

## UDC 656.2:504

A. V. SAMARSKA<sup>1\*</sup>, Y. V. ZELENKO<sup>2</sup><sup>1\*</sup>Dep. «Chemistry and Engineering Ecology», Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (097) 091 74 51, e-mail samarskaya.av@gmail.com, ORCID 0000-0002-0828-9457<sup>2</sup>Dep. «Chemistry and Engineering Ecology», Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (067) 774 04 64, e-mail j.v.zelenko@gmail.com, ORCID 0000-0001-5551-0305

## ASSESSMENT OF THE RAILWAY INFLUENCE ON THE HEAVY METAL ACCUMULATION IN SOIL

**Purpose.** The scientific paper aims at analyzing the current state of the railway infrastructure soil contamination with heavy metals (HM), namely, the three stations of Prydniprovsk railway: Kamianske-Pasazhyrske, Zaporizhzhia-Kamianske and Trytuzna. **Methodology.** The research object is the soil of the above mentioned railway stations, the research subject is the total content of HM. Sampling was carried out every 15 m between and outside both rails up to the end of railway ties. The total area of the investigated sites is 600 m<sup>2</sup>. The total form of Fe, Pb, Zn, Cu, Ni, Cd and Mn concentration was determined by the atomic absorption spectrometry method. The obtained data were compared with the background concentration of HM for Dnipropetrovsk oblast and the results of analyzing the reference control located at a distance of 250 m from the railway stations. **Findings.** It is found out that rail transport is a source of HM emission into soil. The findings indicate that the soil state of the Kamianske-Pasazhyrske station corresponds to a low ecological risk and a low degree of pollution, since the station is a passenger one only and pollution occurs mostly due to the friction of wheels and rails and that of the pantograph and overhead system, as well as the pesticide use. The soil contamination of the Zaporizhzhia-Kamianske station is characterized by a considerable potential environmental risk and a very high degree of pollution. This station is a cargo-passenger one, and this pollution level is mainly due to loading and unloading processes. The soil of the Trytuzna station is characterized by an average potential ecological risk and a moderate degree of pollution. Although this station is mainly used for the freight trains reformation, but due to the transportation of large volumes of bulk ore cargoes HM fall into soil. Besides, the station is not electrified. Recommendations for assessment of the soil pollution levels are given. **Originality.** For the first time the potential ecological risk of soil contamination was determined on the basis of the physical and chemical analysis of the HM content in the soil of the above-mentioned stations. **Practical value.** The results of the study can be used as a justification of the reasonability of introducing the environmental monitoring programs for the railway land, the environmental protection measures for the soil treatment from HM, correcting the railway exclusion zone, as well as protection of adjacent territories from the propagation and accumulation of the mentioned pollutants. The necessity and urgency of the constant control of the HM content in the railway soil and the relevance of the research continuation in this scientific direction are confirmed on the basis of the received data.

**Keywords:** heavy metals; railway transport; soil, railway stations, potential environmental risk

## Introduction

Rail transport operation has a negative influence on the environmental quality. This influence can be seen in the environmental contamination with both organic (oil products, polycyclic aromatic hydrocarbons, polychlorinated biphenyls), and inorganic substances (heavy metals, SO<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>2</sub>, etc.).

Studies devoted to railway transport as a factor of environmental pollution confirm the hypothesis that this mode of transport can bring to soil such persistent and dangerous pollutants as heavy metals (hereinafter – HM) [1, 4-7, 10-14, 17-20].

HM concentration in soil samples taken in the space between rails may exceed the benchmarks ten times. For example, the study of Polish scientists demonstrates the following HM concentration in the soil of the Ława Główna railway junction, mg/kg: in the area of sidings Pb – 448<sup>1</sup>/494<sup>2</sup>; Cd – 5,4<sup>1</sup>/5,1<sup>2</sup>; Cu – 191<sup>1</sup>/161<sup>2</sup>; Zn – 1264<sup>1</sup>/1223<sup>2</sup>; Hg – 0,573<sup>1</sup>/0,969<sup>2</sup>; Fe – 44800<sup>1</sup>/39700<sup>2</sup>; Co – 9<sup>1</sup>/8<sup>2</sup>; Cr – 67<sup>1</sup>/58<sup>2</sup>; Mo – 2<sup>1</sup>/2<sup>2</sup> (<sup>1</sup> – between rails, <sup>2</sup> – outside rails) [13]. The HM content indicators in three reference sites mg/kg: Pb – 1<sup>a</sup>/2<sup>b</sup>/3<sup>c</sup>; Cd – n.d.<sup>a</sup>/n.d.<sup>b</sup>/n.d.<sup>c</sup>; Cu – 4<sup>a</sup>/4<sup>b</sup>/4<sup>c</sup>; Zn – 23<sup>a</sup>/23<sup>b</sup>/18<sup>c</sup>; Hg – 0,014<sup>a</sup>/0,05<sup>b</sup>/0,013<sup>c</sup>; Fe – 4400<sup>a</sup>/4500<sup>b</sup>/5000<sup>c</sup>;

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

Co – 1<sup>a</sup>/1<sup>b</sup>/2<sup>c</sup>; Cr – 5<sup>a</sup>/6<sup>b</sup>/8<sup>c</sup>; Mo – n.d.<sup>a</sup>/n.d.<sup>b</sup>/1<sup>c</sup>. n.d. – not detected, <sup>a</sup> – 500 m southwest from the railway junction, <sup>b</sup> – 500 m to the southeast, <sup>c</sup> – 2 km to the east [13].

The obtained data demonstrate the significant content of iron, which is natural for railway transport, lead, cadmium, copper and zinc, which may indicate specificity of the cargoes transported, loaded and unloaded at this station.

Another study, conducted by Kajetan Dzierżanowski and Stanisław W. Gawronski also confirms the assumption that railway transport plays a significant part in the HM accumulation in soil and plants. The study was conducted *in situ* at the Warsaw-Otwock railway connection using the X-ray fluorescent spectrometer [11]. The authors compare the obtained results with the permissible levels of HM concentration in the surface layer for transport lands, mg/kg approved in Poland [11]. Table 1 presents the results of Kajetan Dzierżanowski and Stanisław W. Gawronski's investigation and the permissible levels of HM concentration in Poland, approved in 2002.

Table 1

**HM concentration in surface layer of the Warsaw-Otwock railway ground and permissible levels of HM concentration**

| HM | Concentration, mg/kg | Standard deviation, mg/kg | Permissible concentration levels of HM |
|----|----------------------|---------------------------|----------------------------------------|
| Ba | 1 092.1              | 299.1                     | 1000                                   |
| Cr | 1 108.4              | 331.4                     | 500                                    |
| Zn | 142.4                | 17.7                      | 1 000                                  |
| Cu | 894.3                | 41.5                      | 600                                    |
| Mn | 1 528.9              | 160.9                     | –                                      |
| Mo | 18.0                 | 4.0                       | 250                                    |
| Ni | 588.1                | 101.1                     | 300                                    |
| Pb | 65.0                 | 8.3                       | 600                                    |
| Hg | 25.3                 | 6.0                       | 30                                     |
| Fe | 196 112.7            | 3 909.8                   | –                                      |

The presented data show the high content of such metals as barium, chromium, copper, nickel, mercury and iron typical of railways. It should be noted that it is difficult to assess the degree of the railway operation influence on the HM accumulation without

comparing the obtained data with those at the referent sites or background concentration. It can only be concluded that the approved standards for Ba, Cr, Cu and Ni have been exceeded.

However, the data on the HM accumulation in plants in the area adjacent to the Warsaw-Otwock railway junction is of greater interest. For example, *Viola arvensis* accumulates approximately 230 mg/kg Zn, *Vicia cracca* –  $\approx$  30 mg/kg Mo, *Cerastium dubium* –  $\approx$  160 mg/kg Cu, 400 mg/kg Mn, 8 mg/kg Pb, 34000 mg/kg Fe [11]. This, in turn, confirms the railway transport influence on the HM introduction and accumulation both in the soil of adjacent territories and in plants that grow there.

According to the results of chemical analysis of the soil samples from the Białystok Fabryczny, Siemianówka and Waliły railway stations in 2015 [20], the pollution levels appear to be much lower than in previous studies. However, the soil biotesting shows significant toxicity of the soil of the Białystok Fabryczny and Siemianówka stations [20]. The information is given in Table 2.

Table 2

**Results of chemical analysis of the soil samples from the Białystok Fabryczny, Siemianówka and Waliły railway stations**

| HM | Station             |             |            |
|----|---------------------|-------------|------------|
|    | Białystok Fabryczny | Siemianówka | Waliły     |
| Zn | 130 ± 10.4          | 75 ± 6.0    | 106 ± 8.58 |
| Cu | 107 ± 16.1          | 27 ± 4.1    | 46 ± 6.9   |
| Pb | 153 ± 27.5          | 20 ± 3.6    | 27 ± 4.9   |
| Ni | 14 ± 3.4            | 17 ± 4.1    | 52 ± 12.5  |
| Hg | 0.06 ± 0.01         | <0.05       | <0.05      |
| Cd | <0.70               | <0.70       | <0.70      |
| Cr | 25 ± 5.3            | 15 ± 3.2    | 70 ± 14.7  |

It is important the fact that at present in Ukraine there are no legally approved permissible levels of HM concentration for transport and communication lands, industry and urban territories.

As for the HM sources at railway transport, they are, in the first place, cargo transportation, its dispersing, scattering and spilling on the track and adjacent territories [1, 5–7, 10–14, 19]. For example, the total amount of losses during the transportation of mineral fertilizers in bulk in covered cars

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

is up to 8%, in gondola cars up to 28%. When transported in multi-purpose cars annually up to 7% of ore and 3% of cement are lost [7].

According to the State Statistics Service of Ukraine [3], the railway transport ranks first in terms of cargo transportation volumes. The Tables 3 and 4 show the cargo turnover, volumes of cargo transportation in 2017, and transportation of various types of cargo by rail in 2017, respectively.

Other sources of HM at railway transport:

– friction in systems: wheel-brake blocks,

wheel-rail, pantograph-contact wire, bearings [5–7, 10–14, 18, 19];

– use of herbicides [7, 13];

– coal heating of cars [5–7];

– exhaust gases of locomotive engines [5–7, 10, 12];

– migration from wooden and ferro-concrete sleepers, from rubble and ballast section materials [5–8, 10, 14];

– garbage discarded from trains and on platforms.

Table 3

**Cargo turnover and volumes of cargo transportation in 2017**

|            | Cargo turnover |               | Volume of transported cargoes |               |
|------------|----------------|---------------|-------------------------------|---------------|
|            | mln. tkm       | in % to 2016. | mln.t                         | in % up 2016. |
| Transport  | 343 057.1      | 105.8         | 635.9                         | 101.8         |
| railway    | 191 914.1      | 102.3         | 339.5                         | 98.9          |
| automobile | 41 178.8       | 108.4         | 175.6                         | 104.7         |
| water      | 4 257.1        | 106.3         | 5.9                           | 88.1          |
| pipeline   | 105 434.4      | 111.7         | 114.8                         | 107.6         |
| air        | 272.7          | 120.5         | 0.1                           | 110.5         |

Table 4

**Cargo transportation in 2017**

|                                   | Performed, mln.t | In % to 2016. |
|-----------------------------------|------------------|---------------|
| Transported cargoes               | 339.5            | 98.9          |
| dispatched                        | 277.3            | 94.9          |
| According to freight nomenclature |                  |               |
| coal                              | 43.9             | 76.2          |
| coke                              | 5.0              | 70.8          |
| oil and petroleum products        | 3.8              | 115.3         |
| iron ore and manganese ore        | 64.9             | 93.5          |
| ferrous metals                    | 20.8             | 82.4          |
| ferrous scrap                     | 3.1              | 114.9         |
| timber cargo                      | 2.8              | 66.8          |
| chemical and mineral fertilizers  | 3.5              | 84.2          |
| grains and grinding products      | 35.7             | 111.8         |
| cement                            | 5.9              | 101.0         |
| construction material             | 41.2             | 116.5         |
| other cargoes                     | 46.7             | 118.0         |

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

Moreover, the HM accumulation in soil during the railway operation is influenced by a wide range of factors: intensity and speed of train movement; age of the railway and degree of its operation; initial braking speed, braking length; the nature and volumes of transported cargoes; weather conditions; relief; granulometric and chemical content of soil; vegetative cover.

Therefore, the HM content in the railway infrastructure soil can differ considerably and vary widely. Accordingly, the study of the railway transport influence on the HM emission into the soil is an important direction of scientific research.

### Purpose

The main purpose of the article is analyzing the current state of the railway infrastructure soil contamination with HM; assessing and determining the rail transport share in the problem of the HM accumulation in soil.

In order to achieve the purpose, the following stages are realized: literary review of the problem; analytical assessment of soil contamination levels of railway stations with heavy metals; calculations of total contamination and potential environmental risks of soil contamination with HM; development of recommendations for further monitoring the toxicological state of soil.

### Methodology

The research object is the soil of the three railway stations of Prydniprovsk railway:

1) passenger station – Kamianske-Pasazhyske, year of opening 1965, electrified (hereinafter – «KP» station);

2) freight-passenger station – Zaporizhzhia-Kamianske, year of opening 1884, electrified (hereinafter – «KZ» station);

3) freight station – Trytuzna, year of opening 1884, non-electrified (hereinafter station «T»).

The research subject is the total content of HM. Determining the total forms are enough for the space between tracks, since the moving ones play a minor role in this case, there is no migration in the «soil-plant» and «soil-plant-man» chains.

The sampling scheme is shown in Figure 1. Sampling was carried out every 15 m between (1) and outside both rails (2). The weight of each sample is 250-300 g, the depth of sampling is 0-20 cm. The total area of the investigated sites is 600 m<sup>2</sup>. The principle of the sampling choice is determined by the fact that the stations are surrounded by buildings and the HM distribution at different distances cannot be assessed.

The reference sites are at a distance 250 m from each station. The sampling was carried out using the «envelope» method.

Figure 2 shows the places of the soil sampling. It was carried out at the end of August 2017 in dry, hot weather.

The HM concentration in station soil was determined by the atomic-adsorption method. Total forms of HM were extracted with nitric acid (1:1). The HM content in the studied soil samples was calculated using the formula (1):

$$X = V \cdot (C_1 - C_0) / m$$

where  $X$  – is the mass fraction of the  $i$ -th metal, determined in the air-dry soil sample, mg/kg;  $C_1$  – is the concentration of the  $i$ -th metal in the studied acid extract of soil, found according to the calibration graph, mg/dm<sup>3</sup>;  $C_0$  – is the concentration of the  $i$ -th metal in the control sample found according to the calibration graph, mg/dm<sup>3</sup>;  $V$  – is the volume of the investigated solution, cm<sup>3</sup>;  $m$  – is the weight of the air-dry soil sample, g.

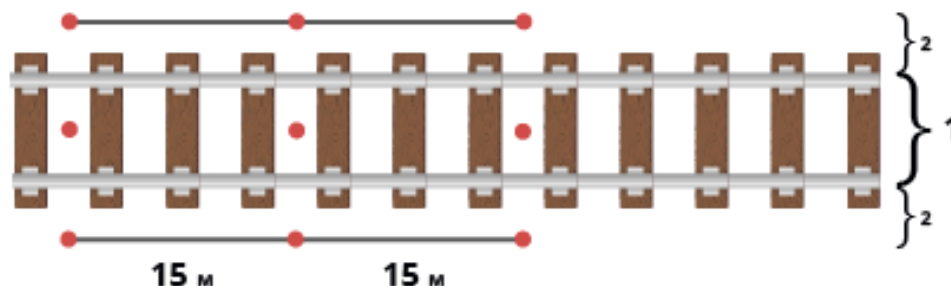


Fig. 1. The scheme of sampling at railway stations  
1 – the area of sampling between rails, 2 – the area of sampling outside both rails

## ЕКОЛОГІЯ НА ТРАНСПОРТІ



Fig. 2. The sampling sites at the station Kamianske-Pasazhyrske

In order to assess the level of the HM accumulation in soil, we calculated a total contamination index  $Z_c$ , which reflects the complex influence of the whole group of elements and is determined as the additive sum of the excess of elements concentration coefficient above the background level using formula 2 [2]:

$$Z_c = \sum_{i=1}^n Kc - (n-1) \quad (2)$$

where  $n$  – is the number of elements under consideration,  $Kc$  – is the coefficient of concentration (accumulation), the ratio of actual concentration to background content [2].

Although this methodology is used in many works related to the assessment of HM accumulation in soil, the disadvantage of the  $Z_c$  indicator is that it does not reflect the toxicity of each metal, therefore, it is advisable to use such an indicator as  $RI$  – potential environmental risk of soil contamination, which is determined by the formula 3 [9, 15, 16]:

$$RI = \sum E_i \quad (3)$$

where  $Ei$  – is a risk factor for the  $i$ -th HM,

$$E_i = T_i f_i = T_i \frac{C_i}{S_i} \quad (4)$$

where  $T_i$  – is the factor reflecting the toxicity of the  $i$ -th HM and the degree of environmental sensitivity to this metal, the values of  $T_i$  for Hg, Cd, As, Ni, Cu, Pb, Cr, Zn and Mn are 40, 30, 10, 5, 5, 5, 2, 1 and 1, respectively;  $f_i$  – is the ratio of the actual concentration of HM, ( $C_i$ ) to its background content ( $S_i$ ) [9, 15, 16]. Classifications of  $Z_c$  and  $RI$  are presented in the Tables 5 and 6.

Table 5

**Classification of the total soil contamination index  $Z_c$** 

| Contamination degree | $Z_c$  |
|----------------------|--------|
| very low             | < 8    |
| low                  | 8–16   |
| moderate             | 16–32  |
| high                 | 32–64  |
| very high            | 64–128 |
| extremely high       | > 128  |

Table 6

**Classification of potential ecological risk of soil contamination**

| $Ei$                | Individual     | $RI$                | General     |
|---------------------|----------------|---------------------|-------------|
| $Ei \leq 40$        | Low            | $RI \leq 150$       | Low         |
| $40 < Ei \leq 80$   | Average        | $150 < RI \leq 300$ | Average     |
| $80 < Ei \leq 160$  | Significant    | $300 < RI \leq 600$ | Significant |
| $160 < Ei \leq 320$ | High           | $RI > 600$          | Very high   |
| $Ei > 320$          | Extremely high |                     |             |

**Findings**

The research results are presented in Table 7. We determined the concentration of total forms of Mn, Cu, Zn, Ni, Pb, Cd, and Fe in the soil of «KP», «ZK», «T» stations and at the three refer-

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

ence sites where the anthropogenic influence is quite insignificant.

The given data across the board exceed the reference indexes and the background concentration, which shows the direct railway transport influence on the HM accumulation in soil.

The obtained results indicate that the soil state of the «KP» station corresponds to a low ecological risk and a low degree of contamination, since it is a passenger station only and pollution occurs mostly due to the friction of wheels and rails, that of the pantograph and contact wire, as well as the herbicide use.

The soil contamination of the «ZK» station is characterized by a significant potential environmental risk and a very high degree of pollution. This station is a freight-passenger one and the pollution level is mainly due to the loading and unloading processes.

The soil of the «T» station is characterized by an average potential environmental risk and a moderate degree of pollution. Although this station is used for the freight trains reformation, but due to transporting large volumes of bulk ore cargoes HM fall into the station soil. Moreover, the station is not electrified.

### Originality and practical value

For the first time the potential ecological risk of soil contamination was determined on the basis of the physical-chemical analysis of the HM content in the soil of the «KP», «ZK» and «T» stations. The obtained data prove the necessity and urgency of constant monitoring the HM content in the railway infrastructure soil.

The results of the study can be used as a justification of the reasonability of introducing the environmental monitoring programs for the railway lands, the environmental protection measures for the soil treatment from HM, protection of the territories adjacent to railway from the propagation and accumulation of the mentioned pollutants as well as correcting the railway exclusion zone

### Conclusions

Taking into consideration the fact that the railway transport operation can lead to the significant level of the soil contamination with HM, which exceeds the regulatory one, it is necessary to develop recommendations for non-purpose (agricultural) use of land sites within the damping zone of railways.

According to the presented data, differentiating the railway mainline zones with high pollution indicators was carried out and the recommendations on the measures for decontamination and detoxification of the railway infrastructure soil were developed.

We recommend to calculate the  $Z_c$  and RI indices for assessing the levels of soil contamination, as well as to determine the HM concentration at the reference sites, since the use of background concentration for comparison generates many questions and concerns, although it is used by many researchers. And as a final stage of assessment we suggest carrying out biotesting, which demonstrates the toxic influence (or its absence) of the investigated soil on plants, crustaceans, bacteria and other living organisms.

Table 7

General indicator of contamination and the potential ecological risk of stations soil pollution

| Stations and indicators according to the methodology | Heavy metal concentration, mg/kg       |     |          |     |          |     |          |     |          |      |         |     |              |        |
|------------------------------------------------------|----------------------------------------|-----|----------|-----|----------|-----|----------|-----|----------|------|---------|-----|--------------|--------|
|                                                      | Mn (600*)                              |     | Cu (20*) |     | Zn (30*) |     | Ni (10*) |     | Pb (10*) |      | Cd (1*) |     | Fe (22 000*) |        |
|                                                      | 1                                      | 2   | 1        | 2   | 1        | 2   | 1        | 2   | 1        | 2    | 1       | 2   | 1            | 2      |
| «KP»                                                 | 654                                    | 670 | 61       | 60  | 178      | 170 | 32       | 31  | 40       | 35   | 1.5     | 1.5 | 35 670       | 35 660 |
| Kc                                                   | 1.1                                    | 1.1 | 3.1      | 3.0 | 5.9      | 5.7 | 3.2      | 3.2 | 4.0      | 3,5  | 1.5     | 1.5 | 1,6          | 1.6    |
| E <sub>i</sub>                                       | 1.1                                    | 1.1 | 15.2     | 15  | 5.9      | 5.7 | 16       | 16  | 20       | 17.5 | 45      | 45  | 1.6          | 1.6    |
| RI                                                   | 103.35 – low potential ecological risk |     |          |     |          |     |          |     |          |      |         |     |              |        |
| Z <sub>c</sub>                                       | 14 – low contamination degree          |     |          |     |          |     |          |     |          |      |         |     |              |        |

**General indicator of contamination and the potential ecological risk of stations soil pollution**

| Stations and indicators according to the methodology | Heavy metal concentration, mg/kg                     |       |                                                |      |                                                   |      |                                                |      |                                                 |      |                                                       |     |                                                         |        |
|------------------------------------------------------|------------------------------------------------------|-------|------------------------------------------------|------|---------------------------------------------------|------|------------------------------------------------|------|-------------------------------------------------|------|-------------------------------------------------------|-----|---------------------------------------------------------|--------|
|                                                      | Mn (600*)                                            |       | Cu (20*)                                       |      | Zn (30*)                                          |      | Ni (10*)                                       |      | Pb (10*)                                        |      | Cd (1*)                                               |     | Fe (22 000*)                                            |        |
|                                                      | 1                                                    | 2     | 1                                              | 2    | 1                                                 | 2    | 1                                              | 2    | 1                                               | 2    | 1                                                     | 2   | 1                                                       | 2      |
| «ZK»                                                 | 2 220                                                | 2 220 | 456                                            | 476  | 678                                               | 656  | 111                                            | 115  | 340                                             | 324  | 4                                                     | 4   | 61 860                                                  | 61 230 |
| Kc                                                   | 3.7                                                  | 3.7   | 22.8                                           | 23.8 | 22.6                                              | 21.8 | 11.1                                           | 11.5 | 34                                              | 32.4 | 4                                                     | 4   | 2.8                                                     | 2.8    |
| E <sub>i</sub>                                       | 3.7                                                  | 3.7   | 114                                            | 119  | 22.6                                              | 21.8 | 55.5                                           | 57.5 | 170                                             | 162  | 120                                                   | 120 | 2.8                                                     | 2.8    |
| RI                                                   | 487.7 – significant potential ecological risk        |       |                                                |      |                                                   |      |                                                |      |                                                 |      |                                                       |     |                                                         |        |
| Z <sub>c</sub>                                       | 94.5 – very high contamination degree                |       |                                                |      |                                                   |      |                                                |      |                                                 |      |                                                       |     |                                                         |        |
| «T»                                                  | 710                                                  | 715   | 75                                             | 67   | 180                                               | 179  | 63                                             | 65   | 150                                             | 130  | 2                                                     | 2   | 48 700                                                  | 48 705 |
| Kc                                                   | 1.18                                                 | 1.19  | 3.75                                           | 3.35 | 6                                                 | 6    | 6.3                                            | 6.5  | 15                                              | 13   | 2                                                     | 2   | 2.2                                                     | 2.2    |
| E <sub>i</sub>                                       | 1.18                                                 | 1.19  | 18.8                                           | 16.8 | 6                                                 | 6    | 31.5                                           | 32.5 | 75                                              | 65   | 60                                                    | 60  | 2.2                                                     | 2.2    |
| RI                                                   | 189.14 – average potential ecological risk           |       |                                                |      |                                                   |      |                                                |      |                                                 |      |                                                       |     |                                                         |        |
| Z <sub>c</sub>                                       | 29.3 – moderate contamination degree                 |       |                                                |      |                                                   |      |                                                |      |                                                 |      |                                                       |     |                                                         |        |
| Reference sites                                      | 340 <sup>1</sup> /240 <sup>2</sup> /300 <sup>3</sup> |       | 6 <sup>1</sup> /5 <sup>2</sup> /6 <sup>3</sup> |      | 23 <sup>1</sup> /30 <sup>2</sup> /40 <sup>3</sup> |      | 7 <sup>1</sup> /6 <sup>2</sup> /7 <sup>3</sup> |      | 10 <sup>1</sup> /8 <sup>2</sup> /5 <sup>3</sup> |      | 0.5 <sup>1</sup> /0.3 <sup>2</sup> /n.d. <sup>3</sup> |     | 2340 <sup>1</sup> /3078 <sup>2</sup> /1460 <sup>3</sup> |        |

\* – background HM content in soil of Dnipropetrovsk oblast

1, 2, 3 – benchmarks of the HM content for the «KP», «ZK» and «T» stations, respectively.

## LIST OF REFERENCE LINKS

- Бобрик, Н. Ю. Поширення та акумуляція важких металів у ґрунтах призалізничних територій / Н. Ю. Бобрик // Вісн. Дніпропетр. ун-ту. Серія: Біологія. Екологія. – 2015. – Вип. 23 (2). – С. 183–189. doi: 10.15421/011526
- Дабахов, М. В. Тяжелые металлы: Экотоксикология и проблемы нормирования : монография / М. В. Дабахов, Е. В. Дабахова, В. И. Титова. – Нижний Новгород : ВВАГС, 2005. – 165 с.
- Державна служба статистики України [Electronic resource]. – Available at: <http://www.ukrstat.gov.ua> – Title from the screen. – Accessed : 23.07.2018.
- Журавлева, М. А. Загрязнение придорожной зоны тяжелыми металлами / М. А. Журавлева, Н. И. Зубрев, С. М. Кокин // Мир транспорта. – 2014. – Т. 12, № 6. – С. 174–178.
- Зеленько, Ю. В. Проблема забруднення важкими металами смуги відводу залізниць / Ю. В. Зеленько, А. В. Самарська // Заліз. трансп. України. – 2014. – № 5 (108). – С. 51–53.
- Казанцева, М. Ю. Железнодорожный транспорт как источник загрязнения окружающей среды / М. Ю. Казанцева, Д. А. Зибарева // Самарский научный вестник. – 2014. – № 4 (9) – С. 54–56.
- Казанцев, И. В. Железнодорожный транспорт как источник загрязнения почв тяжелыми металлами / И. В. Казанцев // Самарский научный вестник. – 2015. – № 2 (11). – С. 94–96.
- Крошечкина, И. Ю. Комплексная оценка загрязнения балластного слоя железнодорожного полотна / И. Ю. Крошечкина, Н. И. Зубрев // XXI век: итоги прошлого и проблемы настоящего плюс. – 2014. – № 1 (17). – С. 100–102.
- Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization / Y. Hu, X. Liu, J. Bai, K. Shih, E. Y. Zeng, H. Cheng // Environmental Science and Pollution Research. – 2013. – Vol. 20. – Iss. 9. – P. 6150–6159. doi: 10.1007/s11356-013-1668-z
- Does the Function of Railway Infrastructure Determine Qualitative and Quantitative Composition of Contaminants (PAHs, Heavy Metals) in Soil and Plant Biomass? / M. Mętrak, M. Chmielewska, B. Sudnik-

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

- Wójcikowska, B. Wiłkomirski, T. Staszewski, M. Suska-Malawska // *Water, Air, & Soil Pollution*. – 2015. – Vol. 226. – Iss. 8. doi: 10.1007/s11270-015-2516-1
11. Dzierżanowski, K. Heavy metal concentration in plants growing on the vicinity of railroad tracks: a pilot study / K. Dzierżanowski, S. W. Gawroński // *Challenges of Modern Technology*. – 2012. – Vol. 3, No. 1. – P. 42–45.
  12. Railway Tracks – Habitat Conditions, Contamination, Floristic Settlement – A Review / B. Wiłkomirski, H. Galera, B. Sudnik-Wójcikowska, T. Staszewski, M. Malawska // *Environment and Natural Resources Research*. – 2012. – Vol. 2, No. 1. – P. 86–95. doi: 10.5539/enrr.v2n1p86
  13. Railway transportation as a serious source of organic and inorganic pollution / B. Wiłkomirski, B. Sudnik-Wójcikowska, H. Galera, M. Wierzbicka, M. Malawska // *Water, Air, & Soil Pollution*. – 2010. – Vol. 218. – Iss. 1-4. – P. 333–345. doi: 10.1007/s11270-010-0645-0
  14. Soil and plants contamination with selected heavy metals in the area of a railway junction / T. Staszewski, M. Malawska, B. Studnik-Wójcikowska, H. Galera, B. Wiłkomirski // *Archives of Environmental Protection*. – 2015. – Vol. 41, No. 1. – P. 35–42. doi: 10.1515/aep-2015-0005
  15. Soil Heavy Metal Pollution and Risk Assessment in Shenyang Industrial District, Northeast China / X. Jiao, Y. Teng, Y. Zhan, J. Wu, X. Lin // *Plos One*. – 2015. – Vol. 10. – Iss. 5. – P. e0127736. doi: 10.1371/journal.pone.0127736
  16. Soliman, N. F. Potential ecological risk of heavy metals in sediments from the Mediterranean coast, Egypt / N. F. Soliman, S. M. Nasr, M. A. Okbah // *Journal of Environmental Health Science and Engineering*. – 2015. – Vol. 13. – Iss. 1. doi: 10.1186/s40201-015-0223-x
  17. The effects of railway transportation on the enrichment of heavy metals in the artificial soil on railway cut slopes / Z. Chen, K. Wang, Y. W. Ai, W. Li, H. Gao, C. Fang // *Environmental Monitoring and Assessment*. – 2013. – Vol. 186. – Iss. 2. – P. 1039–1049. doi: 10.1007/s10661-013-3437-3
  18. The effects of the Qinghai–Tibet railway on heavy metals enrichment in soils / H. Zhang, Z. Wang, Y. Zhang, Z. Hu // *Science of the Total Environment*. – 2012. – Vol. 439. – P. 240–248. doi: 10.1016/j.scitotenv.2012.09.027
  19. The selected trace elements in soil of railway stations in north-eastern Poland / B. Wiłkomirski, M. Suska-Malawska, B. Sudnik-Wójcikowska, T. Staszewski // *Rocznik Świętokrzyski. Ser. B – Nauki Przyr.* – 2013. – T. 34. – P. 171–180.
  20. Wierzbicka, M. Multidimensional evaluation of soil pollution from railway tracks / M. Wierzbicka, O. Bemowska-Kalabun, B. Gworek // *Ecotoxicology*. – 2015. – Vol. 24. – Iss. 4. – P. 805–822. doi: 10.1007/s10646-015-1426-8

A. B. САМАРСЬКА<sup>1\*</sup>, Ю. В. ЗЕЛЕНЬКО<sup>2</sup>

<sup>1\*</sup>Каф. «Хімія та інженерна екологія», Дніпропетровський національний університет залізничного транспорту імені академіка В. Лазаряна, вул. Лазаряна, 2, Дніпро, Україна, 49010, тел. +38 (097) 091 74 51, ел. пошта samarskaya.av@gmail.com, ORCID 0000-0002-0828-9457

<sup>2</sup>Каф. «Хімія та інженерна екологія», Дніпропетровський національний університет залізничного транспорту імені академіка В. Лазаряна, вул. Лазаряна, 2, Дніпро, Україна, 49010, тел. +38 (067) 774 04 64, ел. пошта j.v.zelenko@gmail.com, ORCID 0000-0001-5551-0305

## ОЦІНКА ВПЛИВУ ЗАЛІЗНИЧНОГО ТРАНСПОРТУ НА НАКОПИЧЕННЯ ВАЖКИХ МЕТАЛІВ У ҐРУНТАХ

**Мета.** Наукова стаття має за мету аналіз сучасного стану забруднення важкими металами (ВМ) ґрунтів залізничної інфраструктури, а саме трьох станцій Придніпровської залізниці: Кам'янське–Пасажирське, Запоріжжя–Кам'янське й Тритузна. **Методика.** Об'єкт дослідження – ґрунти вищезазначених залізничних станцій, предмет – валовий вміст ВМ. Відбір проб здійснювався кожні 15 м між рейками та поза ними з обох сторін. Загальна площа досліджуваних територій – 600 м<sup>2</sup>. Методом атомно-абсорбційної спектроскопії визначено концентрації валових форм Fe, Pb, Zn, Cu, Ni, Cd та Mn. Отримані дані порівнювались із фоновими концентраціями ВМ для Дніпропетровської області та з результатами аналізу контрольних ділянок, що знаходились на відстані 250 м від залізничних станцій. **Результати.** Встановлено, що залізничний транспорт є джерелом надходження ВМ у ґрунти. Отримані результати вказують на те, що стан ґрунтів станції Кам'янське–Пасажирське відповідає низькому екологічному ризику й слабкому ступеню

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

забруднення, оскільки станція є тільки пасажирською, і забруднення відбувається за рахунок тертя коліс та рейок, пантографа об контактну мережу, а також використання пестицидів. Забруднення ґрунтів станції Запоріжжя–Кам'янське відрізняється значним потенційним екологічним ризиком і дуже сильним ступенем забруднення. Ця станція є вантажно-пасажирською, і такий рівень забруднення є здебільшого наслідком процесів завантаження й розвантаження. Ґрунти станції Тритузна характеризуються середнім потенційним екологічним ризиком та помірним ступенем забруднення. На цій станції відбувається переформування товарних поїздів, але за рахунок перевезення значних обсягів сипучих рудних вантажів у ґрунти станції потрапляють ВМ. Крім того, станція неелектрифікована. Надано рекомендації щодо оцінки рівнів забруднення ґрунтів. **Наукова новизна.** Вперше на базі проведеного фізико-хімічного аналізу вмісту ВМ ґрунтах вищезазначених станцій визначено потенційний екологічний ризик забруднення ґрунтів. **Практична значимість.** Результати дослідження можуть бути використані як обґрунтування доцільності впровадження програм екологічного моніторингу для земель залізничного транспорту, природоохоронних заходів із очищення ґрунтів від ВМ, коригування зони відчуження залізниць і захисту прилеглих територій від розповсюдження та акумуляції цих політантів. На основі отриманих даних доведена необхідність постійного контролю вмісту ВМ у ґрунтах залізничної інфраструктури й актуальність продовження досліджень у даному науковому напрямку.

*Ключові слова:* важкі метали; залізничний транспорт; ґрунти; залізничні станції; потенційний екологічний ризик

А. В. САМАРСЬКА<sup>1\*</sup>, Ю. В. ЗЕЛЕНЬКО<sup>2</sup>

<sup>1\*</sup>Каф. «Химия и инженерная экология», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днипро, Украина, 49010, тел. +38 (097) 091 74 51, эл. почта samarskaya.av@gmail.com, ORCID 0000-0002-0828-9457

<sup>2</sup>Каф. «Химия и инженерная экология», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днипро, Украина, 49010, тел. +38 (067) 774 04 64, эл. почта j.v.zelenko@gmail.com, ORCID 0000-0001-5551-0305

## ОЦЕНКА ВЛИЯНИЯ ЖЕЛЕЗНОДОРОЖНОГО ТРАНСПОРТА НА НАКОПЛЕНИЕ ТЯЖЕЛЫХ МЕТАЛЛОВ В ГРУНТАХ

**Цель.** Научная статья своей целью имеет анализ современного состояния загрязнения ґрунтов железнодорожной инфраструктуры тяжелыми металлами (ТМ), а именно трех станций Приднепровской железной дороги: Каменское–Пассажирское, Запорожье–Каменское и Тритузная. **Методика.** Объект исследования – ґрунты вышеупомянутых железнодорожных станций, предмет – валовое содержание ТМ. Отбор проб осуществлялся каждые 15 м между рельсами и за ними с обеих сторон. Общая площадь исследуемых территорий – 600 м<sup>2</sup>. Методом атомно-абсорбционной спектрометрии определены валовые концентрации Fe, Pb, Zn, Cu, Ni, Cd и Mn. Полученные данные сравнивались с фоновыми концентрациями ТМ для Днепропетровской области и результатами анализа контрольных участков, находящихся на расстоянии 250 м от железнодорожных станций. **Результаты.** Установлено, что железнодорожный транспорт является источником поступления ТМ в ґрунты. Полученные результаты указывают на то, что состояние ґрунтов станции Каменское–Пассажирское соответствует низкому экологическому риску и слабой степени загрязнения, поскольку станция является только пассажирской, и загрязнение происходит за счет трения колес и рельсов, пантографа о контактную сеть, а также использования пестицидов. Загрязнение ґрунтов станции Запорожье–Каменское отличается значительным потенциальным экологическим риском и очень сильной степенью загрязнения. Эта станция является грузопассажирской, и такой уровень загрязнения является в большей степени следствием процессов загрузки и разгрузки. Ґрунты станции Тритузная характеризуются средним потенциальным экологическим риском и умеренной степенью загрязнения. На этой станции происходит переформирование товарных поездов, но за счет перевозки значительных объемов сыпучих рудных грузов в ґрунты станции попадают ТМ. Кроме того, станция неэлектрифицирована. Даны рекомендации по оценке уровней загрязнения почв. **Научная новизна.** Впервые на основе проведенного физико-химического анализа содержания ТМ в ґрунтах вышеупомянутых станций определены потенциальные экологические риски загрязнения ґрунтов. **Практическая значимость.** Результаты исследования могут быть использованы в качестве обоснования целесообразности внедрения программ экологического мониторинга для земель железнодорожного транспорта, природоохранных мероприятий по очистке ґрунтов от ТМ, корректировки зоны от-

## ЕКОЛОГІЯ НА ТРАНСПОРТІ

чуждения железных дорог и защиты прилегающих территорий от распространения и аккумуляции этих поллютантов. На основе полученных данных доказана необходимость постоянного контроля содержания ТМ в грунтах железнодорожной инфраструктуры и актуальность продолжения исследований в данном научном направлении.

**Ключевые слова:** тяжелые металлы; железнодорожный транспорт; грунты; железнодорожные станции; потенциальный экологический риск

## REFERENCES

1. Bobryk, N. Y. (2015). Spreading and accumulation of heavy metals in soils of railway-side areas. *Visnyk of Dnipropetrovsk University. Biology, ecology*, 23, 2, 183-189. doi: 10.15421/011526 (in Ukrainian)
2. Dabakhov, M. V., Dabakhova, E. V., & Titova, V. I. (2005). *Tyazhelye metally: Ekotoksikologiya i problemy normirovaniya: Monografiya*. Novgorod: VVAGS. (in Russian)
3. *Derzhavna sluzhba statystyky Ukrainy*. Retrieved from <http://www.ukrstat.gov.ua> (in Ukrainian)
4. Zhuravleva, M. A., Zubrev, N. I., & Kokin, S. M. (2014). Contamination of roadside areas with heavy metals. *Worlds of Transport and Transportation*, 6, 174-181. (in Russian)
5. Zelenko, Y. V., & Samarska, A. V. (2014). Problema zabrudnennia vazhkymy metalamy smuhy vidvodu zaliznyts. *Zaliznychnyi transport Ukrainy*, 5(108), 51-53. (in Ukrainian)
6. Kazantseva, M. Y., & Zibareva, D. A. (2014). Rail transport as a source of environmental pollution. *Samara Journal of Science*, 4(9), 54-56. (in Russian)
7. Kazantsev, I. V. (2015). Rail transport as a source of soil contamination with heavy metals. *Samara Journal of Science, Journal of Science*, 2(11), 94-96. (in Russian)
8. Kroshechkina, I. Y., & Zubrev, N. I. (2014). Kompleksnaya otsenka zagryazneniya ballastnogo sloya zheleznodorozhnogo polotna. *XXI vek: itogi proshlogo i problemy nastoyashchego plyus*, 1(17), 100-102. (in Russian)
9. Hu, Y., Liu, X., Bai, J., Shih, K., Zeng, E. Y., & Cheng, H. (2013). Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization. *Environmental Science and Pollution Research*, 20, 9, 6150-6159. doi: 10.1007/s11356-013-1668-z (in English)
10. Mętrak, M., Chmielewska, M., Sudnik-Wójcikowska, B., Wiłkomirski, B., Staszewski, T., & Suska-Malawska, M. (2015). Does the Function of Railway Infrastructure Determine Qualitative and Quantitative Composition of Contaminants (PAHs, Heavy Metals) in Soil and Plant Biomass? *Water, Air, & Soil Pollution*, 226, 8, 1-12. doi: 10.1007/s11270-015-2516-1 (in English)
11. Dzierżanowski, K., & Gawroński, S. W. (2013). Heavy metal concentration in plants growing on the vicinity of railroad tracks: a pilot study. *Challenges of Modern Technology*, 3, 1, 42-45. (in English)
12. Wiłkomirski, B., Galera, H., Sudnik-Wójcikowska, B., Staszewski, T., & Malawska, M. (2012). Railway Tracks – Habitat Conditions, Contamination, Floristic Settlement – A Review. *Environment and Natural Resources Research*, 2, 1, 86-95. doi:10.5539/enrr.v2n1p86 (in English)
13. Wiłkomirski, B., Sudnik-Wójcikowska, B., Galera, H., Wierzbicka, M., & Malawska, M. (2011). Railway transportation as a serious source of organic and inorganic pollution. *Water Air Soil Pollution*, 218, 1-4, 333-345. doi: 10.1007/s11270-010-0645-0 (in English)
14. Staszewski, T., Malawska, M., Studnik-Wójcikowska, B., Galera, H., & Wiłkomirski, B. (2015). Soil and plants contamination with selected heavy metals in the area of a railway junction. *Archives of Environmental Protection*, 41(1), 35-42. doi: <https://doi.org/10.1515/aep-2015-0005> (in English)
15. Jiao, X., Teng, Y., Zhan, Y., Wu, J., & Lin, X. (2015). Soil Heavy Metal Pollution and Risk Assessment in Shenyang Industrial District, Northeast China. *Plos One*, 10(5). doi:10.1371/journal.pone.0127736 (in English)
16. Soliman, N. F., Nasr, S. M., & Okbah, M. A. (2015). Potential ecological risk of heavy metals in sediments from the Mediterranean coast, Egypt. *Journal of Environmental Health Science and Engineering*, 13(1). doi:10.1186/s40201-015-0223-x (in English)
17. Chen, Z., Wang, K., Ai, Y. W., Li, W., Gao, H., & Fang, C. (2013) The effects of railway transportation on the enrichment of heavy metals in the artificial soil on railway cut slopes. *Environ Monit Assess*, 186(2), 1039-1049. doi: 10.1007/s10661-013-3437-3 (in English)
18. Zhang, H., Wang, Z., Zhang, Y., & Hu, Z. (2012). The effects of the Qinghai – Tibet railway on heavy metals enrichment in soils. *Science of the Total Environment*, 439, 240-248. doi: <http://dx.doi.org/10.1016/j.scitotenv.2012.09.027> (in English)

ЕКОЛОГІЯ НА ТРАНСПОРТІ

---

19. Wiłkomirski, B., Suska-Malawska, M., Sudnik-Wójcikowska, B., & Staszewski T. (2013). The selected trace elements in soil of railway stations in north-eastern Poland. *Rocznik Świętokrzyski*, 34, 171-180. (in English)
20. Wierzbicka, M., Bemowska-Kałabun, O., & Gworek, B. (2015). Multidimensional evaluation of soil pollution from railway tracks. *Ecotoxicology*, 24(4), 805-822. doi: 10.1007/s10646-015-1426-8 (in English)

Received: Apr. 26, 2018

Accepted: July 27, 2018