Pertanika J. Sci. & Technol. 31 (3): 1439 - 1451 (2023)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Railway Urbanozems: Interrelation of Physicochemical and Integral Environmental Indicators

Tatyana Anatolyevna Adamovich and Anna Sergeyevna Olkova*

Vyatka State University, 36 Moskovskaya St, Kirov, 610000, Russian Federation

ABSTRACT

Urbanozems with typical pollution are formed along railways: heavy metals (HM), oil products, anthropogenic organic matter. Depending on the natural zone and intensity of the leaching regime, the accumulated pollution can have a different effect on the integral environmental indicators of soils – the toxicity and enzymatic activity. The aim of the work was to determine the influence of the railway on the physicochemical characteristics of adjacent urbanozems that are formed in the southern taiga zone and to find out the interrelation of these indicators with the toxicity and catalase activity of the soil. Samples of urbanozems were taken from the surface layer of 0-10 cm at the distance of 50 m west and east of the railway and at the distance of 100, 500, 1000 m of it (east). The pH, content of organic matter, humus, ammonium nitrogen, mobile forms of HM, mortality for *Daphnia magna* Straus, influence on bioluminescence of *Escherichia coli* Migula, and the catalase activity were determined in the samples. It was shown that the levels of toxicity and the activity of catalase are strongly related to the distance from the railway: Pearson's coefficients (r) were -0.53 (*D. magna*), -0.69 (*E. coli*), 0.95 (catalase). However, the interrelation between the total pollution index (TPI) of metals and integral indicators is lower: r=0.50 for the pair "*D. magna* – TPI", r=0.42 for "*E. coli* – TPI", r=0.19 for "catalase – TPI". Consequently, the reactions of living organisms and the activity of catalase were formed in response to a combination of pollutants, not to one group of compounds.

Keywords: Bioassay, catalase, *Daphnia magna*, *Escherichia coli,* heavy metals, railways, soil pollution, urbanozems

ARTICLE INFO

Article history:
Received: 06 May 2022
Accepted: 07 September 2022
Published: 31 March 2023

DOI: https://doi.org/10.47836/pjst.31.3.17

E-mail addresses:
morgan-abend@mail.ru (Anna Sergeyevna Olkova)
usr08612@vyatsu.ru (Tatyana Anatolyevna Adamovich)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

At present railway transport is of great importance, its economic and social role increases. Development of the network of railways and stations improves the quality of physical and social spaces and increases the economic viability of space (Banerjee & Saha, 2022).

Despite high importance of rail transport, the operation of railways is associated with some environmental problems. The problem of an increased level of acoustic noise near the railway is known. More people are exposed to railway noise at night (>50dB) than during the whole day (>60dB), which is related to higher volumes of freight rail transport at night. Loud noise can lead to irritability and aggression, hypertension (increased blood pressure), tinnitus, and even hearing loss (Wrotny & Bohatkiewicz, 2021).

Long lines of railways significantly affect representatives of the natural biota. For example, railroad lines can create obstacles for the movement of animals, separate populations or restrict their access to resources. This way the barrier effect is formed. Barrier effects, landscape fragmentation, increased accidental mortality lead to the risk of extinction of wild animal populations (Balkenhol & Waits, 2009). Scientists draw attention to the impact of roads on birds and mammals. Thus, the negative impact of the railway on the wealth and animal number was shown (Li, 2012). Causes of negative impacts on flora and fauna include chemical air and soil pollution, soil erosion (Balkenhol & Waits, 2009).

One of the main environmental problems associated with rail transport is the linear pollution of environmental components along the railroads. A number of studies report increased air pollution near railways. In particular, in the immediate vicinity of railway stops there is a violation of air quality and an excess of environmental standards for a number of volatile compounds, which is associated with the migration of pollutants from the surface of fuel tanks into the air (Zvyagintseva et al., 2020).

Soils experience the maximum load near railways. Thus, the study of Szmaglinski et al. (2021) shows that Cr is a specific chemical trace that appears along railways due to the use of chromium compounds to resist increased rail wear. The work of Radziemska et al. (2021) showed that the accumulation of Cd, Cr, Cu, Ni, Pb in soils along railways and biological tissues correlated with each other.

Soils near railroads accumulate other pollutants: polyaromatic hydrocarbons, polychlorinated biphenyls, oil products and pesticide residues. Usually the content of these pollutants does not exceed the established standards. However, the toxic effect of railway urbanozems on numerous test organisms of different trophic levels was shown (Wierzbicka et. al., 2015; Zhang et al., 2012). The authors attribute this to the synergistic effect of low concentrations of several pollutants.

Thus, complex studies of soils associated with railways remain relevant. The degree of anthropogenic transformation of the environment significantly depends on a set of environmental factors. The aim of the work was to determine the influence of the railway on physicochemical characteristics of adjacent urban soils formed in the southern taiga zone and to find out the interrelation of these indicators with the toxicity and catalase activity of the soil.

MATERIALS AND METHODS

Sampling Sites

We assessed the impact of rail transport on urbanozems formed during planning and construction work related to the laying train tracks and organization of land plots adjacent to the railroad tracks. The study sites were located far from large settlements and industrial enterprises, which made it possible to achieve the purpose of the work without imposing additional technogenic factors.

The study area is located in the northeast of the European part of Russia, on the Russian Plain, latitude: 59.363129° N, longitude: 49.0466079° E (Kirov region, the Russian Federation). The climate of this area is similar to the climatic features of the Northern regions of Europe, the northern states of America, most of Canada and other countries of the Northern Hemisphere. The average temperature is 3.5℃, the average winter air temperature is -9.5℃, the average summer temperature is 16.7℃.

The railway in the selected area belongs to the omnibus circuit for passenger and cargo trains. The traffic density of this section of the railway is from 15 to 30 million tons/km. The railway consists of two tracks in opposite directions. The cross-sleepers are made of reinforced concrete. The ballast bearing layer of the railway track consists of gravel, the slopes of the embankment are small - less than 30 m, there is soil covering behind the slopes. The sloping terrain is 7% to the east within 10 km. The area was chosen as the most typical; it represents the longest non-loco shed railway section in the world.

As the distance from the railway increases, the soil cover changes from urbansems to natural soil types. The predominant natural soils are soddy-podzolic, the granulometric composition is sandy and sandy loam, the humus supply is low, the pH reaction of the soil extract is strongly acidic and acidic. The prevailing winds are southern (21.6%), western (17.6%) and northern (15.1%), and the railroad runs in a north-south direction, so the maximum air spread of pollution presumably occurs in the direction of the railway and from west to east. Based on these conditions and the slope of the terrain to the east, the sampling sites were determined.

The samples were taken from the surface layer of 0-10 cm at a distance of 50 m from the western and eastern sides of the railway and at the distance of 100, 500, 1000 m from it (on the eastern side). The background site was located at the distance of 3000 m to the east from the railway to demonstrate a decrease in pollution when moving to distances from a linear anthropogenic object. Sampling was carried out annually at the end of the growing season (at the end of August), since the planned indicators required sufficient development of the soil biocenosis. All plots were covered with natural herbaceous vegetation, gramineous and other weedy plant species (couch grass, quarry and shepherd's purse). After sampling the soil was freed from plant roots and contaminating impurities, dried to an air-dry state, homogenized, and analyzed according to the research plan.

The observation program was carried out for three years to obtain data on the fluctuations of the selected indicators of the state of the soil.

Complex of Research Methods

The pH value was measured by the potentiometric method on the MI-150 pH meter (Environmental Regulation, 2016). The content of organic matter was determined spectrophotometrically according to the Tyurin method (State Standard, 1992). Determination of ammonium nitrogen in the soil samples was carried out spectrophotometrically (State Standard, 1985). The catalase activity of the soil was determined using the gasometric method (Inisheva et al., 2003). The mass fractions of mobile forms of metals (copper, cadmium, lead, and zinc) were determined by the atomic absorption method (Federal Register, 2012). The toxicity of the samples was determined by the mortality of *Daphnia magna* Straus (Federal Register, 2007) and the change in the bioluminescence of *Escherichia coli* Migula bacteria (Environmental Regulatory Document, 2010).

Results Processing Methods

The level of soil contamination with mobile forms of HM was assessed by the concentration coefficient, defined as the ratio of the content of the element in the studied area to its content in the background area. Next, the total pollution index (TPI) was calculated as the sum of HM concentration factors (Saet et al., 1990; Korelskaya & Popova, 2012). The resulting TPIs characterized the degree of soil pollution are: more than 128 – extreme pollution, 32–128 – dangerous, 16–32 –moderately dangerous, less than 16 – permissible pollution (Ministry of Health of the USSR, 1987).

The physicochemical and integral environmental characteristics of urbanisms were determined three times (2017-2019). The annual processing of the results was carried out according to the recommendations of the methods of analysis used. The summary data in Table 1 is presented as a three-year average with a standard deviation and range of three-year values. The figures show the average values obtained over three years of research.

RESULTS

General Characteristics of the Soil Cover Near the Railway Track

The soil in the background plot corresponded to typical soddy-podzolic soils of treeless territories in the southern and middle taiga climatic natural zones (Eremchenko et al., 2016).

The medium acid pH level and high content of organic matter (up to 13.9 mg/kg of dry soil mass) were found out. The activity of catalase in the soil of the background plot also corresponded to the average data for the soils of the so-called "middle latitudes" (Mitrakova, 2018; Wu et al., 2012). When approaching the railway, some indicators changed (Table 1).

The pH level of the soil solution near the railway changes significantly becoming more alkaline. The shift was about 2 pH units in all experimental sites compared to the average background values. Moreover, the maximum pH levels were recorded at the site 1000 m away from the object of influence. An increase in the pH level in soils near railways is obviously associated with emissions of soot and other alkaline products of coal combustion, since diesel locomotives are operated on this part of the railway. The results show that soils that are not adjacent to the railway, but located at a distance from it (1000 m), experience the maximum impact of alkaline emissions.

The content of organic matter in the soils of most sites did not differ significantly from each other ($p>0.05$). Only in the area, situated at the distance of 500 m, increased concentrations of organic matter compared to the background were revealed ($p<0.05$). The relative remoteness of the site and the fact that most trains in Russia are equipped with dry

Table 1
Characteristics of urbanozems adjacent to railways and soils of the background site (2017-2019 years)

Sampling site/ distance from the railway	pH (units pH)	Organic matter (%)*	Ammonium nitrogen (mg/kg)*	Catalase activity (cm^3 O_2 per 1g of soil for 1 min)*
Background site / 3000 м	<u>4.9±0.1</u> 4.8-5.1 medium acid	<u>3.2±0.4</u> 2.6-4.2 low content	<u>4.8±0.2</u> 4.3-5.7	<u>4.0±0.3</u> 3.6-4.3 weak
Site №1 / 50 m west	<u>7,1±0,1</u> 7,0-7,3 close to neutral, alkaline	<u>3,7±0,6</u> 2.4-4.5 low content	<u>2.0±0.4</u> 1.28-3.21	<u>2.0±0.4</u> 1.6-2.7 weak
Site №2 / 50 m east	<u>7.2±0.1</u> 7.1-7.3 close to neutral, alkaline	<u>2.9±0.4</u> 2.8-3.1 low content	<u>5.65±0.02</u> 5.63-5.68	<u>2.6±1.0</u> 1.1-3.6 weak
Site №3 / 100 m east	<u>6.8±0.1</u> 6.7-6.8 close to neutral, alkaline	<u>3.2±0.5</u> 2.6-4.2 low content	<u>6.92±0.12</u> 6.89-6.97	<u>2.53±0.17</u> 2.3-2.7 weak
Site №4 / 500 m east	<u>6.8±0.1</u> 6.7-6.9 close to neutral, alkaline	<u>5.2±0.5</u> 4.8-5.6 average content	<u>4.4±0.4</u> 4.27-4.47	<u>2.70±0.17</u> 2.4-2.9 weak
Site №5 / 1000 m east	<u>7.5±0.1</u> 6.8-7.9 close to neutral, alkaline	<u>2.9±0.4</u> 2.8-3.1 low content	<u>3.18±0.11</u> 3.14-3.21	<u>3.0±0.2</u> 2.7-3.1 weak

Note. The numerator of the conditional fraction shows the average values of the indicator calculated of the results of 2017-2019 years, the denominator indicates the range of values; * – calculation for the dry weight of the soil.

closets suggest that this local increase in the concentration of organic matter in the soil is not related to the influence of the railway. The trend was confirmed during three years of observations, so we also exclude random errors. It is most likely that this is due to the heterogeneity of the soil and its composition.

The content of ammonium nitrogen in all sites, including the background plot, is rather low (from 2.0±0.4 to 6.92±0.12 mg/kg dry weight). There are reports in the literature about the content of ammonium nitrogen in the soil at the level of 20–30 mg/kg (Masclaux-Daubresse et al., 2010). The lowest accumulation of ammonium nitrogen was found for the plot No. 1 closest to the railway (2.0±0.4 mg/kg). This is probably due to the fact that the areas closest to the road are covered with urbanozems - an artificially formed soil layer characterized by a high degree of compaction and a low projective cover of herbaceous vegetation (30% or less). In such soils all natural cycles are slowed down, including the mineralization of organic matter with the initial release of nitrogen in the form of NH_4^+.

This hypothesis is confirmed by a weak positive correlation between the content of ammonium forms of nitrogen and the activity of soil catalase (r=0.21). Both indicators depend on the saturation of the soil with microorganisms. The connection of a low level is explained by the fact that ammonifying microorganisms are only part of the pool of microorganisms that serve as suppliers of catalase to the soil. In general, the catalase activity naturally decreases when approaching the railway (r=0.95). Average levels of the catalase supply were observed only in the background site, and in the experimental sites the activity of the enzyme was weak.

Thus, the pH level and the catalase activity were most associated with the influence of the railway.

The Content of Mobile Forms of Heavy Metals in Urbanosems Adjacent to Railway

Rail transport is one of the most significant HM suppliers to the environment (Abbasi et al., 2013). In this work we determined the content of mobile forms of metals in the soil, since they are available to soil biota, accumulated by living organisms and affect the integral toxicity of soils. In the Russian Federation the content of mobile forms of HM in the soil is standardized (Federal Law of the Russian Federation, 1999). The admissible concentration limit (ACL) for Pb is 6 mg/kg, for Cu – 3 mg/kg, for Cd – 1 mg/kg, Zn – 23 mg/kg of dry soil mass. Exceeding the standard for Zn by 2.9 times was found one time in 2019 for the site located 1000 m from the railway. In other studied areas no excesses of the standards were found. ACL multiples for Pb and Cd were recorded at the level of 0.53 in the site closest to the road (50 m east). However, the analysis of HM concentration coefficients compared with the background area (Figure 1) and the total pollution index (Figure 2) indicates the accumulation of HM.

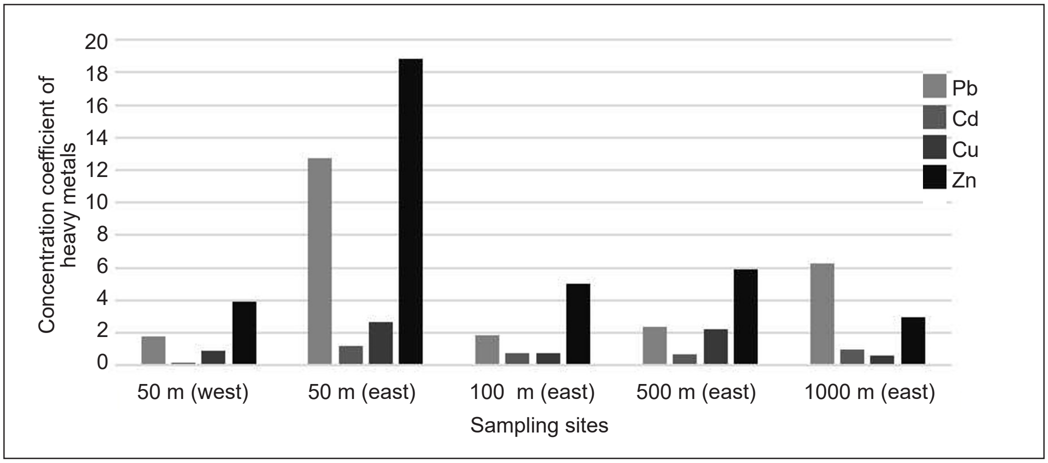

Figure 1. The concentration coefficients of mobile HM forms at different distances from the railway

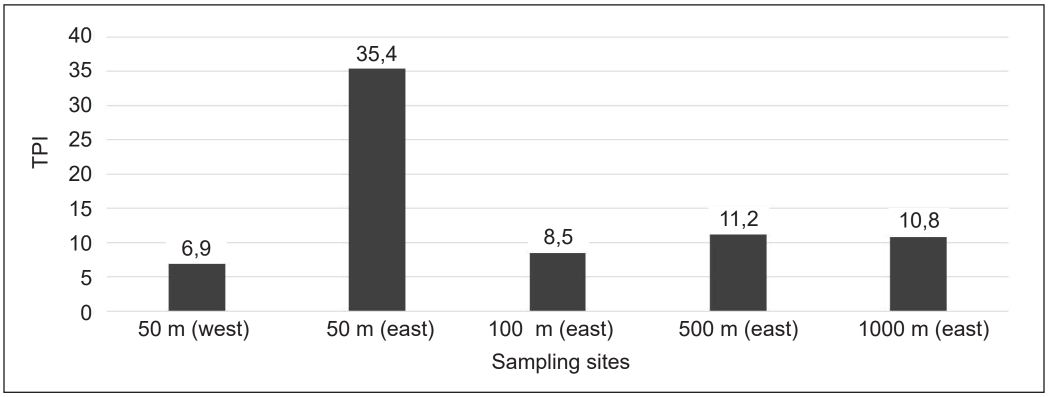

Figure 2. Total indicators of pollution of urbanozems located at different distances from the railway

Zn and Pb take leading positions in terms of concentration coefficients. On average within three years of observations the excess of the Zn content in the soils of railways ranged from 3 to 18.8 times in comparison with the indicator in the background site. A similar comparison is in the range of 1.8-12.7 times for Pb. The maximum concentration coefficients of the mobile forms of Pb, Cd, Cu, Zn were observed in the sites closest to the railway (50 m east), which was also reflected in the highest ACL. It should be noted that to the right of the railway (50 m west) the total pollution indicator was not so high. This is due to the fact that, according to long-term meteorological observations, one of the prevailing wind directions is from west to east.

The accumulation of mobile forms of Cd was comparable to the background area. When calculating the average data within three years, the concentration coefficient of Cd varied from 0.7 to 1.2. The results obtained for mobile forms of Cu are similar: only in two sites the accumulation of copper was 2 or more times compared to the background.

Thus, it is shown that in the site near the railway, the content of mobile HM forms is most often within the established standards, but in comparison with the background territories the accumulation of mobile forms of Zn and Pb is observed. According to the total pollution index, most sites within 50-1000 m from the railway are characterized by an acceptable level of pollution. However, pollution can reach dangerous levels.

Responses of Living Organisms to Soil Pollution Near Railways

Chemical characteristics, which were considered separately, cannot show the consequences of anthropogenic pollution in a certain area. Chemical studies should be combined with environmental quality biodiagnostics. In this work we used two methods of bioassay. Firstly, the lethal effects of water extracts from soils (1:4) for *D. magna* were evaluated within 96 hours. Secondly, we evaluated the prelethal effects of water extracts from soils (1:5) for *E. coli* by changing their bioluminescence (Figure 3).

In the sites closest to the railway the maximum toxicity of soil samples was found. Mortality of *D. magna* in the samples “50 m l west” and “50 m east” was above 50%, that is, the samples had an acute toxic effect on the test organism. Toxicity indices for *E. coli*, taking into account the scatter of results in parallel determinations, indicate a strong toxicity of the samples.

The toxicity indicators expectedly decrease further from the railway. The relationship between the distance from the object of influence and the mortality of *D. magna* is characterized by Pearson’s coefficients equal to -0.53. The correlation coefficient for the relationship “distance - toxicity index for *E. coli*” is -0.69. When taking into account the results of the *E. coli* bioassay, a more strict dependence is associated with the assessment of the pre-lethal reaction of the organism, which can manifest itself at fairly low doses of toxic substances (Olkova & Ashikhmina, 2021).

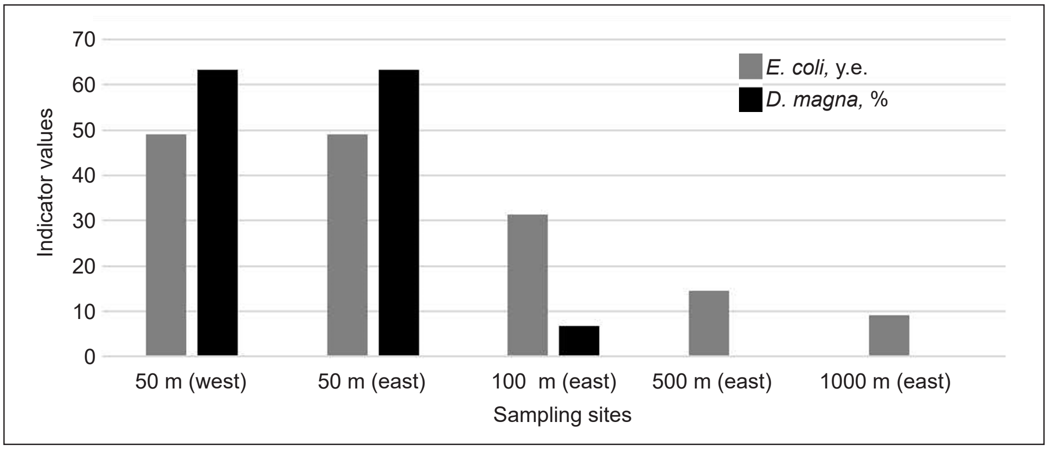

Figure 3. Results of bioassay of water extracts from urbanozems in response to *D. magna* (mortality) and *E. coli* (decrease in bioluminescence)

When analyzing the relationship between the results of bioassay and other characteristics of the studied soils, it was revealed that the highest degree of inverse relationship is observed between the toxicity of the soil and the activity of catalase in it: r=-0.61 for "catalase – *D. magna*" and r=-0.74 for "catalase – *E. coli*". This result is quite natural and is explained by the fact that the levels of toxicity and enzymatic activity are integral indicators that respond to the whole complex of chemicals present in the sample.

The correlation between toxicity and other soil characteristics was much weaker. Thus, even for the pair "total indicator of HM contamination – toxicity for *E. coli*", the Pearson's coefficient was equal to 0.42. This confirms that the detected levels of toxicity were formed in response to a combination of pollutants, and not to one group of compounds.

DISCUSSION

In the first part of the work it was shown that the catalase activity was most associated with the influence of the railway. It is known that the catalase activity is an integral indicator of the state of the soil, which responds both to natural factors (Olkova & Tovstik, 2022) and anthropogenic pollution (Hinojosa et al., 2004; Utobo & Tewari, 2015). In the case of the influence of railways on the soil it can be argued that the catalase activity was inhibited by a complex of pollutants, since a strong dependence of the catalase activity on the distance from the site to the railway was revealed (r = 0.95). In the literature there are data on the relationship between the activity of soil enzymes and chemical pollution. Thus, in Baran et al. (2004), a relationship was established between the content of polycyclic aromatic hydrocarbons (PAH) and the enzymatic activity of soils. It was concluded that the effect of PAH on the enzymatic activity largely depends on such soil properties as the content of total organic carbon and pH. The work Baikhamurova et al. (2020) showed that near the railway the urease activity was reduced by 2 times and the invertase activity was reduced by 3 times compared to the background areas.

It turned out that the soil pH level is associated with the influence of the railway. An increase in pH by 2 units within 3 km without a change in phytocenosis indicates the entry of alkaline products into the soil. In this case soot and other combustion products of coal and diesel fuel, used in diesel locomotives - locomotives with an internal combustion engine, are found on the soil. It should be noted that among the main modes of transport with internal combustion engines (roads, aviation, navigation, and railway) rail transport has the least environmental impact (Paschalidou et al., 2022).

In the second part of the work accumulation of mobile forms of Zn and Pb was shown in the territories adjacent to railways. It was found that an increased content of heavy metals is characteristic of soils directly adjacent to railways. The most likely source of zinc is brass alloys. Bearings, water and steam fittings are made of brass for railway transport. Radiators and heat exchangers are made of sheet brass. In addition, zinc is used in electrical equipment as part of electrically conductive elements. Lead is released into the soil when coal and other biogenic fuels are burned.

The studied HM can be ranked according to the level of accumulation in railway urban soils as follows: Zn > Pb > Cu=Cd. The study in Poland showed a similar pattern: the maximum values for Cr, Cu, Pb and Zn were 31.1, 145, 80.5 and 115 mg/kg soil mass, respectively (Szmaglinski et al., 2021). In the same work, using isotope analysis methods, it was shown that metals are of anthropogenic origin (coal combustion, road vehicles and railroad transport coal combustion, road vehicles, and railroad transport). The latest studies report that metal contamination of railway urbanozems is not limited to "classical" anthropogenic HM (Pb, Zn, Cu, Cr, Cd). Thus, the authors (Stancic et al., 2022) showed that in soils along railways pronounced enrichment of Sb and Sn is found, it is 87 and 33 times higher than the median value for European soils, respectively.

When further determining the toxicity of the studied soils, it was shown that the responses of test organisms increase when approaching the railway, and they are also most closely related to the activity of catalase and the relation to the concentration of mobile HM forms is average. These patterns are consistent with findings of other scientists. Thus, it is proposed to evaluate the activity of catalase and other enzymes to indicate heavy metal contamination of soils near the railway (Xiaoyi et al., 2018).

CONCLUSION

Railways are a source of pollution of adjacent urbanozems. However, the zone of maximum contamination is 50 m. At a greater distance from the railroad track there are higher levels of mobile forms of Zn, Cu, and Pb compared to the background area. Pollution by anthropogenic organic matter and the content of ammonium nitrogen associated with it, apparently, is of a situational local nature. In general, from the economic and environmental point of view the rail transport is more preferable than road transport.

A limitation of this study is that not the full range of pollutants that are markers of the impact of the rail transport on the environment was identified. However, due to the integral characteristics of the soil a negative interrelation between toxicity levels and the distance to the railway and a positive relationship between the catalase activity and this distance were shown. The confirmation that the soil microbiota and test organisms are affected not only by heavy metals is the high level of correlation "pH - distance to the railway" in combination with the average degree of correlation between the total indicator of Cd, Zn, Cu and Pb pollution with the integral environmental indicators of soils. As it was mentioned above the soil near railways can be characterized by high oil pollution. Also scientists began to pay closer attention to the contribution of rare earth elements and platinum group metals to the overall "metal" pollution.

The presented work complements the available scientific information on the influence of the railway transport on the soil pollution (urbanozems) and contains new data on the interrelation of existing pollution with lethal and pre-lethal reactions of test organisms and soil microbiota (through the index of the soil catalase activity).

ACKNOWLEDGEMENT

The authors want to acknowledge Doctor of Technical Sciences, Professor at Vyatka State University, Russia, Tamara Yakovlevna Ashikhmina, for the long learning process and support.

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