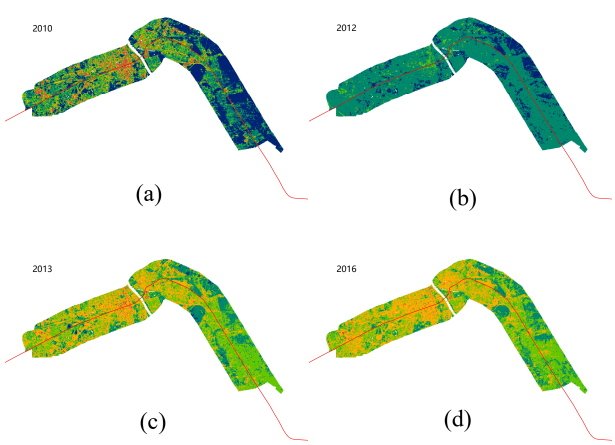
The vectorized CER-Express route data is provided by Ma (Ma et al., 2021). The vector map of administrative division is obtained from the Database of Global Administrative Areas. (https://gadm.org/download_country_v3.html).

3.3 Analysis of ecological environment changes along the CER-Express in Warsaw section

This section analyzes the spatial visualization results based on RSEI maps in 2010, 2012, 2013, 2016, 2018, 2020. Firstly, we show six historical RSEI maps from 2010 to 2020 of the study area to analyze the spatial-temporal changes of eco-environment quality. Secondly, we statistic the distribution of RSEI value in six historical RSEI maps to clearly identify the changes of the median, mean, minimum, maximum values of RSEI in the study area in each year. Thirdly, we statistic the area proportion of each ecological level to show the overall variation of proportion at different level. Then, we use difference distribution maps of RSEI to reflect the distribution of ecological changes in the study area before and after the opening of the CER-Express.

The RSEI results are divided into five grades with an interval of 0.2, i.e., Grade 1: 0-0.2; Grade 2: 0.2-0.4; Grade 3: 0.4-0.6; Grade 4: 0.6-0.8; Grade 5: 0.8-1. They represent poor, fair, moderate, good, and excellent ecological environment quality, respectively (Hu & Xu, 2018; Wang et al., 2020).

Fig. 2 shows the spatial-temporal changes of eco-environment quality of the study area in the study period. A large area of the study area is located at grades 3, 4 and 5 and the overall ecological conditions are good during 2010-2012 (Fig. 2a-b). After the CER-Express operation, the RSEI map result in 2013 (Fig. 2c) shows that a large area is significantly located at grades 1 and 2. At the same time, there is classified as grade 3 on the east of the Vistula River. It can be seen that compared with before opening of the railway, the ecological quality of the regions along the route has generally deteriorated after the express operation. The RSEI spatial distribution results (Fig. 2d-f) are similar to the RSEI map in 2013 (Fig. 2c). It shows that the ecological environment gradually tends to change steadily in the later stage of train operation.



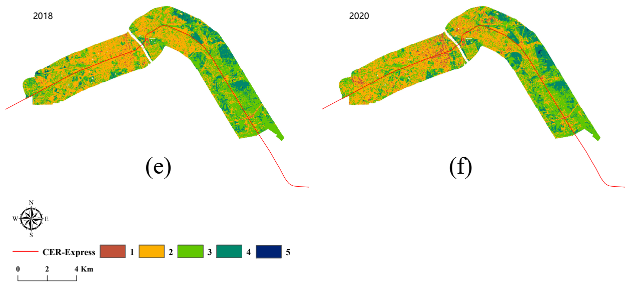
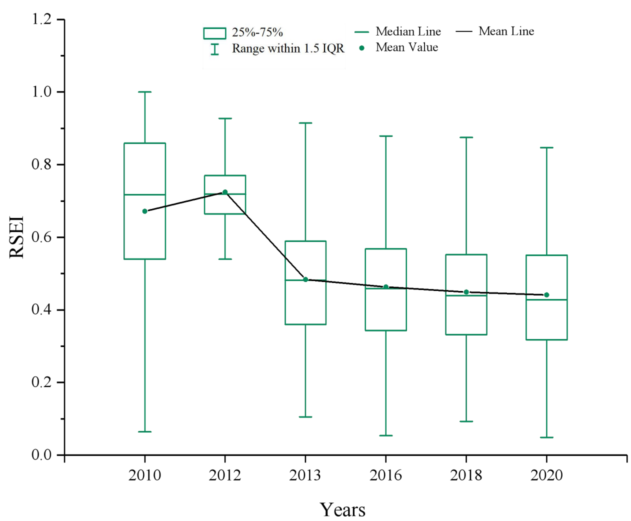
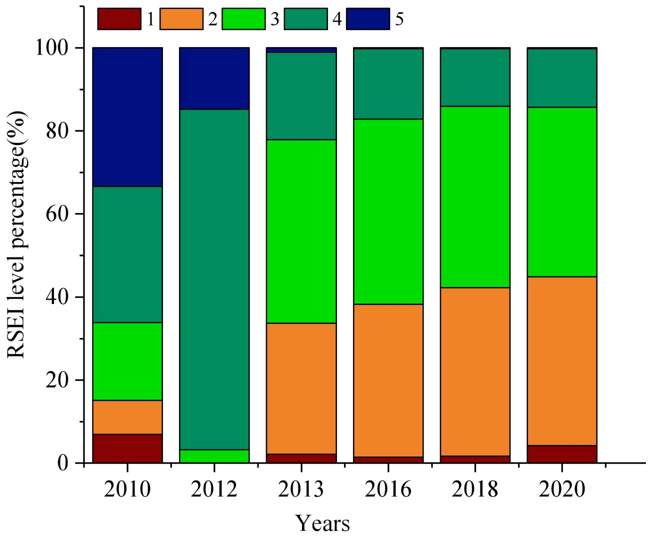


Fig.2. Spatial distribution of RSEI in 2010, 2012, 2013, 2016, 2018, 2020. The legend of Fig.2 is Grade 1: 0-0.2; Grade 2: 0.2-0.4; Grade 3: 0.4-0.6; Grade 4: 0.6-0.8; Grade 5: 0.8-1.

Based on six RSEI spatial distribution maps, the box diagram of the study area and the histogram of the area's percentage of different grades of RSEI by year are drawn in Fig. 3. Specifically, the box diagram (Fig. 3a) reflects the distribution of RSEI value in RSEI maps from 2010 to 2020, and the histogram of grade area percentage (Fig. 3b) delineates the proportional changes of each ecological grade. It can be observed that the total proportion exceeded 90% of grades 3, 4, and 5 along the Warsaw section during 2010-2012 (Fig. 3b). The total area proportion of grades 1, 2 increased significantly to about 40% compared with the before of CER-Express operation, while the total area proportion of grades 3, 4, and 5 decreased year by year during 2013-2020. This indicates that the total proportion of poor and fair RSEI values increases, while the total proportion of moderate, good, and excellent gradually decreases from 2010 to 2020. According to Fig. 3 (a), the mean value of RSEI in 2010 and 2012 fluctuates between 0.6-0.8, and the mean value of RSEI in 2013, 2016, 2018, and 2020 fluctuates between 0.43-0.45. Moreover, the RSEI values at 25% and 75% locations in 2010 are higher than those at the same locations in 2013. From the perspective of the median value line of RSEI, the overall trend is downward from 2010 to 2020 and the median values of 2013, 2016, 2018, and 2020 are significantly lower than those of 2010 and 2012. Therefore, this indicates that the overall level of eco-environment quality shows a downward trend during 2010-2020 in the study area. In addition, the ecological environment of the area along the railway degrades compared with that before the CER-Express operation.



(a)



(b)

Fig.3. RSEI Data Box diagram and Grade Area percentage in 2010, 2012, 2013, 2016, 2018, 2020. (**a**) RSEI Data Box diagram, (**b**) Grade area percentage. The legend of Fig.3b is Grade 1: 0-0.2; Grade 2: 0.2-0.4; Grade 3: 0.4-0.6; Grade 4: 0.6-0.8; Grade 5: 0.8-1.

To reflect the distribution of eco-environment changes in the study area before and after the opening of the CER-Express, this study further calculates the difference distribution maps (Fig. 4) of RSEI. Before the opening, it can be seen that the ecological environment on both sides of the railway has hardly obvious and large-scale deterioration on the spatial scale (Fig. 4a). Through the data survey (Gu, 2017), CER-Express have been put into trial operation in Warsaw, Lodz, and other cities at the end of 2012. But it has not developed into regular operation. After opening in 2013 and arriving in Warsaw directly, there is a large area of ecological degradation on both sides of the railway. It’s red in the spatial difference distribution map and accounts for 74.22% of the study area. The eco-environment of the area near both sides of the Vistula River has been better maintained, which is green or blue in the spatial difference distribution map. The rest of the area is generally degraded (Fig. 4b). The difference result between 2016 and 2018 (Fig. 4c) shows a trend of stable change and a large area of ecological environment on both sides of the railway in the later stage shows no change or improvement, accounting for 83.39% of the study area.

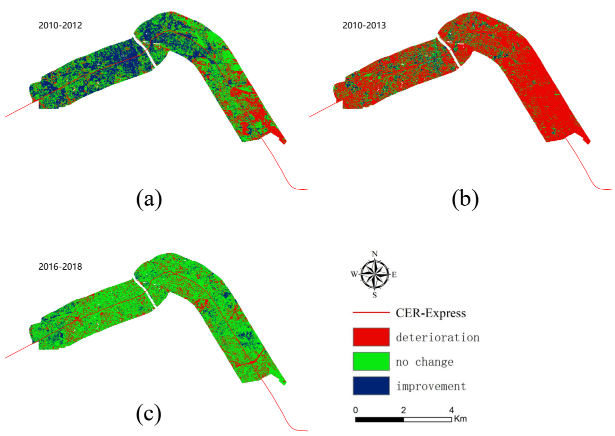


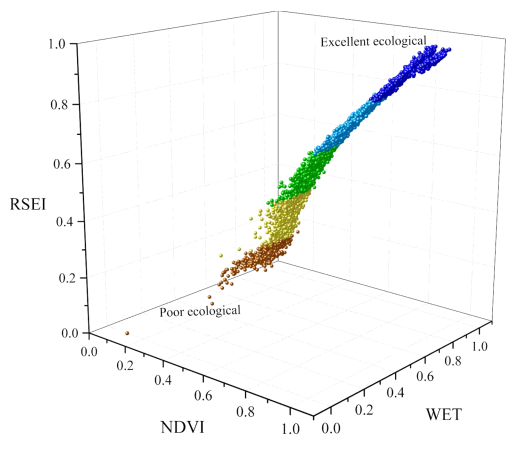
Fig.4. Analysis of the difference before and after the opening of the CER-Express. (**a**) RSEI difference between 2010 and 2012, (**b**) RSEI difference between 2010 and 2013, (**c**) RSEI difference between 2016 and 2018.

To sum up this section, this study takes the first arrival of the CER-Express in Warsaw in 2013 as the time node. The ecological environment along the Warsaw section degraded and gradually changed steadily in the later stage. With the increase of the number of railway trains passing through Warsaw after its operation in 2013, the ecological environment has deteriorated. However, it has maintained stable changes in the late stage of operation.

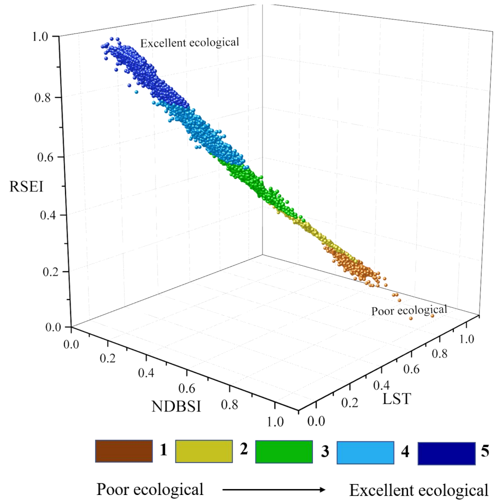
4. DISCUSSION

To verify the effectiveness of the RSEI model in ecological environment quality evaluation of the study area, 7829 points are randomly collected from the 2010 RSEI map, and projected as 3D scatter plot in Fig. 5, proving a visual expression of the aggregation and spatial correlation between RSEI and its factors. The RSEI values within [0, 1] are divided into five grades with an interval of 0.2, i.e., Grade 1 (Poor): 0-0.2; Grade 2 (Fair): 0.2-0.4; Grade 3 (Moderate): 0.4-0.6; Grade 4 (Good): 0.6-0.8; Grade 5 (Excellent): 0.8-1, in order from poor ecological quality to good ecological quality. The relationship between each index and RSEI was analyzed for the positive indicators (NDVI and WET), negative indicators (LST and NDBSI). Fig. 5 (a) shows that the higher NDVI and WET value, the higher RSEI value, which indicates that greenness and wetness are positively correlated with eco-environment quality. Fig. 5 (b) shows that the higher LST and NDBSI value, the lower RSEI value, indicating that heat and dryness are negatively correlated with eco-environment quality. It can be observed that these scatters gather well without dispersion. This indicates that there is a high correlation between variables.

Above 3D scatterplots results are consistent with the actual situation of the earth's surface ecological environment (Hu & Xu, 2018). The 3D scatterplots of this paper are based on the RSEI data of this study area in 2010, and the experimental results of other years are consistent with it. In summary, the RSEI comprehensive index calculated based on PC1 can fully represent the quality of eco-environment and reasonably explain ecological phenomena. At the same time, it can reliably and reasonably assess the ecological environment of the study area.



(a)



(b)

Fig.5. 3D scatterplots of RSEI and NDVI, WET, LST, and NDBSI indicators in 2010.

5. CONCLUSIONS AND FUTURE WORK

Based on long time-series of Landsat remote sensing images, this study calculates the RSEI model on the GEE platform to analyze the ecological environment changes of cities along the CER-Express. In general, the 3D scatterplots of RSEI and NDVI, WET, LST, and NDBSI indicators indicate that there is a high correlation between variables. The results show that the RSEI model can provide a reliable assessment of the eco-environment in the study area. In addition, The RSEI maps from 2010 to 2020 of the study area show that a large area of Warsaw section is located at grades 3, 4 and 5 and the overall ecological conditions are good during 2010-2012. After the CER-Express operation, the RSEI maps in 2013, 2016, 2018, 2020 show that a large area is significantly located at grades 1 and 2. The mean value of RSEI in 2010 and 2012 fluctuates between 0.6-0.8, and the mean value of RSEI in 2013, 2016, 2018, and 2020 fluctuates between 0.43-0.45. The difference result between 2016 and 2018 shows a trend of stable change and a large area of eco-environment shows no change on both sides of the railway in the later stage. Based on above results, the opening of CER-Express may influence and stimulate social and economic activities along the route. However, compared with the status before opening, the eco-environment quality of the regions along the route generally deteriorated after the opening. In general, the eco-environmental quality along the CER-Express fluctuated in the good grade before the opening, declined significantly after the opening, and changed steadily in the later stage. RSEI is formed using the PC1 derived from the four factors (NDVI, WET, LST, NDBSI) and thus it can measure the pressures on the environment caused by human activities, changes in the environmental state and the climate change responses. This conclusion may be related to such factors as population density, climate change and strict local sustainable transport policies in Europe, which are closely related to the operation of CER-Express. Our results also suggest that cities along the CER-Express should pay more attention to the protection of their local environment while using the CER-Express to promote economic development. This preliminary research can provide theoretical basis for cities along the CER-Express, and serve the Goal 15 of the Sustainable Development Goals (SDGs).

As the influence mechanism of the direct relationship between the CER-Express and the ecological environment has not been quantitatively studied, we will focus on the quantitative impact mechanism between them, and verify the reliability of the conclusion in this paper with multi-source data in the future. In addition, the impact of CER-Express on the ecological environment will be analyzed more comprehensively with the influence mechanism between them and the verification of multi-source data.

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REFERENCES

Algretawee, H., Rayburg, S.,Neave, M. (2019). Estimating the effect of park proximity to the central of Melbourne city on Urban Heat Island (UHI) relative to Land Surface Temperature (LST). *Ecological Engineering, 138*, 374-390.

Ascensão, F., Fahrig, L., Clevenger, A. P., et al. (2018). Environmental challenges for the Belt and Road Initiative. *Nature Sustainability, 1*(5), 206-209.

Bai, B. (2020). Chinese ambassador to Poland: 90% of China-Europe Railway Express this year go through Poland, becoming the "Road of Life". *Beijing Daily News*. Retrieved from https://wap.bjd.com.cn/.

Chen, J. M., Chuvieco, E.,Wang, M. (2021). Preface, special issue of “50 Years of environmental remote sensing research: 1969-2019”. *Remote sensing of Environment, 252*, 112113.

Gu, S. (2017). China-Europe Express (Suzhou-Warsaw) Speeds on "One Belt One Road". *People's Daily*. Retrieved from https://people.com.cn.

Hu, X.,Xu, H. (2018). A new remote sensing index for assessing the spatial heterogeneity in urban ecological quality: A case from Fuzhou City, China. *Ecological Indicators, 89*, 11-21.

Li, S., Lang, M., Yu, X., et al. (2019). A sustainable transport competitiveness analysis of the China railway express in the context of the Belt and Road Initiative. *Sustainability, 11*(10).

Liang, L., Wang, Z., Fang, C., et al. (2019). Spatiotemporal differentiation and coordinated development pattern of urbanization and the ecological environment of the Beijing-Tianjin-Hebei urban agglomeration. *Acta Ecologica Sinica, 39*(04), 1212-1225.

Liu, H., Gu, W., Liu, W., et al. (2021). The influence of China-Europe Railway Express on the production system of enterprises: A case study of TCL Poland Plant. *Journal of Geographical Sciences, 31*(5), 699-711.

Ma, B., Guo, X., Jiang, J., et al. (2021). Long-term monitoring of environmental changes along China-Europe railway express (CER Express) using multi-source remotely sensed data. *Int.*

Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLIII-B3-2021, 817-822.

Messer, L. C., Jagai, J. S., Rappazzo, K. M., et al. (2014). Construction of an environmental quality index for public health research. *Environmental health : a global access science source, 13*(1), 39-39.

Network, C.-E. R. E. T. (2017). "Su-Man-Europe"_Suzhou Gusu to Warsaw, Poland China-European Liner Route Map. *China-Europe Raiway Express Transportation Network*. Retrieved from http://cn.cetrains.com/archives/2552.html.

Qi, X., Jia, J., Liu, H., et al. (2019). Relative importance of climate change and human activities for vegetation changes on China's silk road economic belt over multiple timescales. *CATENA, 180*, 224-237.

Radziemska, M., Gusiatin, Z. M., Kowal, P., et al. (2021). Environmental impact assessment of risk elements from railway transport with the use of pollution indices, a biotest and bioindicators. *Human and Ecological Risk Assessment: An International Journal, 27*(2), 517-540.

Wang, Y., Zhao, Y.,Wu, J. (2020). Dynamic monitoring of long time series of ecological quality in urban agglomerations using Google Earth Engine cloud computing: A case study of the Guangdong-Hong Kong-Macao Greater Bay Area. *Acta Ecologica Sinica, 40*(23), 8461-8473.

Xu, H. (2013). A remote sensing urban ecological index and its application. *Acta Ecologica Sinica*. *33*(24), 7853-7862.

Zhao, L., Stoeter, J., Li, H., et al. (2020). European hub location problem for China Railway Express in the context of the Belt and Road Initiative. *International Journal of Logistics Research and Applications, 23*(6), 561-579.

Zhongzhen, Y., Yu, S.,Lee, P. T.-W. (2020). Impact of the development of the China-Europe Railway Express–A case on the Chongqing international logistics center. *Transportation Research Part A: Policy and Practice, 136*, 244-261.