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Environmental Hazards of the Railway Infrastructure of Kazakhstan

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Abstract: The railway sector is the largest branch of the economy in Kazakhstan. Nevertheless, environmental safety issues and the reduction and prevention of harmful impacts are not given sufficient attention. There is very little research on the impact of the railway sector of Kazakhstan on the natural environment, which hinders the further development of the railway sector and thus necessitates the addressal of environment issues. This study aimed to show possible environmentally hazardous sections of the country's railway infrastructure. The criteria chosen for the analysis were soil cover, water resources, rainfall, protected natural areas, and population. A map of environmentally sensitive areas was created to determine which areas require priority protection from the environmental hazards posed by the country's railway infrastructure. The map was developed in a GIS environment using the weighted overlay, expert assessment, and snowball methods. Additionally, a model for the Kazakhstan segment of the International Northern Railway Corridor was constructed in this article to identify integral indices that assess the susceptibility of the territory to environmental hazards. The data and results presented in the article can be used to solve current and future environmental issues concerning the country's railway communications and can be implemented in many practical applications.

Keywords: environment; railway infrastructure; ecological hazard; pollution; vulnerability

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1. Introduction

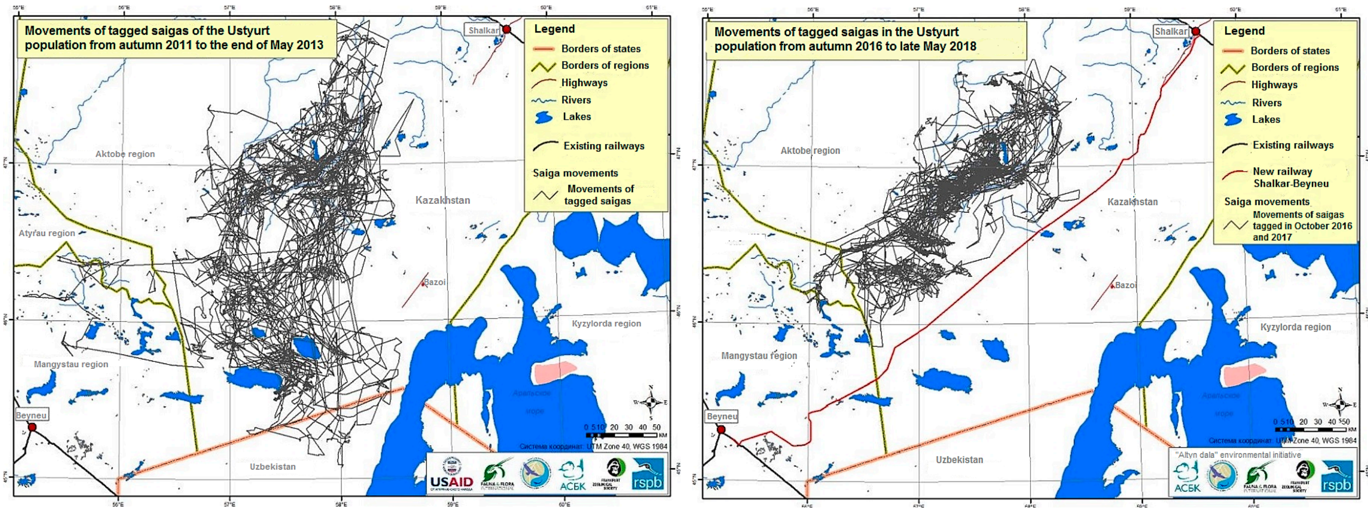
Railway transport plays a leading role in the transportation system of Kazakhstan. Kazakhstan is a landlocked country in Central Asia. It is located in the very heart of Eurasia; thus, it plays a crucial international role in logistics between Asia and Europe—the so-called "Modern Silk Road" [1]. Long transportation distances and relatively cheap tariffs for the transportation of passengers and goods make rail transport the most demanded form of transport by users. However, railway transport and the infrastructure related to it might have a negative impact on the environment [2–5]. Many environmental studies are dedicated to road transport with respect to Kazakhstan's transportation structure. There are only a handful of studies about the impact of the railway industry on the environment. Currently, there is an increased interest in the problem of predicting environmental pollution in the event of an accident during the transportation of dangerous goods [6–9]. It is known that railway transport carries out the transportation of chemically hazardous substances in large volumes in Kazakhstan. Accidents involving the spillage of highly toxic substances during rail transport entail a high environmental risk. In addition, on the Kazakh–Chinese border, transhipping is carried out due to the difference in railroad gauge [10], which can also cause pollution. The lack of such research hinders the further development of the railway sector, thereby prioritizing issues regarding the environment.

In general, the dynamics of freight and passenger traffic in Kazakhstan, including rail passengers, is consistently growing. In addition, the vast majority of Kazakhstan's railway rolling stock is outdated. For example, at the end of 2019, 78.7% of electric locomotives, 57.5% of diesel locomotives, and 50% of passenger and baggage cars had been operating for over 25 years [11]. Specialists of "KTZ-Freight transport" JSC claim that steppe fires occur due to the physical obsolescence of operating locomotives, which primarily refers to the 2TE10M series locomotives.

The transport sector can be considered an essential source of diffuse environmental pollution [12]. Soil cover accumulates all external pollutants and can diffuse pollutants into plants and water resources. Even though water resources are objects of possible chemical pollution, they can also facilitate further transportation to other natural components. Railways, as the main routes for transporting harmful chemicals, are also potential areas of groundwater pollution in the event of an accident [13]. According to a study led by Lacey R. F. and Cole J. A. [14], railways are at particular risk if a pollution incident occurs in areas where the railway passes through both rivers and aquifers.

Railways and the movement of the rail transport on them pose a significant problem in areas with high natural value and protected natural areas [15–17]. The designation of a protected status indicates that the territory or its section belong to zones with special conditions of use. This criterion marks areas of particular importance for the biodiversity-focused conservation of rare and protected species of flora and fauna in order to determine the vulnerability of natural complexes to anthropogenic impacts. The consequences of the adverse effects on these territories may be irreversible. Therefore, the areas with this status are considered the most sensitive. Kazakhstan has had a painful experience with the impact of railway infrastructure on steppe animals; for example, consider the construction of a railway along the Shalkar–Beyneu route, which crosses the range of the Ustyurt saiga population *(Saiga tatarica)*. The saigas constitute a vulnerable species in this country. Saigas were included in the Red List of the International Union for Conservation of Nature (IUCN) in 1996, and since 2002, they have been assigned the status of the highest degree of threat. The saigas with transmitters did not cross the Shalkar–Beyneu railway for more than two years after its construction, from autumn 2017 to the end of December 2019. Figure 1 shows the movement of saigas in the area of the constructed railway, which proved to be a barrier and reduced migration size.

This work's novelty lies in its incorporation of a study that identified sections of the railway infrastructure of Kazakhstan that are vulnerable to environmental risks and hazards.This work is the initial stage of studying the environmental hazards of the railway infrastructure of Kazakhstan. Since such studies have not been carried out in the country nor been given the mentioned international role, the purpose of this research was to show possible environmentally hazardous areas of the railway infrastructure of the Republic of Kazakhstan. To achieve this goal, we sought to, first, develop a map for assessing the environmental vulnerability of the territory of the railway infrastructure of Kazakhstan, and second, to develop a model of the vulnerable sections of the Northern Railway Corridor using the integral index method. The research carried out in the article is significantly crucial for Kazakhstan. The study results will significantly contribute to the system of railway activities in the territory of the Republic and will improve the quality of the work carried out to minimize the negative impacts on the environment in the adjacent territories. The collected data and results can be used to address current and future environmental issues concerning the country's railway communications and can have many practical applications.



(**a**) (**b**)

Figure 1. Changes in the saiga range after the construction of the Shalkar–Beyneu railway, adopted from [18]. (**a**) Movements of tagged saigas of the Ustyurt population from autumn 2011 to the end of May 2013; (**b**) movements of tagged saigas in the Ustyurt population from autumn 2016 to the end of May 2018.

The conducted research was based out of the L.N. Gumilyov Eurasian National University in the soil science and environmental monitoring laboratory during the period of 2020–2021.

2. Materials and Methods

2.1. Study Area

Kazakhstan possesses the third longest railway system among the CIS and Baltic countries, with a track gauge of 1520 mm (Figure 2). The largest operator of the leading railway network in Kazakhstan is JSC "NC "Kazakhstan Temir Zholy", which interconnects 14 regions of the republic and 3 cities of republican significance and passes through 16 joint points with neighbouring countries. Kazakhstan's total land area dedicated to railway transport is about 2000 km^2. Kazakhstan includes 5 international railway corridors [19]:

- The Northern Corridor of the Trans-Asian Railway. It connects Western Europe with China, the Korean peninsula, and Japan via Russia.
- The Southern Corridor of the Trans-Asian Railway. This corridor runs along the following routes: South-Eastern Europe–China and South-East Asia through Turkey, Iran, and Central Asian countries.
- North–South. This line passes through Northern Europe from the Persian Gulf countries through Russia and Iran with the participation of Kazakhstan in the following sectors: the seaport of Aktau to the regions of the Urals of Russia and Aktau-Atyrau, and through the new railway line Uzen-Bereket (Turkmenistan)–Gorgan (Iran).
- The Central Corridor of the Trans-Asian Railway. This corridor is of great importance for regional transit traffic in the direction of Central Asia–North-Western Europe.
- TRACECA. It connects Eastern Europe with Central Asia through the Black Sea, the Caucasus, and the Caspian Sea.

Most domestic and international railway freight comprises bulk cargo such as oil, gas, and liquid freight; coal and coke; ores and metals; chemicals and fertilizers; and grain. Most of KTZ's cross-border freight traffic is carried out to and from the Russian Federation, Uzbekistan, and the PRC. This includes traffic in transit to, from, or through these countries [20]. It is worth noting that the delivery of rocket fuel components from Russia to the Baikonur cosmodrome is carried out by rail.

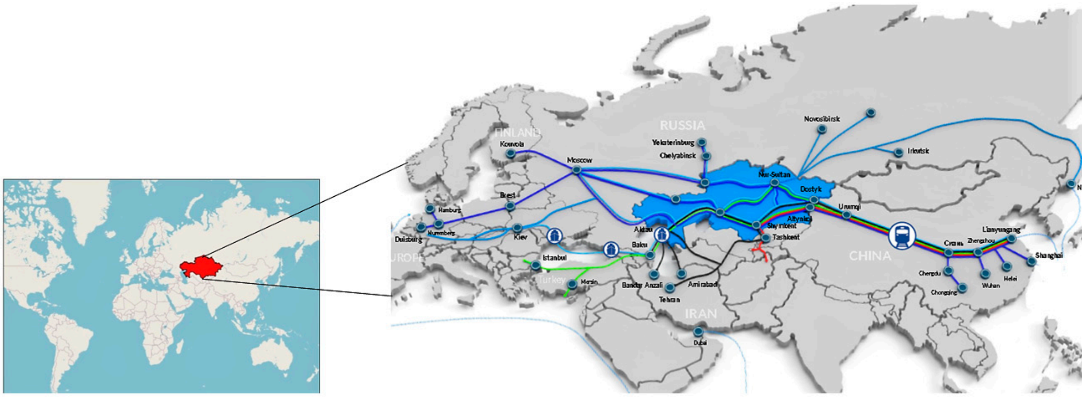


Figure 2. Research area.

Rail transport runs throughout the country, crossing various ecosystems and natural environments. The generation of several types of pollution and the threat of danger to living organisms are always great along the entire railway track.

There are railway transport areas in all regions of the country. Table 1 shows the parameters of railways throughout Kazakhstan.

Table 1. Main parameters of the railways of the Republic of Kazakhstan.

Kazakhstan Railway	Kilometers
Operational length	**16,060.8**
length of single-track lines	11,021.5
length of double-track and multi-track	5039.3
length of continuous welded tracks	13,839.9
length of electrified tracks	4237.5
length of non-electrified tracks	11,823.3

The operational length and density of railway tracks for each region are presented in Table 2 concerning the end of 2019 [21,22]. The Karaganda, Aktobe, Akmola, and Almaty regions are leading areas in terms of the length of Kazakh railways, among which the densest in the country is in the Akmola region.

Table 2. The length and density of the railways of the regions of Kazakhstan.

Region	km	Density per 1000 km^2	Region	km	Density per 1000 km^2
Akmola	1579	10.81	Kostanay	1336	6.48
Aktobe	1839	6.08	Kyzylorda	871	3.85
Almaty	1401	6.27	Mangystau	1097	6.62
Atyrau	742	6.26	Pavlodar	925	6.32
West Kazakhstan	431	2.11	North Kazakhstan	807	6.31
Zhambyl	1104	7.23	Turkestan	552	4.75
Karaganda	2467	5.76	East Kazakhstan	1209	4.27

The prominent, frequent cases on the railways of Kazakhstan that can be hazardous to the environment include derailment of cars during the transportation of liquid and dangerous goods and spills as a result of an accident; leakage of liquid cargo and oil products during loading or unloading; the occurrence of fires and explosions; the impact of noise and vibration on the human and animal habitat; reduction in animal habitats from the railway network, especially protected animals, including those at high risk of extinction; death of animals on the railways; and injuries and deaths of people on the railways. By identifying areas exposed to environmental hazards with the help of maps focused on the country's railway infrastructure, it can be clearly shown which areas require priority protection. Therefore, we used the cartography method to build maps of the railways of Kazakhstan, thereby discerning certain areas' vulnerability to environmental hazards. To this end, to assess the ecological vulnerability of the territory containing the railway infrastructure of the republic, the following criteria were chosen: soil cover, water resources, precipitation, protected natural areas, and population.

This study used geographic information system technology to build a map. The geographic information system allows a researcher to determine the total volume of environmental problems, view the complete picture of the situation, and anticipate potential risks and consider them in detail [23]. The sequence of the performed procedures and operations is shown in Figure 3.

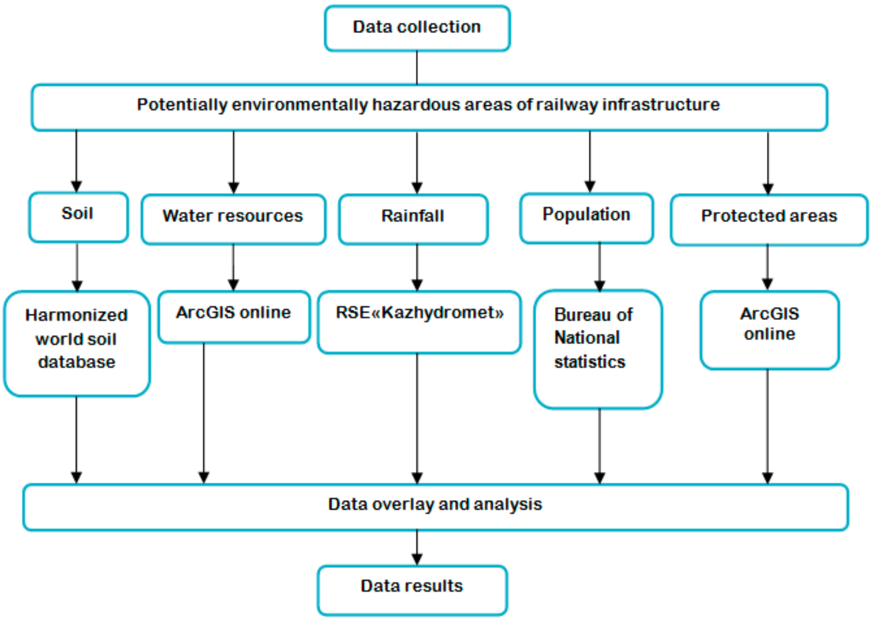


Figure 3. Flowchart of the processes and operations executed to create a map of railroads' ecologically vulnerable areas.

Using the ArcGIS 10.8 program, we collected spatial and non-spatial data on the administrative borders of Kazakhstan, the railway network, soil cover, water resources, rainfall, protected natural territories, and population.

2.2. Soil

The soil cover of potentially ecologically hazardous sections of the railway network of Kazakhstan was studied in terms of soil texture. Information about soils used originated from the Harmonized World Soil Database. The database shows the composition of each soil-mapping unit and standardized soil parameters (Table 3) [24]. The degree and path of movement of a chemical substance during infiltration depend on the properties of the soil, the chemical substance, and their interaction. Various soil characteristics, such as grain size, reactivity, and sorption character, affect the fate and transport of the spilled chemical in the soil [25]. Therefore, the "soil texture" was suitable for study based on the parameters presented in the database. Soil texture is a soil property that describes the proportion of different grain sizes of mineral particles in the soil. According to the USDA texture triangle, the particles were divided into soil groups: clay, silt, and sand. Anand P. and Barkan C.P. [26] state that these categorization levels are suitable for purposes of determining hazardous materials' level of risk. Soils with a coarse texture contain a large amount of sand, silt predominates in soils with a medium texture, and clay is prevalent in the majority of soils with a fine texture.

Table 3. Grouping particles according to their size into soil separates [24].

Soil Separates	Diameter Limits (mm) (USDA Classification)
Clay	Less than 0.002
Silt	0.002–0.05
Sand	0.05–2.00

The HWSD classifies soils into 13 texture classes, ranging from clay to sandy. The grouping of soils was carried out in the same way as in the study by Anand P. and Barkan C.P. [26]. Thus, the classification of soils used in our analysis was similar. Texture classes were divided into three categories according to the permeability rate (or infiltration rate), as shown in Table 4 [27]. Soils of large granulometric composition have good infiltration properties, while those with small granulometric composition act as water barriers, thereby increasing underground water's degree of protection from the seepage of pollutants from the surface. The data used in the study determined the infiltration coefficients of each soil group [28].Consequently, sandy soils are more vulnerable since the processes of liquid penetration are much more active in them than in soils with a predominantly clay composition. Spills of hazardous liquid cargo, leakage of oil products, and the infiltration of various pollutants occur on the soil surface. Thus, the surface layer is the most crucial soil attribute.

Table 4. Generalization of soils based on infiltration rate and coefficient, adopted from [27,28].

Class	Maximum Infiltration Rate	Soil Structure	Generalization Adopted	Infiltration Coefficient
Rapid	>7.5 cm/h	Sands, loamy sands, sandy loams	Sand	25%
Moderate	0.5–7.5 cm/h	Fine sandy loam, silt loam, silty clay loam, sandy clay loam, loam, clay loam, sandy clay, and others	Silt	13%
Slow	<0.5 cm/h	Silty clay loam, silty clay, sandy clay, clay	Clay	8%

2.3. Rainfall

Precipitation was included as a factor since it facilitates the penetration of pollutants deeper through the soil cover. Consequently, pollutants can enter the groundwater horizon. The average annual rainfall in Kazakhstan ranges from 130 to 1600 mm. Thus, in the areas located in the northeast of the Aral Sea and the western part of Lake Balkhash, only 100 mm of precipitation falls, and in some years, even less. The most significant amount of precipitation occurs in the Western Altai region [29]. To create a layer accounting for the precipitation level, a map of the average long-term values of annual and seasonal rainfall in the territory of Kazakhstan for the period 1981–2010 was digitized using the source provided by the RSE "Kazhydromet" Ministry of ecology, geology, and natural resources of the Republic of Kazakhstan [30]. Areas where the intensity of precipitation is high were considered the most exposed to pollution, and where the intensity is low, the degree of exposure was considered weak.

2.4. Water Resources

There are about thirty-nine thousand rivers, temporary streams, and several thousand lakes in the republic. Most of the rivers of Kazakhstan belong to the internal closed basins of the Caspian and Aral seas, as well as the Balkhash, Alakol, and Teniz lakes. Only the Ertis River belongs to the Arctic Ocean basin. A significant portion of the lakes is concentrated in the north, and the largest (Balkhash, Zaisan, and Alakol) are located in the eastern and south-eastern regions. Cartographic materials of surface water resources of Kazakhstan were taken from the open-access database as a separate shape file from ArcGIS Online [31]. The water resources data were converted through the application of density analysis. Determining the distribution of water resources and where they are concentrated helped to predetermine the areas most prone to pollution.

2.5. Protected Areas

Any environmental threat, especially fires and explosions in the territory of protected natural areas, can lead to irreversible situations. As of 2019, Kazakhstan contained 10 state natural conservations, 14 state national natural parks, 6 state natural reserves, 50 state nature sanctuaries, 5 state preserved areas, 25 state nature monuments, and 7 state botanical gardens (including 1 dendrological park of republican significance. The country's total protected natural areas amount to 26.2 million hectares (9.6% of the country's area) [32]. Data regarding protected natural areas were obtained from the official site of ArcGIS [31], whose source is the Ministry of ecology, geology, and natural resources of the Republic of Kazakhstan. In addition, saiga habitats from the National Atlas of the Republic of Kazakhstan were vectorized in this layer [33]. There are five saiga populations in the world—three of which are in Kazakhstan (Betpakdala, Ustyurt, and Ural regions).

2.6. Population

The impact of environmental hazards on the population posed by the railway infrastructure was considered in terms of the people's territories. The environmental impact of railway infrastructure is most pronounced in densely populated areas. Urbanized regions with large populations have a highly branched railway network running in residential areas, which leads to unfavourable environmental conditions for residents of nearby territories. The population datasets employed corresponded to the official data of the Bureau of National Statistics of the Republic of Kazakhstan [34]. In general, at the beginning of 2021, the population of Kazakhstan was 18,879,552. The populations of major cities and districts of regions were entered manually into the attribute table of this layer.

2.7. Data Overlay

All the necessary data for layering and analysis were collected and prepared in the ArcGIS 10.8 program (Figure 4).

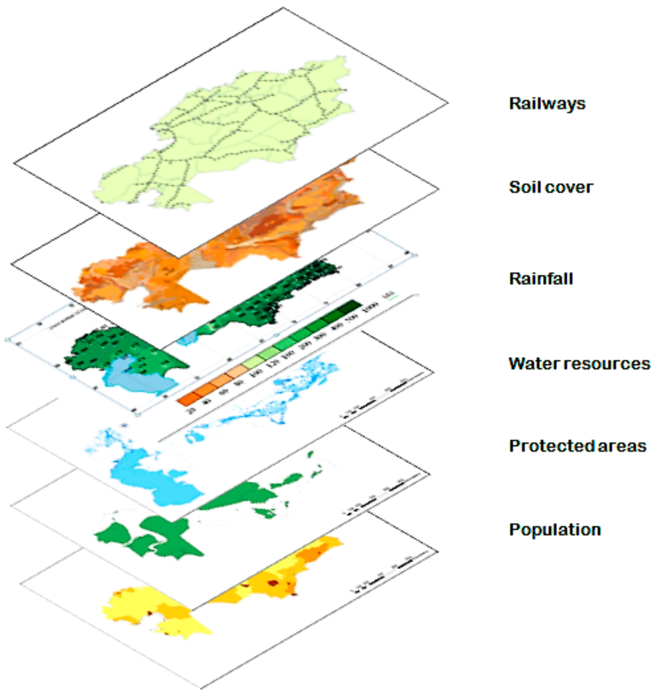


Figure 4. Layers of collected cartographic data for Kazakhstan were used to analyse ecologically vulnerable sections of railways.

Data overlay was carried out using the Weighted Overlay tool (ArcGIS 10.8), which is commonly used as it is one of the most efficient methods for performing multi-criteria spatial analysis. Weighted overlay analysis is a component of spatial modeling that uses multi-criteria evaluation, ascribing importance to the criteria in a differentiated manner [35]. This is a very convenient geographic information system-based technique that is very useful for solving problems that require a large set of variables covering vast areas that are sometimes inaccessible. For example, other authors have used this technique to find suitable sites for mangroves [36] and fisheries [37], assess vulnerability to COVID-19 infection [38], monitor the impact of metals on algae [39], and, in general, create various environmental evaluation maps.

However, despite this, there are very few examples of the use of this method for the environmental assessment of railway sectors.

The weighted overlay analysis was performed using the following Formula (1):

$$\mathrm{V} = \sum_{i=1}^{n} \mathrm{Wi} \times \mathrm{Ri} \tag{1}$$

where Wi denotes the weight for factor i, Ri denotes the rate of the class of factor i, and *n* is the total number of factors.

When working with the WO tool, parameter scores need to be reclassified, and the weight of each parameter or layer needs to be determined. Using the Reclassify tool, the scores of the input rasters were classified from 1 to 5. Values have been assigned in ascending order in terms of environmental vulnerability. To determine the weight of each parameter, expert assessments were used in the form of online questionnaires answered by experts, wherein the degree of influence of parameters on the vulnerability of the railway infrastructure area was estimated from 1 to 5. The most important parameter was assigned an indicator of 5, and the least important was assigned 1. The questionnaire was distributed by the snowball method, and the results were obtained from various experts in the field of ecology. The results were normalized to a 100% scale and entered using the WO tool.

2.8. Building a Model for Determining the Ecological Vulnerability of Railways

Since the map demonstrates a general idea of the environmental vulnerability of railways and the territories adjacent to them, this article also proposes a model aimed at identifying integral indices that assess the territory's exposure with respect to environmental risks. Employing the data used to build the map, we decided to evaluate, ingreater detail, the section of the international Northern Corridor of the Trans-Asian Railway in the territory of the Republic of Kazakhstan using a model. The Northern Corridor connects Western Europe with China, the Korean Peninsula, and Japan through Russia (on the section Dostyk/Khorgos–Aktogay–Sayak–Mointy–Nur-Sultan–Petropavlovsk (Presnogorkovskaya), which spans 1910 km). The Northern Corridor is considered one of the leading international transit and transport corridors in the Republic of Kazakhstan, as it passes through the industrially developed regions of the country. It should be noted that the main areas with the largest cargo transportation volume specialize in mining.

When building the model, to begin with, the data were normalized. All the initial data were normalized according to Formula (2) based on the Min–Max method [39]. The Min–Max normalization method linearly changes the scale of each function to the interval [0, 1]:

$$\mathrm{U}^{\mathrm{ma}} = \frac{\mathrm{u} - \mathrm{u}_{\mathrm{min}}}{\mathrm{u}_{\mathrm{max}} - \mathrm{u}_{\mathrm{min}}} \times 100 \tag{2}$$

where U^{ma} is the normalized value of the indicator; u is the current initial value of the indicator; $\mathrm{u}_{\mathrm{min}}$ is the minimum among all values of the indicator; and $\mathrm{u}_{\mathrm{max}}$ is the maximum among all values of the indicator. Therefore, for our indicators, normalized values were calculated for each block across the corridor territories. Then, using the weights of each parameter presented above and determined by experts, the integral indices of the environmental vulnerability of the territory were calculated using the SUMPRODUCT formula in

Excel. The values of the integral indices also ranged from 0 to 1, where an increase in the value of the indicators designated a high vulnerability to environmental hazards.

3. Results

3.1. Using the Results of the Survey of Experts to Identify the Weights of Parameters

According to the survey results obtained from the experts, estimates were obtained regarding the degree of influence of the parameters on the environmental vulnerability of the territory of the railway infrastructure. In total, the number of experts who participated in the survey using the snowball method was 13, and all the results differed from each other (Table 5). Concerning the expert assessment results, the soil's infiltration capacity and precipitation scored the same amount, namely, 45. The sums of the water resources and population were close: 55 and 53, respectively. The parameter "protected areas" scored the highest amount, namely, 61. Based on this, the percentage of the weight of each parameter was distributed as follows: soil cover (infiltration coefficient) and precipitation—17%; population and water resources (which had similar weights)—21%; and protected natural areas (the most significant indicator)—24%.

Table 5. Expert evaluation results of input parameters for analysis.

Experts	Soil Cover (Infiltration Capacity)	Rainfall	Water Resources	Protected Areas	Population
E1	5	4	3	5	5
E2	3	2	5	5	5
E3	4	4	4	4	3
E4	3	5	4	5	3
E5	3	4	3	4	3
E6	3	5	5	5	5
E7	4	2	5	5	3
E8	1	5	5	5	5
E9	4	3	5	3	2
E10	4	3	5	5	5
E11	4	4	5	5	4
E12	3	2	3	5	5
E13	4	2	3	5	5
Sums of each parameter	45	45	55	61	53
Weight, %	17	17	21	24	21

As claimed by the experts, each of the selected parameters in its own way affects the environment of the adjacent territory of the railways. Almost all the experts noted that of all the parameters, greater attention should be paid to protected natural areas. Then, "population" was considered to be the most vulnerable parameter because all the sanitary and epidemiological rationing focuses on the population. Several experts chose water resources as the most important since their pollution significantly influences aquatic organisms and the entire ecosystem. Some experts believed that soil infiltration accounts for a significant share of the environmental safety factor, as this is difficult to control by man. Although the experts were less acceptive of the impact of precipitation on the railway since its effect is mediated by pollution, precipitation was attributed the same weight as the soil cover.

3.2. Environmental Map of Vulnerability to Rail Infrastructure Impacts

As a result of preparing the data for ecological mapping, the initial data of the layers were numerical and categorical. Population and rainfall are numeric, and soil, water resources, and protected areas are categorical. According to statistics, the population varied between 4792 and 1,977,258. The smallest population belonged to the city of Ekibastuz and the largest to the metropolis of Almaty. Concerning the average long-term values of annual and seasonal precipitation in the country, according to the RSE «Kazhydromet», the values ranged between 100 and 1000 mm. It was determined that the smallest amount of precipitation is characteristic of the southern—especially the Kyzylorda—region and the western part of Kazakhstan. The highest amount of precipitation belongs to the mountainous parts of the country. The country's water resources were assessed by the density of the location of its water bodies. They were divided into five categories from the lowest density to the highest density of water resources. The division of the listed layers into five categories was carried out by the Jenks optimization method. The method of natural faults (Jenks) has good adaptability and high accuracy with respect to dividing units of the geographical environment [40]. As for the soil, the soil cover was divided into three categories, which were split into groups of soils: clay, silt, and sand. Values were assigned according to the level of infiltration: one, three, and five, respectively. Protected areas were set as the highest value, five, since this parameter was considered the most vulnerable according to experts. The categorization of data and their reclassification for the weighted overlay of layers, accounting for the weights of the influence of parameters for the environmental vulnerability assessment of the railway territory, are presented in Table 6.

Table 6. Categorization and reclassification of data for weighted overlay.

Parameter	Category	Value	Influence (Weight)
Population	4792–47,582	1	21%
	47,582–128,837	2	
	128,837–270,134	3	
	270,134–513,004	4	
	513,004–1,977,258	5	
Rainfall	100–120 mm	1	17%
	120–200 mm	2	
	200–300 mm	3	
	300–500 mm	4	
	500–1000 mm	5	
Soil cover (infiltration capacity)	Clay 8%	1	17%
	Silt 13%	3	
	Sand 25%	5	
Water resources	Very low density	1	21%
	Low density	2	
	Moderate density	3	
	High density	4	
	Very high density	5	
Protected areas	Completely area	5	24%

The environmental vulnerability of the adjacent railway territories was assessed according to the vulnerability level from one to five, where one is very low, two is low, three is medium, four is high, and five is a very high level of vulnerability.

After compiling all the data in the GIS program and carrying out a weighted overlay of the layers, a map of the environmentally vulnerable sections of Kazakhstan's railway infrastructure was obtained (Figure 5).

The resulting cartographic assessment demonstrates that the assessment scale varied between "very low" and "high vulnerability". A very low level of environmental vulnerability has been determined on the railway section in the Pavlodar region, and this level covers the smallest part of all the assessed sections. Railway territories with a low level of environmental vulnerability are present in all regions of the country. However, the locations of the sites corresponding to the low level of vulnerability are concentrated in the northern regions of Kazakhstan. Generally, the country is dominated by a moderate level of environmental vulnerability in the railway area. A moderate level of ecological vulnerability was also observed in all regions of Kazakhstan except for the Kostanay region. The results concerning the high level of vulnerability turned out to be very important for us. According to the created map, these sites stand out, especially in the Karaganda, Kostanay, and Almaty regions. It should be noted that there are small areas of railway infrastructure with a high level of environmental vulnerability in each region. A very high level of vulnerability throughout the country's railway network has not been identified. With the help of the GIS program, the lengths of the estimated levels of environmental vulnerability of the railway infrastructure of Kazakhstan were calculated according to the developed map and are presented in Table 7.

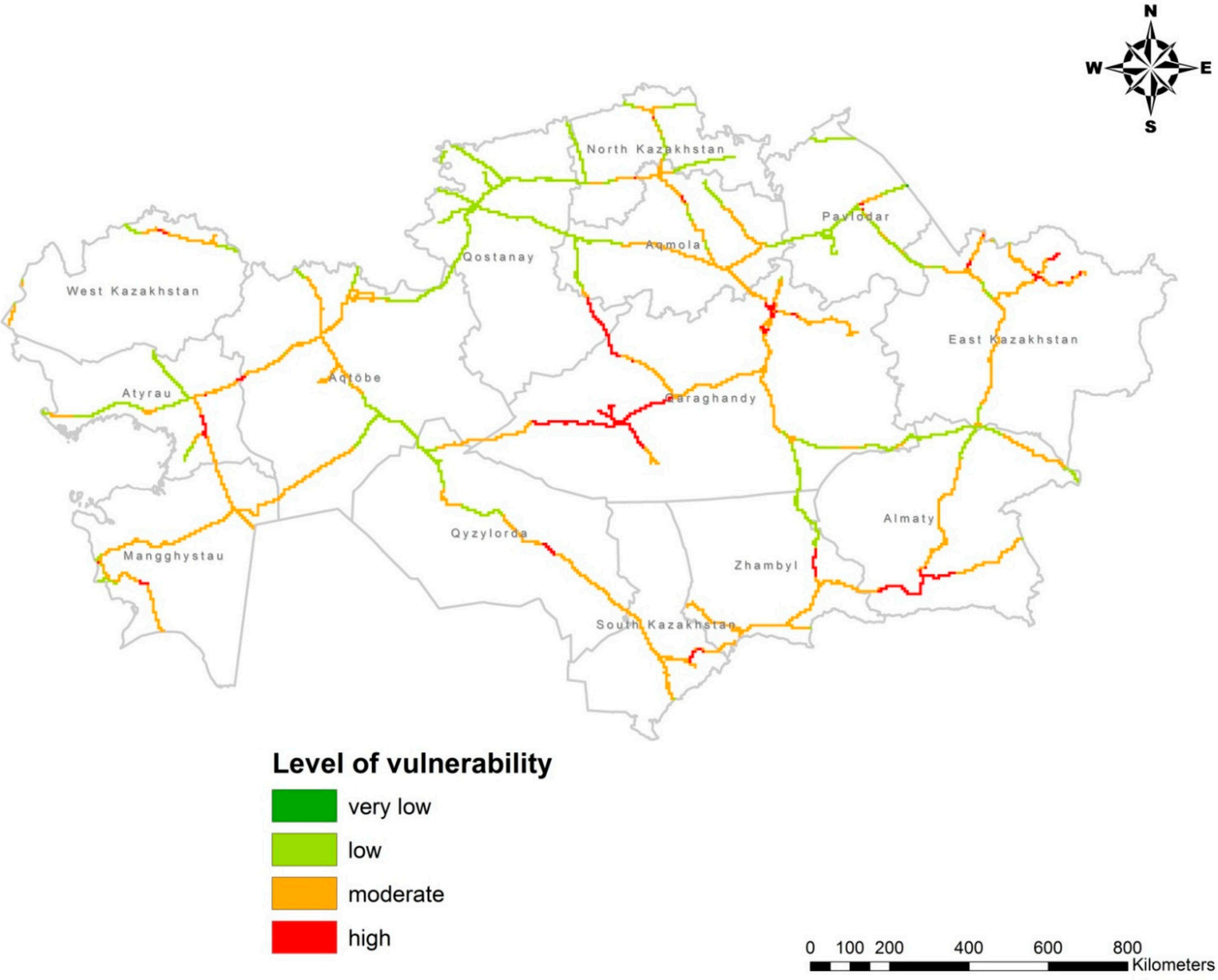


Figure 5. Map concerning assessment of the environmental vulnerability of the territory of Kazakhstan's railway infrastructure.

Sections with a low level of vulnerability to the negative impacts of the railway infrastructure accounted for only 0.03% of the entire railway network, which constituted the smallest part (5 km). The sections of low level of vulnerability accounted for 35.22% of the railway network, i.e., 5657 km. The most significant part of the railway network belonged to the "moderate vulnerability" level, accounting for 54.72%, that is, 8788 km, which is slightly more than half of the railway line. The sections with a high level of vulnerability accounted for 10.03%, which is approximately 1611 km of the entire railway system in operation.

Table 7. Shares of levels of environmental vulnerability of the railway network of Kazakhstan.

Level of Vulnerability	% of Railroad	Kilometers
Very low	0.03	5
Low	35.22	5657
Moderate	54.72	8788
High	10.03	1611
Very high	0	0

3.3. Environmental Susceptibility Model of the Northern Railway Corridor

The results of the constructed model concerning the environmental susceptibility of the territory of the international Northern Railway Corridor located in Kazakhstan (Table 8) show that the section of the Northern Corridor covers such regions of the country as Almaty, Karaganda, Akmola, and North Kazakhstan, and such large cities as Nur-Sultan and Karaganda. The index components represent the calculated normalized indicators of each parameter. However, some districts of the regions are repeated several times since the areas of the districts are large, and some parameter indicators differ regarding the site of one district. The calculated integral indices are indicators of the environmental vulnerability of the territory of the Northern Corridor. The railway corridor, starting from the Dostyk station on the border with China, passes through the Almaty region. Here, the corridor is only present in the Alakol region; however, at the same time, the amount of precipitation, the soil structure, and the locations of the water resources are different, and the integral indices were between 0.18–0.37. After the Almaty region, the corridor moves through the Karaganda region, starting from the south-eastern part to the northern part of the region, and passes through the territories of five districts and the city of Karaganda. Here, precipitation values increase along the northward corridor from 0 to 0.893. In the Aktogay region, the railway passes through the area where the minimum amount of precipitation falls. Near the city of Karaganda and the Bukhar-Zhyrau region, there is relatively heavy rainfall. All three soil groups are found in this area, and the most vulnerable places in terms of soil structures were revealed to be in the Aktogay, Shet, and Abay districts. Concerning the water resources in the adjacent areas of the railways, the density increases towards the northern part of the region. In the Karaganda region, the highest integral indices belonged to the Bukhar-Zhyrau (0.48), Abay (0.47), and Shet (0.47) districts. Then, the Northern corridor runs through the city of Nur-Sultan to the Akmola region. Nur-Sultan has the largest population along the corridor. In addition, a large amount of precipitation falls in the capital; this is made evident by the index component, which is 0.745. The closer the corridor is to the Northern part of the country, the more precipitation falls on the territories of the railway tracks. In the city of Nur-Sultan, the integral index was 0.40. Further, on the section passing through the Akmola region, the Northern Corridor includes seven districts. In the Bulandy and Shchuchinsk districts, the corridor passes through protected areas that significantly impact the environmental vulnerability of the railway infrastructures. These sections in the index component represent the maximum indicator: 1. The integral indices of the Akmola region ranged between 0.20 and 049, and the index values increased compared to the previous regions. The most recent corridor includes the North Kazakhstan region, which includes four districts of the region on the border with the Russian Federation. Parts of the corridor in the Akkaiyn, Kyzylzhar, and Mamlyut regions also pass through protected areas. For the considered section of the Northern Corridor, the highest precipitation indicator belongs to the Kyzylzhar region. In addition, heavy rainfall (0.963) and sandy soil texture (1) were observed in the Mamlyut region. Accordingly, in these areas, the integral indices were the highest along the entire corridor.

Table 8. Model for determining the environmental vulnerability of the territory of the Northern Corridor.

Territories		Index Components (Pop;R;S;W;PA) [1]	Integral Index
Region	**District**		
Almaty	Alakol	(0.03;0.712;0.294;0.333;0)	0.251620907
	Alakol	(0.03;0.712;1;0;0)	0.303479488
	Alakol	(0.03;0.712;1;0.333;0)	0.374264559
	Alakol	(0.03;0.21;1;0;0)	0.216249401
	Alakol	(0.03;0.588;1;0;0)	0.282029467
	Alakol	(0.03;0.021;1;0;0)	0.183359368
Karaganda	Aktogai	(0.079;0.021;1;0;0)	0.193486977
	Aktogai	(0.079;0;1;0;0)	0.189911974
	Shet	(0.021;0.305;0.294;0.333;0)	0.179067905
	Shet	(0.021;0.872;0.294;0.667;0)	0.348523074
	Shet	(0.021;0.872;1;0.667;0)	0.471166726
	Abay	(0.036;0.872;1;0.667;0)	0.474168967
	Bukhar-Zhyrau	(0.286;0.893;0.294;0.667;0)	0.406250775
	Bukhar-Zhyrau	(0.286;0.893;0.294;1;0)	0.477035845
	Karaganda c.	(0.415;0.893;0.294;0.667;0)	0.432672629
	Osakarov	(0.011;0.848;0.294;0.667;0)	0.342296672
-	Nur-Sultan c.	(1;0.745;0;0.333;0)	0.404833405
Akmola	Arshaly	(0.009;0.695;0.294;0.667;0)	0.315309601
	Tselinograd	(0.056;0.745;0.294;0.333;0)	0.262731307
	Tselinograd	(0.056;0.745;0.294;0.667;0)	0.333516378
	Tselinograd	(0.056;0.745;1;0.333;0)	0.385374959
	Shortandy	(0.01;0.93;0.294;0.333;0)	0.285525872
	Shortandy	(0.01;0.93;1;0.333;0)	0.408169524
	Shortandy	(0.049;0.761;0.294;0;1)	0.428941879
	Akkol	(0.065;0.93;0.294;0.333;0)	0.296686366
	Bulandy	(0.014;0.761;0.294;0.333;1)	0.492533914
	Zerendi	(0.157;0.7;0.294;0;0)	0.204793987
North Kazakhstan	Tayinsha	(0.021;0.835;0.294;0;0)	0.200538612
	Akkaiyn	(0.141;0.835;0.294;0;1)	0.460714472
	Kyzylzhar	(0.212;1;0.294;0;1)	0.503691631
	Mamlyut	(0;0.963;1;0;1)	0.576576577

[1] Pop—population. R—rainfall, S—soil cover, W—water resources, and PA—protected areas.

All the above territories of the Northern Corridor are summarized by the value of the integral index of environmental vulnerability and presented in Figure 6. The overall results ranged from 0,18 to 0,58. Of all the territories considered, the highest integral index of exposure belonged to the Mamlyut district of the North Kazakhstan region, while the weakest vulnerability was in the Shet district of the Karaganda region.

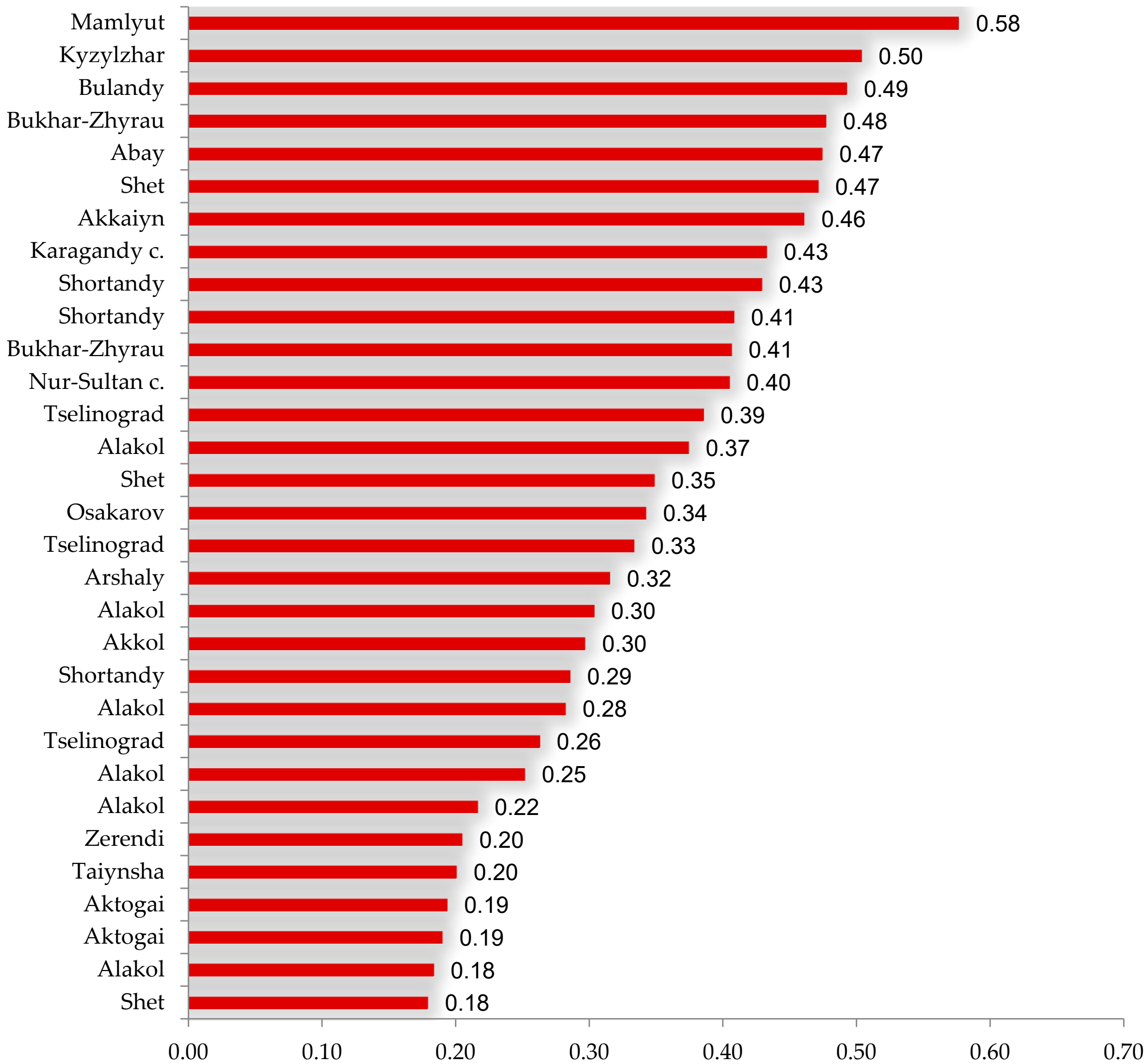


Figure 6. Indicators of the integral index calculated for the Northern Corridor according to districts of regions and arranged in ascending order.

4. Discussion

In the Kazakh railway sector, the issues of environmental safety and the reduction and prevention of harmful impacts have not yet been fully resolved. In addition, the environmental impact of the railway infrastructures in the country has been minimally researched.This research is the initial stage of the study of the territory of the railway infrastructure of Kazakhstan, where attention is paid to vulnerable areas of the environment of the adjacent territory. Our study assessed the area of railways in Kazakhstan by mapping and developing a model that incorporated the main components of the environment that may be exposed to environmental hazards from the railway infrastructure.

The use of weighted layering via GIS technology and the determination of the integral index constitute a new approach for analyzing Kazakhstan's Railway. The weighted overlay method used for the construction of the map of railways has also been used in other works [41–43] to study the choice of optimal railway routes for the transportation of hazardous substances, the identification of dangerous places of a railway accident, and vulnerabilities. The criteria chosen for the assessment were soil cover, water resources, rainfall, protected areas, and population.

The consideration of soil cover in this work was similar to the work of P.Anand and C.P.L.Barkan [26], who investigated the impact of hazardous material spills caused by railway accidents in the United States of America on soil and groundwater. According to the results of their study of the probabilistic distribution of soil types, silts were the most common soils under railway tracks, while sands were the most common throughout the country. Our results showed that in Kazakhstan, under the railway tracks, soils of the silty soil group (more than 70%) with an average infiltration capacity predominate. The same phenomenon exists regarding the clay soil texture, which can infiltrate very slowly and create a protective layer and occupies the smallest portion (4%), as in the United States.The most vulnerable zones with sandy soil texture accounted for 23%. Decisions regarding groundwater protection are ambiguous, but these results can be considered as an initial approximate division of soil groups since additional studies on the location and depth of groundwater are required, which require a great deal of work. The importance of studying groundwater pollution along railway lines is also due to the fact that there are still wagons with open toilets in the country that do not have a collection system. Human excrement and garbage are dumped on railway tracks and adjacent areas. This waste accumulates without any treatment, and precipitation contributes to its penetration deeper into the soil horizons. In the future, it is recommended to study the relationship between soil pollution and groundwater, which is very relevant to and extremely necessary for solving the environmental problems in this area of activity.

As for surface water bodies, water resources were considered in terms of their density and considering the scale of the country's territory. The intersection of railways with water bodies was often found in the Central, Northern, Eastern, and South-Eastern parts of Kazakhstan. Among them were quite large water bodies, such as the rivers Tobol, Ishim, Irtysh, Ilek, Zhaiyk, Nura, Sagyz, Emba, Syrdariya, Shu, and Ile, and Lake Balkhash. Lake Balkhash and the Yertis river are water bodies of special national importance.In further studies, it is planned to additionally consider water objects of fishery-related significance.The environmental requirements for fishery water bodies are stricter and any chemical pollution is prohibited. In this regard, we consider it necessary to expand the field of research and determine which water resources and their fauna may be at risk of pollution from railway infrastructure.

Using GIS technology, an analysis of protected areas showed that the railways cross eight protected areas and saiga habitats. At the same time, it should be emphasized that on the sections of railways where they cross protected natural territories and along the entire length of the railway line of Kazakhstan, there are no special crossings, landscape bridges, or ecoducts designed for the passage of wild animals. As the situation with saigas shows, the appearance of a new railway line on the migratory paths of wild animals is particularly dangerous, leading to the fragmentation of and reduction in animal habitat.

In general, the entire railway network of the country is to some extent exposed to environmental hazards from the railway infrastructure, and the mapping assessment showed us four levels of ecological vulnerability, ranging from very low to high levels. It is assumed that a very high level of environmental vulnerability may have yet to be identified due to insufficient study parameters. In further studies, the results presented in the article can be explored more profoundly in the area of one region using more accurate and detailed data. For example, using the slope of the terrain and landscape features of any site, while also considering our data presented, it is possible to conceive of effective and appropriate measures for spills of hazardous substances and prevent pollutants from entering a river or lake. However, this still depends on related factors, such as the year's season, weather conditions, etc. The existing operational railways in protected natural areas should be under exceptional control, and with the further development of the railway infrastructure, it is recommended that such railways bypass protected natural areas.

Thus, if the constructed assessment map shows a comprehensive assessment of environmentally sensitive sections of the railway infrastructure, then using the presented model, one can see the values of each component used in the evaluation. Our constructed model for determining the vulnerability of the territory using the example of the Northern Corridor shows, in detail, the values of the integral index of the environmental vulnerability of the territory of the international corridor. The components of the index allow one to see the dominant factors influencing the ecological vulnerability of each site. These values indicate which parameters to scrutinize and help identify high-risk routes and develop adaptational measures with which to reduce the risk from the rail infrastructure.

The presented results regarding the assessment of the ecologically vulnerable areas of the railway infrastructure were obtained for Kazakhstan. Future projects concerning the international construction of railway corridors should be based on transnational studies and not be limited to one country. The environmental hazards that often occur on the railways of Kazakhstan occur in other countries as well [44,45], which allows the methods applied in this article to be used for any territory with railways. For example, the snowball method and the questionnaire for expert assessment apply to all studies in the field of railways. In addition, the selected criteria can be supplemented with other parameters characteristic of other natural conditions. The developed model of the environmentally susceptible sections of the Northern International Railway Corridor can not only be used for international routes adjacent to Kazakhstan but also for other countries worldwide, especially in developing countries where data are limited.

Systematically planned actions help to prevent or significantly reduce the damage from the negative impacts of railway infrastructure. For example, to assess the impact of rail transport, the International Union of Railways has developed two online calculators, namely, "EcoTransIT" for freight and "EcoPassenger" for passenger traffic, which are focused on the operation of vehicles and consider emissions from energy supply. In the future, the development of railway infrastructure in the international direction should be focused on countries' adjacent territories, especially for transit countries in international corridors.

5. Conclusions

In general, according to the developed map, it was revealed that Kazakhstan is dominated (54.72%) by an average level of environmental vulnerability of the railway territory, which covers 8788 km of the total length. The sections with a very low level of vulnerability to the negative impacts of railway infrastructure amounted to only 0.03% and constituted the smallest portion (5 km). The sections with a low level of vulnerability accounted for 35.22% (5657 km) of the railway area. The sections with a high level of vulnerability constituted 10.03%, which corresponds to approximately 1611 km. A significant result was that high levels of ecological vulnerability stand out in the Karaganda, Kostanay, and Almaty regions. Additionally, the utilized model of integral indices, using the example of the Northern International Corridor, showed that it is possible to examine the evaluated components in detail and to understand the influence of parameters on the site's vulnerability, which is not visible on the map. In the Mamlyut (0.58), Kyzylzhar (0.50), and Bulandy (0.49) districts, the highest indicators of the integral index were obtained, wherein protected natural areas were observed to be the dominant factor influencing the ecological vulnerability of the corridor.There are many state plans and programs for the further development of the railway infrastructure of Kazakhstan, and such studies are necessary for future improvement. There is also the problem conducted the limited availability of data, which prevented us from considering some points in detail. The selected parameters for performing the analysis can be further supplemented with other parameters and provide a more detailed description since some issues require further comprehensive research.

Recommendations based on the results of the study:

1. The identified environmentally sensitive sections of railways should be organized by incorporating protective integrated environmental measures to mitigate the impacts of railways on the environment.
2. When planning the construction of new railway routes, it is necessary to consider this study's results in order to prevent environmental hazards posed by the railway infrastructure. Future railway development projects should avoid environmentally sensitive areas.

3. The Northern Corridor is an international transport route of significant economic importance. Therefore, the integral indices of the Northern Corridor should be incorporated into the environmental monitoring system in the territory of the railway infrastructure to maintain the favourable ecological state of the adjacent territories.
4. It is necessary to implement the developed map and model in order to determine the environmental vulnerability of the territory in the process of making strategic and operational decisions according to JSC "NC "Kazakhstan Temir Zholy", as well as the activities of authorized state bodies responsible for fulfilling the requirements of the Law "On Railway Transport" and the state program of infrastructure development of the Republic of Kazakhstan "Nurly Zhol" for 2020–2025.

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