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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 Prydniprovska 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^2. 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_2, CO, CO_2, NO_2, 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 Iława Główna railway junction, mg/kg: in the area of sidings Pb – $448^1/494^2$; Cd – $5{,}4^1/5{,}1^2$; Cu – $191^1/161^2$; Zn – $1264^1/1223^2$; Hg – $0{,}573^1/0{,}969^2$; Fe – $44800^1/39700^2$; Co – $9^1/8^2$; Cr – $67^1/58^2$; Mo – $2^1/2^2$ (^{1} – between rails, ^{2} – outside rails) [13]. The HM content indicators in three reference sites mg/kg: Pb – $1^a/2^b/3^c$; Cd – n.d.^{a}/n.d.^{b}/n.d.^{c}; Cu – $4^a/4^b/4^c$; Zn – $23^a/23^b/18^c$; Hg – $0{,}014^a/0{,}05^b/0{,}013^c$; Fe – $4400^a/4500^b/5000^c$; Co – $1^a/1^b/2^c$; Cr – $5^a/6^b/8^c$; Mo – n.d.^{a}/n.d.^{b}/1^c. n.d.

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– not detected, [a] – 500 m southwest from the railway junction, [b] – 500 m to the southeast, [c] – 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	1092.1	299.1	1000
Cr	1108.4	331.4	500
Zn	142.4	17.7	1000
Cu	894.3	41.5	600
Mn	1528.9	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	196112.7	3909.8	–

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* – ≈ 30 mg/kg Mo, *Cerastium dubium* – ≈ 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 is up to 8%, in gondola cars up to 28%. When transported in multi-purpose cars annually up to

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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	343057.1	105.8	635.9	101.8
railway	191914.1	102.3	339.5	98.9
automobile	41178.8	108.4	175.6	104.7
water	4257.1	106.3	5.9	88.1
pipeline	105434.4	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

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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 Prydniprovska railway:

1) passenger station – Kamianske-Pasazhyrske, 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^2. 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^3; C_0 – is the concentration of the i-th metal in the control sample found according to the calibration graph, mg/dm^3; V – is the volume of the investigated solution, cm^3; m – is the weight of the air-dry soil sample, g.

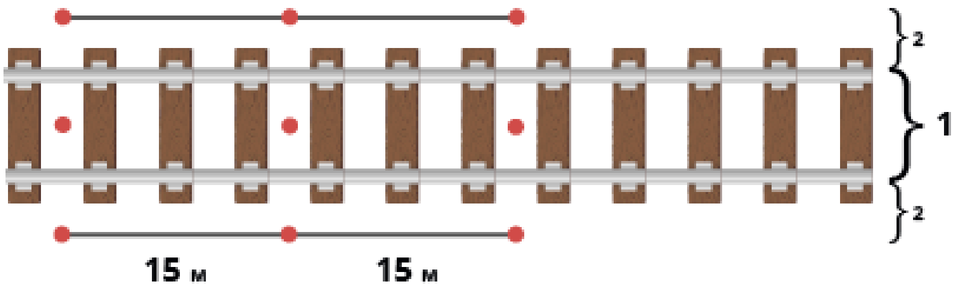

Fig. 1. The scheme of sampling at railway stations
1 – the area of sampling between rails, *2* – the area of sampling outside both rails

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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]:

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

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

Although this methodolgy 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]:

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

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

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

where Ti – is the factor reflecting the toxicity of the i-th HM and the degree of environmental sensitivity to this metal, the values of *Ti* for Hg, Cd, As, Ni, Cu, Pb, Cr, Zn and Mn are 40, 30, 10, 5, 5, 5, 2, 1 and 1, respectively; *fi* – is the ratio of the actual concentration of HM, (*Ci*) to its background content (*Si*) [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 Zc

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 ≤40	Low	RI ≤150	Low
40<*Ei*≤80	Average	150<RI≤300	Average
80<*Ei*≤160	Significant	300<RI ≤600	Significant
160<*Ei*≤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-

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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_i	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_c	14 – low contamination degree													

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Continuation of a table 7

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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»	2220	2220	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_i	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_c	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_i	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_c	29.3 – moderate contamination degree													
Reference sites	$340^1/240^2/300^3$		$6^1/5^2/6^3$		$23^1/30^2/40^3$		$7^1/6^2/7^3$		$10^1/8^2/5^3$		$0.5^1/0.3^2$/n.d.^{3}		$2340^1/3078^2/1460^3$	

* – background HM content in soil of Dnipropetrovsk oblast
1, 2, 3 – benchmarks of the HM content for the «KP», «ZK» and «T» stations, respectively.

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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^2. Методом атомно-абсорбційної спектрометрії 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

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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 полютантів. 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

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ОЦЕНКА ВЛИЯНИЯ ЖЕЛЕЗНОДОРОЖНОГО ТРАНСПОРТА НА НАКОПЛЕНИЕ ТЯЖЕЛЫХ МЕТАЛЛОВ В ГРУНТАХ

Цель. Научная статья своей целью имеет анализ современного состояния загрязнения грунтов железнодорожной инфраструктуры тяжелыми металлами (ТМ), а именно трех станций Приднепровской железной дороги: Каменское–Пассажирское, Запорожье–Каменское и Тритузная. **Методика.** Объект исследования – грунты 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^2. 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 грунты. Полученные результаты указывают на то, что состояние грунтов 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 грунтов 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. Грунты 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 грунты 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 грунтах вышеупомянутых станций определены потенциальные экологические риски загрязнения грунтов. **Практическая значимость.** Результаты исследования могут быть использованы в качестве обоснования целесообразности внедрения программ экологического мониторинга для земель железнодорожного транспорта, природоохранных мероприятий по очистке грунтов от ТМ, корректировки зоны от-

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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

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