Environment Monitoring along China-Europe Railway Express with Remote Sensing and Artificial Intelligent Technology: A Regional Collaboration Project between China and Serbia

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ABSTRACT:

The operation of the China-Europe railways has facilitated economic development and improved regional connectivity along the route, while impacting the environment. Effective monitoring of the environmental status along the railway is necessary to promote the sustainable development of the Belt and Road Initiative (BRI). Existing remote sensing-based monitoring methods depend on local prior knowledge and model selection, resulting in insufficient specificity when applying to the China-Europe railways, which have a large spatial extent and complex ground variability across nations. Financed by the 2020 China-CEEC Joint Education Project of Institutions of Higher Education, we combined the preponderant research fields of the Beijing University of Civil Engineering and Architecture (BUCEA) and the University of Novi Sad (UNS) and established an environmental monitoring process based on artificial intelligence and remote sensing techniques. More specifically, an online annotating platform and deep learning based classification procedure were established, followed by environmental analysis conducted with comprehensive indicators and a difference-in-difference method. Our results provide 10 years of monitoring data on the environmental status of the China-Europe Railway Express, based on which, the impacts of the economic corridors on the local environment before & after the establishment were evaluated specifically. This collaborative project supports the BRI initiative and highlights the potential for international collaboration in large-scale environmental monitoring.

1. INTRODUCTION

The China-Europe Railway Express (CRE) is an international joint railway transportation service based on fixed train numbers and lines, schedules and whole-course operation hours between China and Europe and other Belt and Road Initiative (BRI) countries. The CER-Express is of great significance in promoting trade between East and West, leveraging its advantages in capacity, security, and expense. Until July 2021, more than 41,000 China-Europe trains were operated, reaching 23 countries in Europe[1], bringing a positive impact on resource allocation and economic growth for the route (Xu, 2020). However, an intensively constructed transportation network and the operation of CRE may gradually impose unprecedented pressure on the local environment in the regions along the railway (Hafeez et al., 2020), leading to degradation, including land degradation, vegetation habitat fragmentation, biodiversity reduction, and ecosystem degradation, etc. (Ascensão et al., 2018). In addition, CRE crosses multiple countries and regions, passing through different landscapes such as deserts, mountains, and frozen areas, and its geographical substratum presents a high degree of heterogeneity, which poses extensive challenges for accurate landscape interpretation. It is urgently needed to quantitively assess and monitor the environmental status along the CRE while considering the diverse geological and ecological characteristics across the route.

Remote sensing is an effective tool for Earth Observation (EO) and can be used to detect spatial variations across large regions on multiple scales. In literature, it is commonly used to evaluate environmental changes, such as atmosphere pollution (Wu et al., 2020), deforestation (Griffiths et al., 2018), and urban development on scales ranging from countrywide to worldwide. Since Goal 15 was mentioned in the Sustainable Development Goals (SDGs) proposed by United Nations (UN), many studies have explored the worldwide environmental issues involved in the sustainability of terrestrial ecosystems, desertification, and land degradation (Kavvada et al., 2020), whereas limited research has been conducted on the topic along the China-Europe Railway Express. In addition, current ecological remote sensing monitoring methods rely on local prior knowledge and model selection, lacking specificity when applied to the large spatial extent and complex surface variability of the CRE. An international collaboration between research groups from China and European countries will integrate research bases related to CRE, thus alleviating the challenges.

China-CEEC is short for 'China and Central and Eastern European Countries', and China-CEEC Higher Education Institutions Consortium was established in September 2014 within the framework of the China-CEEC dialogue of education policy. By September 2020, The Consortium has 178 Chinese

[1] http://www.china-railway.com.cn

universities and 37 universities from Central European and 17 from Eastern European countries[2]. This Consortium aims to establish a cooperative platform between China and Central and Eastern European universities, to integrate and share resources, as well as to deepen the educational exchange and cooperation between China and CEEC, to promote the development of national education and consolidate the public opinion basis of the regional economic construction, cultural progress, and social sustainable development. Beijing University of Civil Engineering and Architecture (BUCEA), China, and University of Novi Sad (UNS), Serbia, are members of the Consortium, and have a research base in environmental monitoring and deep learning.

Supported by China-CEEC Higher Education Institutions Joint Educational Program 2020, we established an artificial-intelligence-based environmental monitoring process that incorporates remote sensing techniques with artificial intelligence and spatiotemporal data analysis, leveraging the advantages of BUCEA and UNS. The proposed process consists of collaborative annotations construction, deep learning based land cover identification, and comprehensive environmental analysis.

As far as we know, this is the first regional collaboration project addressing the long-term monitoring of environmental status along the CRE, and this work highlights the potential for international collaboration in large-scale environmental monitoring. The remainder of this paper describes the study area and data (section 2), the method (section 3), the results (section 4), and concluding remarks (section 5).

2. STUDY AREA AND DATA

2.1 Study Area

As shown in Fig.1, our study area encompasses a total of 38 countries and regions in Europe. Among them, there are 18 countries and regions along the CRE, i.e., Austria, Belarus, Belgium, Czech Republic, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, Monaco, Netherlands, Poland, Serbia, Slovakia, Spain, United Kingdom.

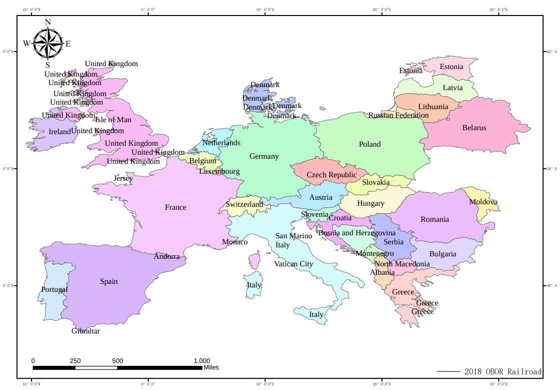


Fig. 1. Location of the study area

2.2 Datasets

2.2.1. Time-series Landsat & Sentinel-2 imagery

As a single Landsat mission cannot cover the whole period of 2000 to 2020, all available Landsat 7&8 and Sentinel-2 imageries archived on the Google Earth Engine (GEE) computation platform, were collected to monitor the spatiotemporal dynamics of environment status along CRE. Preprocessing has been conducted on the obtained imageries to minimize the scattering and absorption effects of the atmosphere, and these poor observations (including snow, shadow, cloud, and saturated pixels) were masked or removed.

2.2.2. Environmental Dataset

The 0.01° × 0.01° resolution particulate matter (PM2.5) dataset was obtained from the Atmospheric Composition Analysis Group at Dalhousie University.

The monthly Terra Moderate Resolution Image (MODIS) was used to calculate the vegetation indicator (MOD13A3), which is provided at a spatial resolution of 1 km.

We collected MOD11A2 (version 6) and MYD11A2 (version 6) products to obtain an average of 8 days of land surface temperature and emissivity (LST&E) with a spatial resolution of 1 km.

2.2.3. CRE Outline Data

The CRE (Europe Section) outline data is the basis for our study to separate regions along or not. This data was manually outlined and vectorized by referring to the ESRI official dataset and railway dataset (from 'Natural Earth' with the precision of 1:10m).

In addition, we collected Google Earth images, the Global 30 landcover dataset, and country-specific socioeconomic (i.e., population and GDP) data for auxiliary.

3. METHODOLOGY

The CRE traverses the Eurasian continent and exhibits distinct data characteristics of large spatial extent and strong heterogeneity. Deep learning has made progress in fine-scale environment problems due to its excellent and efficient feature representation capabilities. However, current researches focused on relatively small study areas, and the use of local annotations will lead to low diversity and generalizability, which is not conducive to accurate monitoring of the environment across large heterogeneous spatial areas. Although there are some large-scale remote sensing datasets available(Sumbul et al., 2021), such as UC Merced, BigEarthNet, RSC11, and SIRI-WHU, they are limited by their sampling range, resolution, and availability, and cannot be directly applied to long-term monitoring for CRE.

3.1 Collaborative annotating platform and deep learning driven landcover identification

For annotation, we developed an online semantic annotating editor platform (shown in Fig. 2) based on the open-source project. This platform allows project participants to annotate separately wherever they are. We collaboratively built a deep learning sample library containing 10 categories, including forests, cities, farmlands, and roads, based on a large volume of long-term, high-resolution remote sensing data from Landsat-7 & 8 and Sentinel-2.

[2] http://ccheic.xjtu.edu.cn/en/Members.htm

https://doi.org/10.5194/isprs-annals-X-5-W1-2023-31-2023 |

Fig. 2. The developed online annotating platform.

Based on the constructed annotation library, we employed an efficient land-cover identification framework for the study area by combining transfer learning and deep convolutional neural network. The classic VGG16 network was firstly modified to accept multispectral information. The improved network with 13 convolutional layers and 3 fully connected layers will fully utilize the multi-scale information. In addition, pre-training information was transferred from ImageNet into the network, which enhanced the ability to discriminate fine edge features, and further improved the robustness and accuracy of identification.

3.2 Environment assessment with CEI indicator and difference-in-difference (DID)

Proved as a valid index for a comprehensive assessment of environmental conditions in large scale areas(He et al., 2017), CEI involves three indices that have the most significant impact on environmental quality (Lu et al., 2019), i.e., PM2.5, LST and NDVI. The formula is as follows:

$$CEI = \sqrt[3]{(DeltaPM + 1)*(DeltaLST + 1)*(Delta\ NDVI_{nor} + 1)} \quad (1)$$

Where, $DeltaPM$, $DeltaLST$, $Delta\ NDVI_{nor}$ determines the normalization of annual difference of PM2.5, LST, and NDVI, respectively. It should be noted that a higher CEI value means more degradation in this region.

To evaluate the net impact of the CRE on the environmental status, we introduced the Differences-in-differences (DID) model (Abadie, 2005), with the operation of the CRE as the core explanatory variable. All CEI data of different countries and regions were divided into treatment and control groups, according to the establishing time. Through two difference-operations before and after the establishment of the CER, we eliminated the heterogeneity of individuals that did not change over time and the incremental changes over time. The modelling is:

$$Y_{i,t} = a_0 + \beta CER_{i,t} + \mu_i + \Theta_t + \varepsilon_{i,t} \quad (2)$$

$$Y_{i,t} = a_1 + \beta_1 CER_{i,t} + \beta_2 X_{i,t} + \mu_i + \Theta_t + \varepsilon_{i,t} \quad (3)$$

Where i and t refer to the city and year; $CER_{i,t}$ is a binary dummy variable and the core explanatory variable; city- and time-fixed effects are controlled with μ_i and Θ_t, respectively; $X_{i,t}$ is the control variable, and $\varepsilon_{i,t}$ is the residual term; a_0 and a_1 are the constant terms; The impact of CRE can be evaluated by β and β1.

4. RESULTS

4.1 CRE environment data set and identification results

At present, over 600 Landsat 7&8 and over 27,000 Sentinel-2 imageries have been processed. Poland and Serbia have been fully annotated and achieved overall coverage, while other countries and regions have been sampled to achieve comprehensive consideration of different surface types. In addition, rotation and scaling have been applied to meet the requirements of multi-scale interpretation. Figures 3-4 show the labeling for forests and cities along the CRE in Poland.

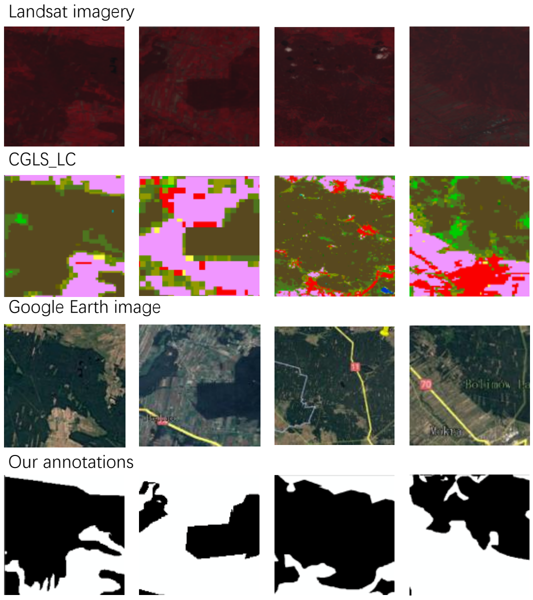


Fig. 3. Comparison of our annotations with other references for Forests in Poland.

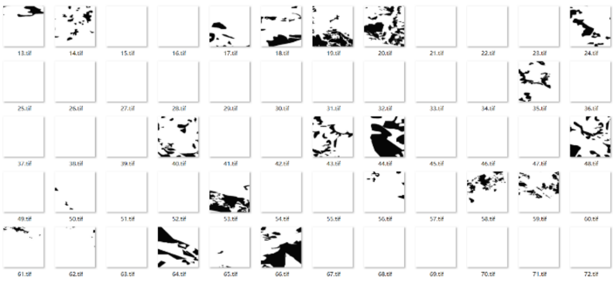


Fig. 4. Our annotations for Built-up (part).

With the developed annotation library and DL method, we obtained nearly 20 years of land cover results for the entire CRE, which provides data support for the subsequent environment monitoring along the express. Fig. 5 shows the landcover recognition results in Novi Sad, Serbia. This method can alleviate technical problems such as low monitoring accuracy due to the differences in multiple scenes and land cover along the CRE. More details could be referred to previous work (Pavlovic et al., 2022).

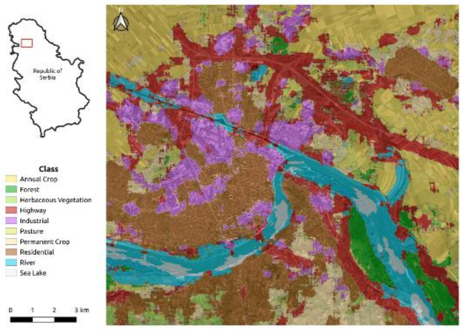


Fig. 5. Landcover recognition results in Novi Sad, Serbia.

4.2 CEI Results for the Europe Continent

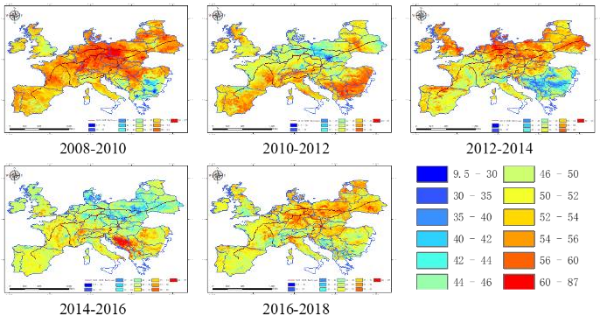
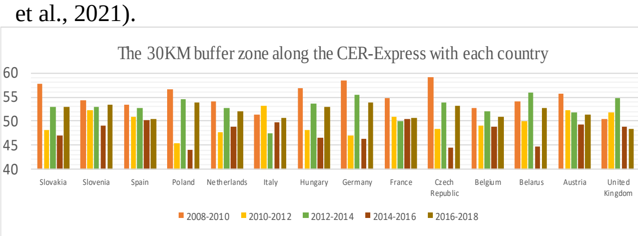
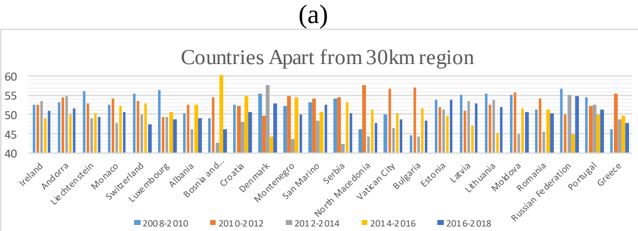


Fig. 6. The CEI for the study area from 2008 to 2018, where higher values (red) indicate higher degradations

Fig. 6 reports the mean CEI values of the study area. Continuous fluctuations can be observed from 2010 to 2018, among the countries, Hungary, Poland and Germany showed a general upward trend, especially during 2016-2018, when the CRE were intensively constructed and operated. indicating the environmental degradation. Comparing the mean CEI values of regions along and off the CRE, it could be observed that environmental degradation was more severe in the buffer zone along the CER Express (Fig. 7a) than the off-line counterparts (Fig. 7b). More details could be referred to previous work (Ma et al., 2021).



(a)



(b)

Fig. 7. From 2008-2018, the mean CEI values falling (a) within and (b) outside 30 kilometers buffer zone of CER

4.3 Net impact analysis of CRE

There is a general and unprecedented trend in urbanization for European countries during the past decade, which may also degrade the local environment. The extent to which the CRE dynamically impacts on the local environment remains unclear. By applying the DID analysis to the study area, which includes countries and regions on/off the CRE, we can figure out the net impact of CRE on the environment in different countries and regions over different operation periods. Figure show that: (1) the environmental degradation is not significant during the early stages of CRE establishment, but it can be inferred that some areas had already experienced degradation; (2) After continuous express operations, the local environmental conditions deteriorated, but the impact (-5 in value) was relatively small compared to that before establishment (+6 in value), which also implies the degradation is controllable.

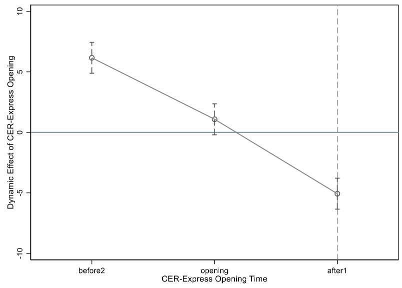


Fig. 8. The dynamic net-impact of the CRE, with negative impact below the 0-axis and absolute values representing the magnitude of the impact

4.4 Implications of international collaboration in large-scale environmental monitoring

This project is a collaboration between BUCEA and the UNS. It relies on the research base of BUCEA in urban remote sensing and UNS in artificial intelligence. Utilizing open-source data and models, the two universities jointly carried out high-precision remote sensing monitoring of the environment status along the CRE. The project aims to construct a regional environment remote sensing annotation library, develop rapid DL-based land cover interpretation technology, and analyze long-term environmental change along the express.

During the execution, BUCEA is responsible for constructing the Landsat-7 & 8 annotation library, and conducting comprehensive monitoring and evaluation of the environmental change at multiple scales. UNS is responsible for constructing the Sentinel-2 annotation library and developing rapid DL-based land cover interpretation. Throughout the project execution, the two universities closely collaborated and communicated progress via email and regular meetings, and data sets, models, and software are shared for joint use via git.

Fig. 9. Regular meeting during the collaboration.

5. DISCUSSIONS AND CONCLUSIONS

The long-term monitoring and assessment of environmental changes along the CRE are urgently needed. In this study, we established an artificial-intelligence-based environmental monitoring process that incorporates remote sensing techniques with artificial intelligence and spatiotemporal data analysis, with the support of China-CEEC Higher Education Institutions Joint Educational Program 2020. After two-year regional collaborations between BUCEA and UNS, we can come to the following conclusions:

1. This project has developed a practical framework for

monitoring large scale environmental change along the CRE. As the first regional collaboration project addressing the long-term monitoring of environmental status along the CRE, it delineates 10-years environmental changes in a spatiotemporal way, and quantitatively evaluates the net impact caused by the establishment of the CRE. In addition, a comprehensive environmental annotation library was constructed to address the issue of sample diversity. Moreover, the developed landcover identification framework alleviates the challenge posed by highly heterogeneous surface cover types with the support of transfer learning and deep learning.

2. This project is a good start and trial to integrate the research capacities from China and other countries. Through the joint research and academic exchange, the project developed a long-term monitoring and analysis system for ecological changes, and demonstrated its applications in countries and regions along CRE. The implementation of this project also explored a new way to promote scientific research through international collaboration, which helps enhance international academic exchange, and serves as an effective way for cultivating innovative and high-level talents.

3. From the perspective of practical applications for promotion, the proposed workflow shows potential in various studies related to large-scale environmental monitoring and location services. Present results can offer a reference for scientific decision-making in BRI related economic corridor construction, management, and social services. With continuous monitoring, early warnings of ecological problems during the operation of CRE trains can be drawn. Furthermore, as the impacts of the economic corridors on the local environment have been evaluated, trains management can be fine-tuned according to the diverse geological and ecological characteristics of the study area, which will contribute to ensuring that BRI brings long-term green and sustainable development to all concerned countries along the railway.

6. ACKNOWLEDGEMENTS

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