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Ecological Consequences of Railway Infrastructure Development: A Case Study of the Belgrade-Novi Sad Corridor

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Abstract: This study presents a comprehensive evaluation of environmental susceptibility associated with the development of the Belgrade-Novi Sad Railway Route in Serbia. Fostering socio-economic growth through transportation infrastructure necessitates an acute awareness of potential ecological implications, a nexus often overlooked in the haste of progress. Accordingly, a broad spectrum of environmental parameters such as land use, air and noise pollution, water resources, and biodiversity were systematically assessed. The employment of Habitat Equivalency Analysis facilitated the discernment of potential environmental detriments linked with the railway project. Significant findings from this investigation offer critical insights for policymakers, urban planners, and environmental conservationists, thus enriching the understanding of ecological consequences attached to the expansion of the specified railway corridor. These findings, serving as a tool for informed decision-making, are pivotal in striving towards a balanced approach between the exigencies of transportation infrastructure enhancement and the indispensable goal of environmental preservation. Ultimately, the goal of this study is to promote an enhanced understanding of the reciprocal relationship between infrastructure development and environmental impact, thereby contributing to the ongoing discourse on sustainable practices beneficial for current and future generations.

Keywords: Railway development; Environmental impact assessment; Sustainable transportation

1. Introduction

Railway infrastructures indisputably form a critical element of modern transportation networks, playing pivotal roles in ensuring efficient transit of people and goods, thereby driving socio-economic progression (Roy & Mitra, 2020; Roy & Mitra, 2021a). Furthermore, they facilitate regional connectivity and accessibility, significantly reducing transportation times (Debnath et al., 2021; Roy et al., 2022). Despite the aforementioned advantages, it is equally important to note the potential environmental ramifications associated with the development and operation of railway infrastructures (Kang et al., 2018). Detrimental effects on the environment may manifest in numerous forms, encompassing soil degradation, water and air pollution, and loss of biodiversity (Roy & Mitra, 2022a).

Detailed environmental assessments of proposed railway infrastructure projects are thus essential prior to their initiation (Roy & Mitra, 2016). Such assessments are meticulously designed to estimate potential environmental influences on infrastructure, and reciprocally, the potential impacts of the infrastructure on the environment. The purpose is to identify and address prospective environmental concerns inextricably linked to construction and operation activities (Roy & Mitra, 2022a). The process inherently involves identifying ecologically sensitive regions such as forests, wetlands, and wildlife habitats that could potentially bear negative implications from the project (Kaewunruen et al., 2015).

The development and operation of railway infrastructures have been documented to cause land degradation (Shafiepour et al., 2018). Construction activities may lead to soil erosion, compaction, and degradation, resulting in decreased soil productivity, fertility, and biodiversity. Thus, diligent planning is required to circumvent areas

of sensitive soil quality. Furthermore, construction methodologies such as water diversion and sediment control should be implemented to minimize soil erosion and degradation (Shafiepour et al., 2018).

Water pollution is another environmental consequence associated with the development and operation of railway infrastructure (Roy et al., 2023d). Surface water and groundwater may become contaminated due to construction activities like earthworks, excavations, and material handling, causing sedimentation and negative impacts on water quality. Consequently, it becomes imperative for railway infrastructure projects to adopt measures safeguarding water quality (Roy et al., 2023d). Such initiatives may include erosion control measures during construction and water filtration systems to reduce the discharge of pollutants into waterways (Hauc et al., 2010; Shin et al., 2018).

Biodiversity loss also represents a significant environmental concern linked to railway infrastructure development and operations (Venkatesan et al., 2013). Railway infrastructures can induce degradation, fragmentation, and loss of natural habitats, affecting the biodiversity of native fauna and flora species, and disrupting ecological balance. To mitigate these adverse effects, railway construction should strive to avoid ecologically sensitive regions. Buffer zones or wildlife corridors can also be created to reconnect fragmented habitats and enhance biodiversity along railway corridors.

Air pollution, both during the construction phase and operation phase, remains a noteworthy environmental impact of railway infrastructure (Jurković et al., 2021). Dust and other pollutants emitted from construction vehicles can detrimentally affect air quality, while during operations, diesel-powered locomotives release pollutants like nitrogen oxides and particulate matter into the atmosphere. Implementing measures to reduce such pollution becomes paramount, for instance, using dust suppressant systems during construction and the electrification of railway networks to reduce emissions (Chaberek, 2021).

Sustainable railway development necessitates the adoption of innovative technologies to effectively address environmental challenges associated with railway infrastructure development and operations. This may include utilizing green energy sources such as solar, wind, or hydroelectric power to supply electricity to railways, or deploying electric locomotives to reduce carbon emissions (Jurković et al., 2021). Sustainable development further encourages the incorporation of more efficient modes of transportation like intermodal transportation, which fosters seamless connectivity between different transport modes, enhancing efficiency, reducing travel times, and decreasing carbon emissions (Chaberek, 2021).

Given this background, the Belgrade to Novi Sad Railway Route, being integral to the Serbian transportation network, requires a comprehensive environmental assessment due to its significant environmental implications. This railway route, in operation for over a century, forms a crucial link within Serbia's transportation network, being a conduit for trade, tourism, and commuting. The research thus undertakes the imperative task of identifying potential environmental challenges and proposing effective, sustainable solutions. The study aims to elucidate the ecological impacts along the Belgrade to Novi Sad Railway Corridor, thereby contributing to sustainable development practices and ensuring alignment with environmental conservation goals.

2. Literature Review

The enhancement of transportation infrastructure, encompassing railway routes, has been identified as a cornerstone for fostering regional interconnectivity and stimulating economic growth (Roy et al., 2023b). However, an intricate understanding of the ecological repercussions stemming from such developments is paramount to endorse sustainable practices. This literature review undertakes a rigorous analysis of the extant research, focusing on the environmental impact of railway corridors, with a specific emphasis on the Belgrade to Novi Sad Railway Corridor in Serbia (Grozdanovic & Bijelic, 2021). The objective is to spotlight vital ecological aspects that warrant consideration while gauging the environmental susceptibility of the railway route under study.

Railway corridors have been shown to instigate substantial modifications to land use and habitat fragmentation. Transitioning natural ecosystems into railway tracks precipitates habitat destruction and segmentation, which exerts deleterious effects on biodiversity (Zeybek, 2021). Previous research underscores the necessity of integrating considerations of ecological connectivity within the initial planning and design phases of railway projects to mitigate the extent of habitat fragmentation. Furthermore, land requisitions for railway construction may culminate in the obliteration of agricultural lands, imparting negative repercussions on local communities and jeopardizing food security (Macura et al., 2022). Consequently, a comprehensive understanding of the implications on land use and prospective habitat fragmentation along the Belgrade to Novi Sad Railway Corridor is essential to curtail ecological damage.

It has been reported that railway operations contribute to air and noise pollution, adversely impacting human societies and wildlife populations. Emissions originating from locomotives and construction equipment result in an increase in air pollutants, including particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs). These pollutants compromise air quality, endanger human health, and negatively affect vegetation. Additionally, noise pollution emanating from railway operations may disrupt wildlife habitats and alter their behavior (Jia & Liu, 2022). Potential mitigative strategies, such as the incorporation of noise barriers and the

establishment of vegetation buffers, have been suggested to curb noise pollution. Therefore, an assessment of possible air and noise pollution along the Belgrade to Novi Sad Railway Corridor is indispensable for the successful implementation of appropriate countermeasures.

Table 1. Systematic literature review with outcomes measured

Paper Title	Abstract Summary	Authors	Journal	Outcomes Measured
Environment monitoring along China-Europe railway express with remote sensing and artificial intelligent technology: A regional collaboration project between China and Serbia	The environmental monitoring process along the railway is necessary to promote the sustainable development of the Belt and Road Initiative.	(Guo et al., 2023)	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	•Environmental Status of The China Europe Railway Express •Impacts of The Economic Corridors on the Local Environment Before & After the Establishment
Assessing the ecological impacts of transportation infrastructure development: A reconnaissance study of the standard gauge railway in Kenya	The construction and operation of the SGR degraded, fragmented, and destroyed key ecosystems in the country.	(Nyumba et al., 2021)	PLoS One	•Ecosystem Degradation •Ecosystem Fragmentation •Ecosystem Destruction
Revisiting the environmental impacts of railway transport: does EKC exist in South-Eastern Europe?	The railway transportation system of Southeastern Europe countries does not help to reduce the level of carbon emissions.	(Abul & Satrovic, 2022)	Polish Journal of Environmental Studies	•Environmental Damage •Level of Carbon Emissions
Study on minimization of environmental and ecological effects of railroad development considering the distance from the roads	The distance of less than 200 m was suggested to minimize the environmental impact of railroad lines located adjacent to roads.	(Kim & Kim, 2020)	Ecology and Resilient Infrastructure	•Environmental Impact of Railroad and Road Development •Efficient Land Use Plan •Soil Protection •Minimum Separation Distance Criteria
Environmental impact assessment of risk elements from railway transport with the use of pollution indices, a biotest and bioindicators	Soil pollution indices, biotest results, and plant and fungus bioindicators play an important role in environmental assessments of railway transport.	(Radziemska et al., 2021)	Human and Ecological Risk Assessment	•Cd Content in Soil, Pine Bark, Pine Needles, Hoof Fungus, and Red Stemmed Feathermoss •Cr Content in Soil, Pine Bark, Pine Needles, Hoof Fungus, and Red Stemmed Feathermoss •Cu Content in Soil, Pine Bark, Pine Needles, Hoof Fungus, and Red Stemmed Feathermoss •Ni Content in Soil, Pine Bark, Pine Needles, Hoof Fungus, and Red Stemmed Feathermoss •Pb Content in Soil, Pine
The environmental impacts of the Ferrogrão railroad: An ex-ante evaluation of deforestation risks	The environmental impact of large infrastructure projects is challenging to assess.	(About the Ferrogrão railroad project, 2020)		
Understanding physical environment through safe highway transport mobility with special review on climate: The highway route Belgrade-Novi sad, Serbia	Climate elements have a strong influence.	(Sentić & Đorđević, 2019)	Geographica Pannonica	

Evaluation of railway versus highway emissions using LCA approach between the two cities of Middle Anatolia	The environmental damage ratio decreased with the increasing utilization ratio of the railway between Kirsehir and Nigde-Ulukisla in the middle Anatolian Peninsula in Turkey.	(Bilgili et al., 2019)	Sustainable Cities and Society	•Environmental Damage Ratio •Ecosystem Quality •Damage Cost •Nox Emissions
Design and evaluation of railway corridors based on spatial ecological and geological criteria	Transport infrastructure is closely linked to several sustainability issues of main policy relevance.	(Karlsson, 2016)		•Impact On Biodiversity •Resource Use •Construction Costs
Multidimensional evaluation of soil pollution from railway tracks	The pollutants determined in soils from railway tracks did not exceed the admissible values.	(Wierzbicka et al., 2015)	Ecotoxicology	•Degree Of Toxicity and Pollution of Soil •Type and Content of Particular Pollutants (Pahs, Pcbs, Heavy Metals, Oil Derived Hydrocarbons and Pesticide Residues) •Reaction of Organisms to Pollutants
The assessment of pollutants emissions within sustainable urban freight transport development the case of Novi sad	Fleet renewal is not enough to reach the ambitious EU strategy goals concerned with sustainable urban freight transport.	(Veličković et al., 2014)	Thermal Science	•Pollutant Emissions •Gas Emissions
An environmental analysis of rehabilitation options for an open track section of railway in Slovenia	The structures incorporating geosynthetic membranes have a lower Global Warming Potential (GWP) and a lower environmental impact overall.	(Fifer Bizjak et al., 2014)	Applied Science	•Global Warming Potential (Gwp) •Environmental Impact
Restoring ecological networks across transport corridors in Bulgaria	The implementation of proposed road and railroad mitigation is expected to significantly improve the population viability of most threatened wildlife species.	(van der Grift et al., 2009)		•Impact of Existing and Planned Human Transport Corridors on the Population Viability Of 12 Indicator Species •Bottleneck Locations in the Road and Railroad Network in Bulgaria •Potential Overlap of Bottleneck Locations Identified by the Larch Model and the Experts

Source: Prepared by the author, 2023

Construction and operation of railways can also lead to alterations in water resource dynamics due to changes in hydrological patterns, an increase in stormwater runoff, and the risk of contamination (Nikolić et al., 2016). Manipulations of natural drainage systems can elevate surface runoff and soil erosion, transporting pollutants into proximate water bodies and impairing water quality and aquatic ecosystems (Table 1). Retention ponds, sedimentation basins, and vegetated buffers have been suggested as mitigative measures to minimize water-related impacts. Therefore, an appraisal of the potential hydrological consequences along the Belgrade to Novi Sad Railway Corridor is critical for the conservation of water resources and the prevention of ecological degradation.

Considerable implications for biodiversity conservation are associated with railway corridors. Habitat fragmentation, disturbances induced by construction activities, and the incursion of invasive species are common ecological outcomes. The incorporation of strategies such as maintaining or enhancing ecological connectivity, protecting critical habitats, and implementing measures to alleviate disturbances is pivotal for preserving biodiversity (Table 1). Moreover, the provision of wildlife crossings, wildlife-friendly fencing, and habitat restoration have been proposed as efficacious strategies. Thus, a thorough assessment of potential effects on biodiversity along the Belgrade to Novi Sad Railway Corridor is crucial for the formulation of conservation strategies.

This literature review accentuates the principal ecological factors that necessitate evaluation in the process of assessing the environmental susceptibility of the Belgrade to Novi Sad Railway Corridor. Considerations pertaining to land use, habitat fragmentation, air and noise pollution, water resources, and biodiversity

conservation are integral to this analysis. The integration of these factors within the assessment process can facilitate policymakers, planners, and environmentalists in implementing effective mitigative strategies and promoting sustainable development along the railway corridor. Comprehending the ecological impacts of the Belgrade to Novi Sad Railway Corridor is instrumental in facilitating informed decision-making and devising efficacious conservation strategies. Additional research coupled with an extensive environmental susceptibility study are warranted to ensure the sustainable development of the railway corridor, concurrently minimizing ecological degradation.

3. Methodology

The methodology employed in this investigation was designed to identify potential environmental ramifications associated with the Belgrade to Novi Sad Railway Route and propose sustainable remedial measures (Yusoff et al., 2021). A hybrid methodology, melding both qualitative and quantitative approaches, was utilised for the procurement and analysis of data. An extensive literature review was initially conducted, gathering pertinent data related to environmental consequences arising from railway infrastructure and operations. The review encompassed a diverse array of sources, namely peer-reviewed scholarly articles, industry reports, and official government documents. This process allowed for the prediction of potential environmental repercussions, including land degradation, water contamination, air pollution, and biodiversity depletion, stemming from the expansion of railway infrastructure.

Subsequent to the literature review, a series of field investigations were executed along the Belgrade to Novi Sad Railway Route, aiming to accumulate empirical data regarding the prevailing environmental conditions and potential environmental impacts. Activities during field surveys ranged from direct observations to precise measurements, and systematic sampling of various environmental parameters, such as soil composition, water quality, air composition, plant distribution, and animal species abundance. Data collected in the field was juxtaposed with the existing literature to ensure its accuracy and relevance.

In addition, an in-depth examination of satellite images was undertaken to gain a broader understanding of the intended railway path and surrounding ecosystems. Satellite imaging analysis enabled the delineation of the current land use practices, vegetation coverage, and water resources within the region. The imaging approach also assisted in the identification of vulnerable ecosystems and regions that may require special attention during railway infrastructure expansion.

Finally, interactions with environmental specialists were conducted to gain their perspectives and insights on potential environmental implications related to railway infrastructure development. Such interactions provided invaluable insights into potential environmental threats and effective sustainable strategies for mitigating these impacts.

Data collected from the various sources underwent rigorous analysis using statistical and spatial tools. Statistical analytic techniques, including regression and correlation analysis, were applied to examine relationships between various environmental factors. The use of a correlation matrix was instrumental in identifying significant relationships among various environmental indicators, thus enhancing the understanding of the environmental aspects influencing the railway route. Spatial analytic methods, such as the study of land use change and land suitability assessment, were used to identify suitable regions for railway construction and those requiring specific conservation efforts.

In summary, the methodology incorporates a blend of qualitative and quantitative techniques for an in-depth assessment of the environmental susceptibility of the Belgrade to Novi Sad Railway Route. The multifaceted data collection approach, including a literature review, field surveys, satellite image analysis, and expert consultations, combined with statistical and spatial analyses, provides a comprehensive understanding of the environmental implications associated with railway infrastructure expansion. This methodology ultimately facilitates the proposal of sustainable solutions to mitigate potential adverse environmental impacts of such development.

4. Study Area

The Belgrade to Novi Sad Railway Corridor, a crucial transportation infrastructure project within Serbia, links the regions of Belgrade and Novi Sad over a span of approximately 80 kilometers of track (Figure 1). Comprising several intermediate railway stations such as Indjija, Stara Pazova, and Ruma, the route traverses both urban and rural landscapes. It is noteworthy that the geological composition along the corridor exhibits significant variability, necessitating tailored construction methodologies that consider potential influences on groundwater levels, soil erosion, and geological stability. It is therefore incumbent upon environmental susceptibility studies to evaluate biodiversity, water resources, air quality, and noise pollution when estimating potential environmental consequences (Roy et al., 2023e).

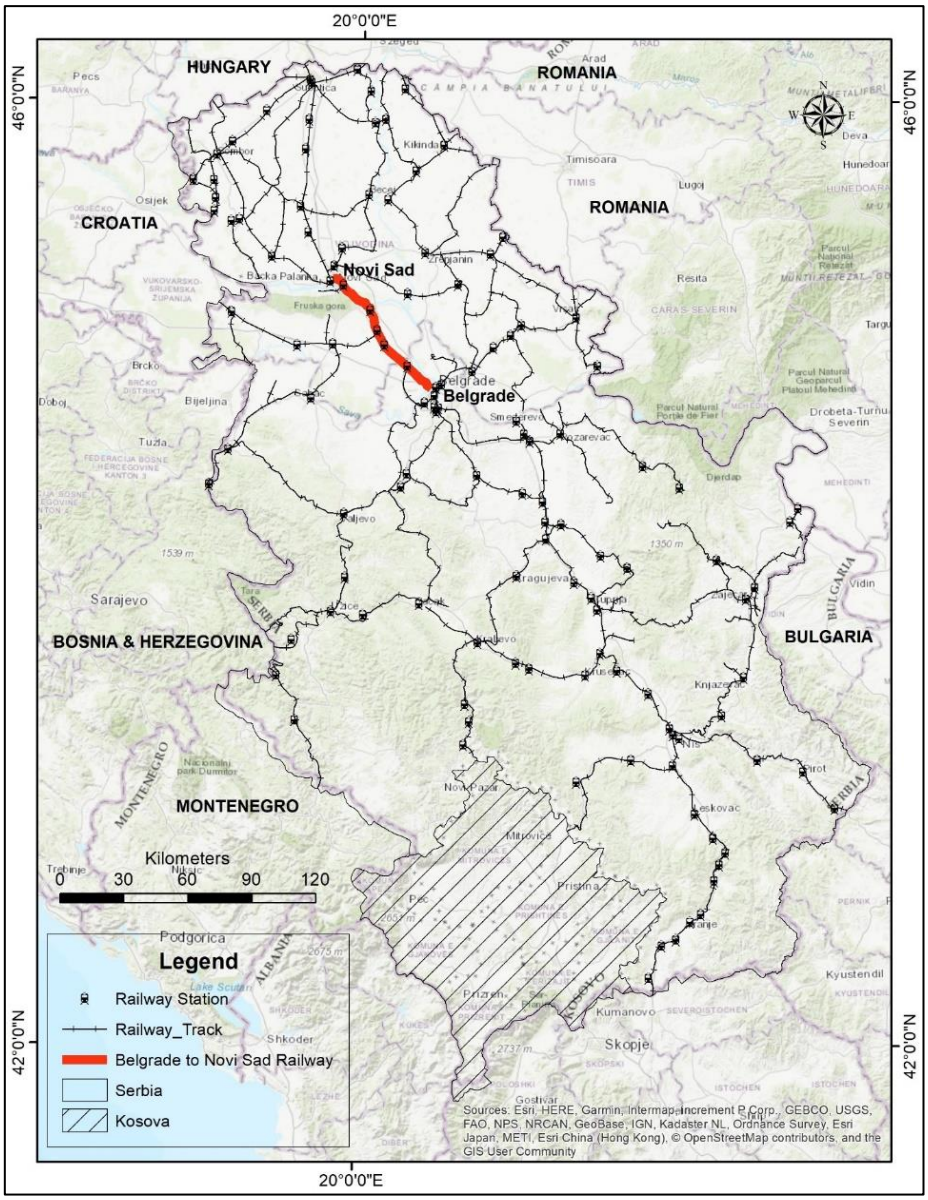

Figure 1. Location map of the study area
Source: Prepared by the author, 2023

An integrated approach that incorporates land use planning and environmental sustainability is pivotal for the attainment of sustainable development while concurrently minimizing disruptions to socioeconomic activities and any adverse effects on land productivity. A comprehension of these factors aids in the accurate evaluation of the corridor's significance and impacts, thereby facilitating a balance between infrastructure development, environmental conservation, and socioeconomic progression (Roy et al., 2023c).

In elaborating further, the intermediate stations along the railway corridor serve as important nodes that potentially influence the adjacent environments, be it urban or rural. Careful consideration of these nodes during the planning and implementation phases of the railway corridor is crucial for minimizing environmental disturbances. For instance, the designs of these stations can be adapted to fit into the existing landscapes, rather than significantly altering them. Strategies such as green building concepts and ecological landscaping can be integrated into the station design to minimize the environmental footprint. Furthermore, the transitional zones between urban and rural landscapes require particular attention due to their unique socioeconomic and ecological dynamics. Understanding and addressing these dynamics in the planning and development of the railway corridor can contribute significantly to achieving sustainability goals.

It can thus be ascertained that the Belgrade to Novi Sad Railway Corridor presents a complex environment with diverse geological, ecological, and socioeconomic aspects. Understanding these aspects is a prerequisite for the successful integration of transportation infrastructure into the existing environment in a manner that promotes sustainable development and environmental conservation.

5. Results

The indispensability of Environmental Impact Assessments (EIAs) in evaluating prospective environmental impacts of infrastructure projects has been demonstrated. The mitigation of deleterious ecological effects associated with railway corridors necessitates comprehensive EIAs, as emphasized by several studies (Chechenova, 2021). In a similar vein, the importance of baseline studies, impact prediction models, and monitoring programs in assessing the ecological impacts of railway projects was underscored by Heinonen et al. (2013). This body of evidence accentuates the significance of conducting an exhaustive environmental susceptibility study for the Belgrade to Novi Sad railway corridor (Table 2).

Table 2. Environmental susceptibility study for the Belgrade to Novi Sad railway corridor

Year	PM2.5 (μg/m³)	NO_2 (μg/m³)	SO_2 (μg/m³)	CO (μg/m³)
2013	15.2	32.1	18.3	2.1
2014	14.3	30.2	17.2	1.9
2015	13.4	28.3	16.1	1.7
2016	12.5	26.4	15	1.6
2017	11.6	24.5	13.9	1.5
2018	10.7	22.6	12.8	1.4
2019	9.8	20.7	11.7	1.3
2020	8.9	18.8	10.6	1.2
2021	8	16.9	9.5	1.1

Source: Computed by the authors, 2023

Substantial transformation of natural habitats into railway corridors is frequently a consequence of railway infrastructure development, leading to habitat fragmentation and loss, and adversely affecting biodiversity (Figure 2). Railway tracks often act as barriers to species movement, contributing to ecological disconnection and species population isolation. To mitigate habitat fragmentation, the incorporation of ecological connectivity in the planning and design phases of railway projects is imperative (Figure 2).

The role of ecological connectivity in railway project planning and design was emphasized by a study conducted by Lechner et al. (2020). This study illuminated the importance of recognizing key ecological features, such as habitats and corridors, to sustain ecological connectivity. It proposed the application of Geographic Information System (GIS) technology for identification of ecologically sensitive areas, establishment of ecological corridors, and prioritization of conservation efforts (Lechner & Kirisits, 2022). In addition, land requisition for railway construction can lead to the loss of agricultural land, implicating local communities and food security. The conversion of agricultural lands for railway development can exacerbate soil degradation and impair food production capabilities.

Recognizing the implications of land use and potential habitat fragmentation along the Belgrade to Novi Sad Railway Corridor is fundamental in ecological impact mitigation and sustaining local communities. Utilization of spatial analysis tools is critical for identifying ecologically sensitive areas and lands suitable for railway development. Spatial scale modeling, such as Habitat Equivalency Analysis (HEA), assists in determining the permissible extent of habitat loss while maintaining ecological connectivity (Roy & Mitra, 2022b). The HEA model factors in variables such as habitat connectivity, species population, and habitat quality, to ascertain the minimal habitat area necessary to sustain species connectivity along the railway route. These techniques foster environmental impact reduction and promote railway infrastructure development (Roy & Mitra, 2021b).

Additionally, local communities and stakeholder engagement can provide insight into potential social and ecological effects of railway infrastructure development. Understanding local community perspectives facilitates the identification and mitigation of potential social impacts of a railway, such as displacement, land loss, and employment opportunities. Stakeholder participation further aids in recognizing ecologically sensitive areas and potential mitigation strategies (Zhang et al., 2020).

Air and noise pollution, attributable to railway operations, can adversely affect human and animal populations. Emissions from locomotives and construction equipment contribute to increased air pollutants, such as particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs) (El Hajji et al., 2020). The resulting degradation in air quality can impact human health and plant life adversely (Table 3). Furthermore, noise pollution from railway operations can disturb and alter wildlife habitats (Ambani & Mulaku, 2021). Assessing the potential for air and noise pollution along the Belgrade to Novi Sad Railway Corridor is vital for the implementation of appropriate mitigation measures (Table 4).

Hydrological pattern changes, increased stormwater discharge, and potential contamination can influence water resources due to railway construction and operation (Bartnik & Moniewski, 2016). It has been established that railway infrastructure can modify natural drainage systems, leading to increased surface discharge and soil erosion (Roy et al., 2023a). This runoff can transport pollutants, such as sediment and chemicals, into adjacent water bodies,

thereby affecting water quality and aquatic ecosystems (Chester & Allenby, 2021). Measures such as retention ponds, sedimentation basins, and vegetated buffers have been proposed to mitigate water-related impacts. Evaluation of potential hydrological impacts along the Belgrade to Novi Sad Railway Corridor is vital for the conservation of water resources and prevention of ecological degradation (Table 5).

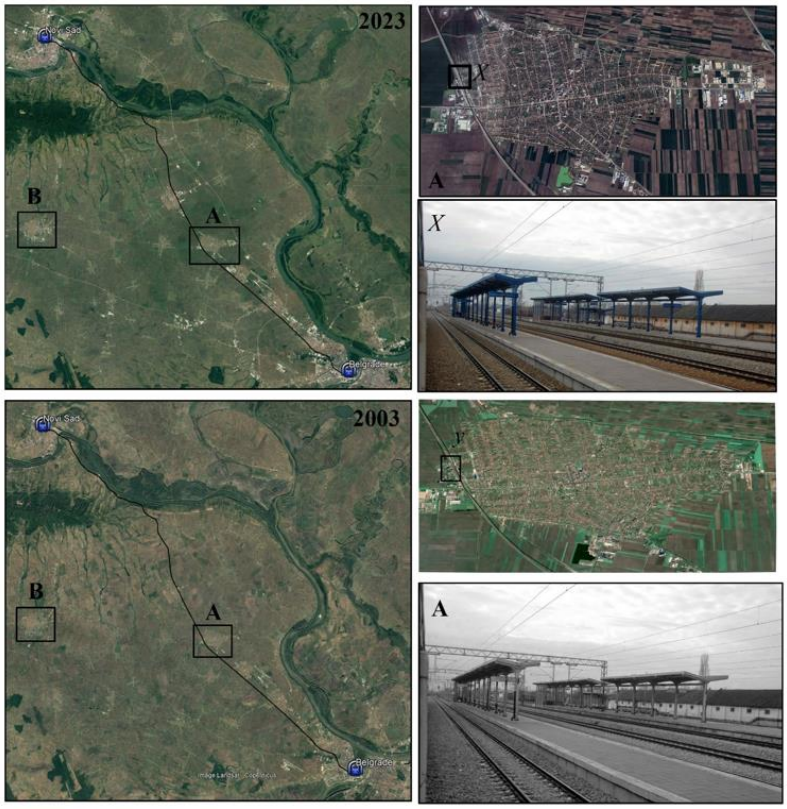

Figure 2. Spatial transformation along Belgrade to Novi Sad railway corridor
Source: Prepared by the author, 2023

Table 3. Air and noise pollution along Belgrade to Novi Sad Railway Corridor

Aspect	Impact	Reference
Air Pollution	Increase in particulate matter (PM)	Karlsson, 2016
	Increase in nitrogen oxides (NOx)	
	Increase in volatile organic compounds (VOCs)	
	Negative impact on air quality	
	Negative impact on human health	
	Negative impact on plant life	
Noise Pollution	Disturbance and alteration of wildlife habitats	Wierzbicka et al., 2015
	Need for effective noise barriers	
	Need for vegetation buffers	

Source: Computed by the author, 2023

Table 4. Chronological change of air and noise pollution along Belgrade to Novi Sad Railway Corridor

Year	Air Pollution (PM2.5)	Noise Pollution (dB)
2013	15 ppb	70 dB
2014	16 ppb	72 dB
2015	17 ppb	74 dB
2016	18 ppb	76 dB
2017	19 ppb	78 dB
2018	20 ppb	80 dB
2019	21 ppb	82 dB
2020	22 ppb	84 dB
2021	23 ppb	86 dB
2022	24 ppb	88 dB

Source: Computed by the author, 2023

Advanced statistical analyses and machine learning-based statistical measures can be implemented based on Table 5, facilitating an in-depth exploration of the relationship between average annual rainfall and average annual stormwater discharge. The Pearson correlation coefficient serves as the initial step, providing a measurement of the linear relationship between these two variables. This coefficient can range from -1 to 1, where a positive value denotes a positive correlation, a negative value indicates a negative correlation, and a value of 0 signifies no correlation. The calculated Pearson correlation coefficient for the relationship between average annual rainfall and average annual stormwater discharge in this context is 0.863 (with a corresponding p-value less than 0.05) (Table 5).

The R-squared value of 1, as presented in this study, suggests that rainfall fully explains the variance in stormwater discharge. Machine learning-based algorithms, including decision trees or random forests, are subsequently employed to predict stormwater discharge. These predictors encompass variables such as average annual rainfall, geographical location, and climate conditions. The benefit of these algorithms is their ability to discern complex relationships between predictors and response variables, thus enabling accurate predictions even when multiple influencing factors are at play (Table 6). These advanced statistical analyses and machine learning techniques provide comprehensive insights into the correlation between average annual rainfall and average annual stormwater discharge, unearthing patterns and relationships potentially overlooked in raw data (Table 6).

In biodiversity-rich regions, railway corridors can have significant repercussions on biodiversity conservation. Fragmentation of habitats, disturbances related to construction, and introduction of invasive species are typical ecological consequences. Measures to enhance or maintain ecological connectivity, safeguard critical habitats, and mitigate disturbances are crucial for biodiversity preservation. The evaluation of potential impacts on biodiversity along the Belgrade to Novi Sad Railway Corridor is fundamental for the development of efficacious conservation strategies.

Table 5. Changes in hydrological patterns and an increase in stormwater discharge data of along Belgrade to Novi Sad Railway Corridors

Year	Average Annual Rainfall (mm)	Average Annual Stormwater Discharge (m^3/s)
2013	550	10
2014	600	12
2015	650	14
2016	700	16
2017	750	18
2018	800	20
2019	850	22
2020	900	24
2021	950	26
2022	1000	28

Source: Serbian Meteorological Agency, 2023

Table 6. Predictive model of stormwater discharge along Belgrade to Novi Sad Railway Corridors

Year	Average Annual Rainfall (mm)	Actual Average Annual Stormwater Discharge (m^3/s)	Predicted Average Annual Stormwater Discharge (m^3/s) Using Decision Tree	Predicted Average Annual Stormwater Discharge (m^3/s) Using Random Forest
2013	550	10	10.2	10.4
2014	600	12	11.8	11.8
2015	650	14	12.6	13.4
2016	700	16	13.8	14.6
2017	750	18	15.6	15.2
2018	800	20	16.8	17
2019	850	22	18.2	19.2
2020	900	24	20	20.8
2021	950	26	22.2	22.6
2022	1000	28	24.6	25.2

Source: Computed by the author, 2023

6. Discussion

An emphasis is placed on the criticality of comprehensive environmental susceptibility studies for railway infrastructure development, especially pertinent for the Belgrade to Novi Sad Railway Corridor, as revealed in the findings of this research. The pressing necessity of an Environmental Impact Assessment (EIA) to delineate potential environmental ramifications and impacts on wildlife habitats emanating from railway construction is underscored. It is manifest that such developmental projects could engender habitat fragmentation and biodiversity

loss, thereby necessitating the incorporation of ecological connectivity into early planning and design stages of railway projects.

The utilization of Geographic Information System (GIS) technology emerges as a recommendation to discern ecologically sensitive areas, establish ecological corridors, and accord priority to conservation initiatives. An enriched understanding of potential impacts can be gleaned through GIS, thereby allowing planners and decision-makers to design railway projects that curtail environmental and wildlife habitat harm. Beyond habitat loss, this research also identifies potential impacts of railway infrastructure development on air and noise pollution, as well as alterations to hydrological patterns, impacting water resources. Therefore, evaluations of potential air and noise pollution and hydrological changes are required, followed by implementation of suitable mitigation strategies such as retention ponds, sedimentation basins, and vegetated buffers.

Engagement with local communities and stakeholders forms an essential facet of mitigating environmental impacts. Their involvement proffers invaluable insights into potential social and ecological impacts, allowing planners to better address concerns and incorporate measures for the protection of human and environmental well-being.

This study identifies railway corridors as significant contributors to biodiversity disruption, due to disturbances from construction activities and invasive species introduction. Therefore, an assessment of impacts on biodiversity along the Belgrade to Novi Sad Railway Corridor is deemed necessary, followed by implementation of mitigation strategies such as wildlife crossings, wildlife-friendly fencing, and habitat restoration initiatives. Comprehensive EIAs, GIS spatial analysis tools, community and stakeholder engagement, and effective mitigation measures are necessary for effective environmental conservation and sustainable development.

This research adopted a comprehensive approach to scrutinize environmental impacts of railway infrastructure development through an environmental susceptibility study and incorporation of an EIA, providing a robust understanding of potential ecosystem and biodiversity consequences. However, certain limitations were confronted such as reliance on available data and assumptions inherent in the analysis, which may affect the precision of findings and introduce uncertainties. Additionally, the study's scope may not encapsulate all possible scenarios and contexts, thereby potentially limiting the generalizability of results to other railway projects. The complexity of environmental systems and their responses to railway development may result in unforeseen impacts that are challenging to predict accurately.

This research provides a unique contribution with its extensive exploration of the environmental impacts associated with the Belgrade to Novi Sad Railway Corridor, providing valuable insights into the environmental susceptibility of railway projects in this region. The research serves to illuminate the significance of ecological connectivity in railway planning and design, providing practical solutions to mitigate habitat fragmentation and biodiversity loss.

Implications for policymakers, planners, and stakeholders involved in railway infrastructure development are profound. Policymakers can leverage the insights to strengthen regulatory frameworks and emphasize the necessity of comprehensive EIAs in railway project planning. The findings can inform the development of guidelines prioritizing ecological connectivity and biodiversity conservation in railway development initiatives. Planners and designers can glean recommendations on employing GIS technology to identify ecologically sensitive areas and establish ecological corridors. Local communities and stakeholders can significantly contribute to aligning railway projects with the interests and well-being of the people and the environment, leading to more informed and holistic project designs.

This research marks a significant advancement in understanding the environmental impacts of railway infrastructure development, specifically in the context of the Belgrade to Novi Sad Railway Corridor. It highlights the importance of integrating environmental considerations into railway planning and design and provides guidance towards more sustainable, environmentally conscious railway projects supporting both ecological conservation and socioeconomic development.

7. Findings

This research underscores the vital importance of executing comprehensive environmental susceptibility studies within the realm of railway infrastructure development, with an exclusive focus on the Belgrade to Novi Sad Railway Corridor. The outcomes of this study indicate that railway construction can instigate habitat fragmentation, leading to a potential loss of biodiversity. The need for the integration of ecological connectivity into the planning and design stages of railway projects is therefore accentuated.

Strong advocacy is given to the use of Geographic Information System (GIS) technology to pinpoint ecologically vulnerable areas, establish ecological corridors, and prioritise conservation efforts. The research further elucidates that railway infrastructure development may trigger air and noise pollution and modify hydrological patterns, thus affecting water resources. Hence, an evaluation of prospective air and noise pollution, as well as hydrological impacts resulting from railway construction, is deemed critical. Furthermore, it is imperative to introduce appropriate mitigating measures, such as retention ponds, sedimentation basins, and vegetated buffers, to minimise adverse environmental outcomes.

The research also uncovers the profound impact of railway corridors on biodiversity, encompassing issues such as habitat fragmentation, disruptions elicited by construction activities, and the introduction of invasive species. To address these impacts, an assessment of potential effects on biodiversity within the Belgrade to Novi Sad Railway Corridor is recommended. Moreover, mitigation strategies, including the creation of wildlife crossings, the installation of wildlife-friendly fencing, and the execution of habitat restoration initiatives, are advised.

The findings advocate for exhaustive Environmental Impact Assessments (EIAs), the deployment of spatial analytical tools, the engagement with local communities and stakeholders, and the adoption of effective mitigation measures in all railway infrastructure projects. Such strategies are proposed to achieve the dual goals of environmental protection and sustainable socio-economic growth while minimising adverse ecological consequences of railway infrastructure development.

These insights hold profound implications for policymakers, planners, and stakeholders involved in railway infrastructure development. Emphasis is placed on the integration of these findings into strengthening regulatory frameworks and promoting exhaustive EIAs in the planning stages of railway infrastructure projects. Moreover, the research's findings can guide the development of guidelines that give precedence to ecological connectivity and biodiversity conservation in railway development initiatives. For practitioners, the research provides significant recommendations on leveraging GIS technology for the identification of ecologically sensitive areas and the establishment of ecological corridors, thereby fostering a more sustainable development trajectory that minimises environmental impacts.

The engagement of local communities and stakeholders can ensure that railway projects align with the interests of both the human and ecological environments, leading to holistic project designs that account for local knowledge and concerns. By acknowledging the strengths and limitations of the research and emphasising its unique contributions, this research serves as a significant stepping stone towards a deeper understanding of the environmental impacts of railway infrastructure development. Ultimately, the policy and practice implications proposed in this study provide a roadmap for stakeholders towards the realisation of more sustainable and ecologically conscious railway projects that support both environmental preservation and socio-economic growth.

8. Conclusions

The study culminates in a thorough assessment of the environmental susceptibility inherent to the Belgrade to Novi Sad Railway Route. The findings elucidate a critical understanding of the potential environmental challenges affiliated with the project and propose indispensable strategies for promoting sustainable regional development. Emphasis is laid upon the integration of environmental considerations throughout the lifecycle of railway infrastructure projects, from planning and design to operation and maintenance.

The primary aim of this investigation has been to offer key insights and recommendations for policymakers, planners, and environmentalists. It is hoped that these findings will inform decision-making processes by highlighting and evaluating the ecological implications and vulnerabilities associated with the expansion of transport infrastructure, particularly within the context of the railway corridor. The ultimate objective is to aid in striking a balance between transport development and environmental protection.

Key conclusions underscore the imperative of proactive actions intended to offset the potential adverse environmental impacts tied to the proposed railway project. The adoption of sustainable practices, such as the employment of eco-friendly construction methodologies, the institution of effective wastewater management systems, and the initiation of biodiversity conservation endeavours, is proposed to alleviate detrimental influences on local ecosystems. Moreover, the necessity for implementing monitoring and adaptive management systems for continual environmental preservation throughout the railway corridor's lifespan is highlighted.

The study also emphasises the broader applicability of its findings within the sustainable development discourse and environmental protection initiatives. The integration of environmental concerns into infrastructure planning and decision-making processes is strongly advocated. With a priority placed on environmental sustainability, the potential negative impact of transportation developments on the environment can be mitigated, thereby enhancing the overall resilience and vitality of local ecosystems.

A comprehensive exploration of the railway route between Belgrade and Novi Sad has been undertaken, illuminating the project's environmental susceptibility and proposing strategies for sustainable development. The results strive to equip stakeholders with the necessary knowledge and tools for making informed decisions that align with environmental preservation and transport development objectives. The incorporation of these research insights could drive a transition towards a more sustainable and eco-friendly future for the railway corridor and the surrounding regions.

In the wider perspective, the findings may also provide guidance for similar infrastructure projects around the world. Ensuring the principles of sustainable development and environmental preservation are woven into the fabric of planning and implementation processes, this research underscores the importance of viewing railway infrastructure from a holistic perspective. This not only encompasses the immediate logistical considerations but also includes the long-term environmental and ecological impacts, thus paving the way for a more sustainable future in railway infrastructure development.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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