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Investigation into the Contamination of Soil with Multiple Components in the Vicinity of Municipal Solid Waste Landfills

Oleh Bereziuk[1], Mykhaylo Pashechko[2], Valeriy Savulyak[1], Galyna Kalda[3,4], Aleksandra Prus[2*]

[1] Vinnytsia National Technical University, Vinnytsia, 95, 21021, Khmelnytske Shose, Vinnytsia, Ukraine
[2] Lublin University of Technology, ul. Nadbystrzycka 38 D, 20-618 Lublin, Poland
[3] Khmelnytskyi National University, Instytuts'ka St, 11, 29000 Khmelnytskyi, Khmelnytskyi Oblast, Ukraina
[4] Rzeszow University of Technology, Aleja Powstańców Warszawy 12, 35-959 Rzeszów, Poland
* Corresponding author's e-mail: a.prus@pollub.pl

ABSTRACT

Here determination of the level dimensions regularity of the multicomponent contamination zones (by heavy metals and petroleum products) of the soils adjacent to the municipal solid waste landfill. The dependences of the mercury, copper and zinc concentrations in the soil on the distance to the landfill of municipal solid waste were determined, similar dependence was specified for petroleum products for a distance of up to 500 m. The research employed the regression analysis technique for investigating single-factor experiments and other paired patterns. The selection of a suitable function was based on commonly utilized options, determined by the criterion of achieving the maximum correlation coefficient value. Regression analyses were conducted by employing linearizing transformations, facilitating the conversion of non-linear regularities into linear forms. Graphical dependences, describing the change in the concentrations of individual soil pollutants with the distance from the municipal solid waste landfill have been built, they enable to demonstrating the satisfactory convergence of theoretical outcomes with empirical observations was achieved. The level regularity of multicomponent soil contamination (with petroleum products and heavy metals) at the distance from the municipal solid waste landfill has been obtained, it's required for determining the dimentions of the zones of multicomponent soil contamination. Applying the method of iterations, the dimensions of the multicomponent contamination zones (with petroleum products and heavy metals) of the soils, adjacent to the landfill of municipal solid waste have been determined: very heavy pollution – 22.93 m, heavy pollution – 81.77 m, average pollution – 474.9 m from the foot of the landfill.

Keywords: ecology, multicomponent contamination, soil pollution, heavy metals, petroleum products, landfill, municipal solid waste, iteration.

INTRODUCTION

Municipal solid waste (MSW) (Hamer 2003; Widomski et al., 2017), which is a heterogeneous multicomponent mixture of complex morphological composition, has a significant negative enduring consequences on human health and the environment over an extended period were assessed unlike epy construction or industrial waste (Bieganowski et al., 2018; Skliar et al., 2020; Synyuk et al., 2020), which is basically, homogeneous and relatively easy to be further processed. In Ukraine, the annual formation of solid waste surpasses 54 million m^3, with the majority of this volume being deposited in 6,107 landfills and dumpsites covering 7,700 hectares. However, only a small portion of the waste undergoes partial recycling or is directed to incineration plants. This stands in contrast to highly developed countries, where advanced recycling and disposal technologies are prevalent (US Environmental Protection Agency 2017). Between 1999 and 2014, the overall expanse of landfills and dumpsites in Ukraine experienced a threefold increase. The expanses of overloaded landfills and dumpsites in Ukraine, where environmental safety standards are breached, pose a significant risk of environmental pollution. Specifically, there is a threat of chemical contamination of the soil with heavy metals and petroleum products, both inherent components of the waste or by products resulting from its decomposition (Duda-Saternus et al., 2023; Kujawska et al., 2023; Szarlip et al., 2014). These contaminants have adverse effects on the physical, chemical, and biological properties of the soil, contributing to the onset of diseases in living organisms (Huliaieva et al., 2021). Additionally, there is a risk of pollution extending to adjacent land plots (Cabinet of Ministers in Ukraine 2004), leading to the exclusion of fertile soils from agricultural production. Hence, the management of solid waste emerges as one of the most pressing environmental challenges faced by humanity. In accordance with Cabinet of Ministers of Ukraine Decree No. 265, ensuring oversight of both operational and closed municipal solid waste landfills to prevent adverse effects on the environment and human health stands as a key priority in the realm of solid waste management in Ukraine (Blokhina et al., 2019). That is why, establishing the dependences of the individual pollutants concentrations (heavy metals and petroleum products) on the distance to the MSW disposal site in order to determine of the level and dimensions regularity of the multicomponent pollution zones of these soils is an urgent scientific and technical task.

The aim of this paper is to establish the concentrations dependence of individual pollutants (heavy metals and petroleum products) on the distance to the MSW disposal site in order to determine the level and dimentions regularity of the multicomponent pollution zones of these soils.

MATERIALS AND METHODS

The paper focuses on determining the paired dependencies between the concentrations of individual soil pollutants and the distance from the municipal solid waste disposal site, employing the method of regression analysis (Cabinet of Ministers in Ukraine 2004). The regressions were derived through linearizing transformations, facilitating the conversion of non-linear patterns into linear ones. The coefficients of the regression equations were calculated using the least squares method, facilitated by the specialized computer program "RegAnalyz". This program, detailed in work (Bereziuk et al., 2021), is protected by a Certificate of State Registration for copyright and plays a key role in the analytical processes undertaken in this study.

Determination of the level regularity of multicomponent soil contamination around the municipal solid waste landfill was carried out according to a general index that takes into account all pollutants, – aggregate coefficient of the complex pollution, determined by the formula (Mykhailiv et al., 2022):

$$K_k = \sum_{i=1}^{n} \frac{C_i}{MCP_i} \quad (1)$$

where: K_k – the aggregate coefficient of the complex pollution; C_i – the i-th soil pollutant concentration, mg/kg; MPC_i – maximum permissible i-th soil pollutant concentration, mg/kg; n – the pollutants number.

Zoning of multicomponent soil contamination around the MSW landfill was carried out on the values basis of the aggregate coefficient of the omplex pollution according to the Table 1. The dimentions of the zones around of multicomponent soil contamination the MSW disposal site were determined by the method of iterations (Skliar et al., 2020) in the MathCAD environment, using the formula, obtained on the basis of the regularity (1), paired dependences of the concentrations of individual soil pollutants and their *MPC*.

RESULTS AND DISCUSSION

The environmental hazard assessment of the Novoyavoriv landfill in Lviv Region of Ukraine, located on the border with Poland, was carried out in the study (Popovych et al., 2018), in particular, the chlorides and sulfates content in the soils around the landfill was determined by quantitative and qualitative methods. It was found that the chlorides and sulfates content is different in different areas of the landfill. The areas exhibiting the highest levels of pollution are situated at distances of 10 meters and 50 meters from the base of the landfill. At a distance of 100 m from the landfill, the chlorides decreases concentration to 0.001% (at a depth of 5 cm) and 0.1% (at a depth of 10–20 cm). A notable sulfate content of 1% is detected at a distance of 10 meters from the base of the landfill, specifically at a depth ranging

Table 1. Zoning of the multicomponent soil contamination (DSTU 4362:2004 2005)

Zones of soil contaminatin	Aggregate coefficient of the complex pollution K_k	Possible use of agricultural soils (Synyuk et al., 2020)
Uncontaminated	< 0.5	Can be used for any crops
Slightly polluted	0.5–1.5	
Moderately polluted	1.5–2	Can be used for any crops, under conditions of quality control of crop production
Heavily polluted	2– 2.5	Can be used for the industrial crops without obtaining food and fodders from them
Very heavily polluted	> 2.5	Exclude from agricultural use

from 10 to 20 centimeters. In the paper (Floria 2012), the impact of the soil pollution with petroleum products, such as gasoline, diesel fuel, and used motor oil, on plant growth was determined. It was established that within five years after the contamination, petroleum products negatively affect plant growth due to a substantial rise in peroxidase activity and increase of the proline content, as well as the decrease of the nutrients (P, Mg and Ca) content in plants. Diesel fuel reduced the content of N and K, whereas used motor oil reduced Fe. Petroleum products contributed to a notable increase in the levels of cadmium and lead, while some of them resulted in a decrease in the content of copper, manganese, and zinc. This mutual influence stipulates the need to study the multicomponent contamination of soils with petroleum products and heavy metals.

The article (Kanmani et al., 2013) provides insights into the analysis of heavy metal concentrations in the fine fraction of municipal solid waste and soil samples gathered in the vicinity of an open dump site for solid waste in Ariyamangalam, Tiruchirappalli District, Tamil Nadu State, India. The analysis of the collected soil sample revealed the concentration of heavy metals in the following sequence: manganese (Mn) > lead (Pb) > copper (Cu) > cadmium (Cd). The detection of heavy metals in the soil sample suggests a substantial contamination of the soil due to leachate migration from the nearby open dumpsite. The research has confirmed that these contaminants have the potential to persistently migrate and infiltrate through various soil layers. Without intervention, there is a risk that, over time, they may contaminate the groundwater system. Preventative measures are crucial to mitigate this phenomenon. The study presented in (Ihedioha et al., 2017) investigates the levels of soil contamination with specific heavy metals in the vicinity of the municipal solid waste dump site. The aim is to furnish information regarding the extent of contamination, assess the ecological risk posed by metals in the soil, and evaluate the potential health risks for the residents of the city of Uyo, Nigeria. Soil samples were collected during both the rainy and dry seasons, and their metal content, including Pb, Cd, Zn, Mn, Cr, Ni, and Fe, was analyzed using atomic absorption spectrometry. The concentrations of heavy metals (mg/kg) at the dumpsite during the rainy season were as follows: Pb (9.90), Zn (137), Ni (12.56), Cr (3.60), Cd (9.05), and Mn (94.00). In the dry season, the concentrations were Pb (11.80), Zn (146), Ni (11.82), Cr (4.05), Cd (12.20), and Mn (91.20). Studies of contamination indices showed that soil samples from the dampsite and at a distance of 10–20 m to the dampsite east were heavily contaminated with Cd. The environmental risk assessment indicates that cadmium contributes to 98–99% of the overall potential environmental risk. No apparent health risk was identified, as the total hazard index of all the metals was below one. Nevertheless, it was revealed that children exhibit a higher susceptibility to heavy metals pollution compared to adults.

In the paper (Wang et al., 2022), an evaluation of the environmental risk and factors influencing heavy metal impacts on soils at municipal solid waste landfills was conducted through a comprehensive analysis of literature, field studies, and statistical methods. The findings revealed that chromium (Cr) emerged as the primary contributor to heavy metal pollution in the landfill soil, with Nemerow Pollution Index (NPI) values ranging from 22.7 to 44.3, followed by zinc (Zn) with NPI values ranging from 0.7 to 9.8. Substantial variations in concentrations of Cr, Hg, Pb, Zn, and arsenic (As) were observed between soil samples from sanitary and nonsanitary landfills, highlighting more pronounced heavy metal contamination in the latter.

The authors of the paper (Chatterjee et al., 2015) conducted the analysis of the multielement soil contamination with metalloids and heavy metals of the soil around the landfill of municipal solid waste according to the following criteria: maximum admissible concentration coefficient, concentration coefficient, aggregate concentration coefficient. Calculation of the total pollution index of the soil was carried out based on the complex of all analyzed indices. Heavy and very heavy soil contamination was most evident for Cd and Pb at a distance of up to 600 m. However, at the same time, heavy soil contamination was noted only in the individual samples for Cu and Zn or was not recorded at all (for Ni).

The article (Mavakala et al., 2022) undertook an analysis of the heavy metal content in surface soils gathered from 15 municipal solid waste landfills in the city of Kinshasa, Democratic Republic of Congo. The average concentration of heavy metals in all soil samples was established in the following sequence: Zn > Pb > Cu > Cr > Co > Cd > As > Hg. The computed pollution indices, encompassing geoaccumulation, enrichment factor, degree of pollution, and potential environmental risk, indicated the prevalence of polymetallic pollution for several of these metals. Among them, Zn, Cu, Pb, and Hg stood out as of particular concern due to their elevated environmental risks.

Experimental data regarding the concentration of the heavy metals (copper, lead, mercury, zinc) and petroleum products in the soil at a distance range of 0 to 500 meters from the municipal solid waste landfill are presented in (Pisarenko et al., 2022). In the materials of the article (Bereziuk et al., 2022), using the method of regression analysis, the lead concentration dependence in the soils within the distance range of 0 to 500 meters from the solid waste landfill was determined, it can be used for the regularity construction of multicomponent contamination level of these soils:

$$C_{Pb} = 19.76 - 2.761x^{0.3} \text{ [mg/kg]} \quad (2)$$

where: C_{Pb} – the lead concentration in the soil, mg/kg; x – the distance from the landfill site, m.

The author of the paper (Bereziuk 2022) established the relationship between petroleum product concentrations in soils within a distance range of 0 to 200 meters from the landfill site. However, further clarification is needed before utilizing this data for constructing the pattern of multicomponent pollution levels in these soils at a distance of 0 to 500 meters. The authors did not identify any mathematical regularities describing the relationships between mercury, copper, and zinc concentrations in the soil and the distance to the landfill site.

Table 2 displays the concentrations of heavy metals and petroleum products in the soil surrounding the municipal solid waste landfill in the village of Sencha, Lohvytsky District, Poltava Region of Ukraine. The data was acquired through the atomic absorption method, utilizing the C-115 Y type atomic absorption spectrophotometer (Pisarenko et al., 2022). Also Table 2 presents the maximum permissible concentrations (MPC) in the specified chemical substances soil in accordance with the Hygienic Regulations (Order of the Ministry of Health of Ukraine 2020).

Based on the data in the Table 2, it was planned to obtain mathematical models in the form of paired regression dependences of the concentrations of individual pollutants (heavy metals and petroleum products) in the soil on the distance to the MSW disposal site. The outcomes

Table 2. Concentrations of petroleum products and heavy metals in the ground around the solid waste disposal site (Pisarenko et al., 2022)

Distance to the landfill of MSW, m	Concentrations of soil pollutants, mg/kg				
	Lead Pb	Mercury Hg	Copper Cu	Zinc Zn	Petroleum products
0	18.65	0.5	2.45	18.63	1500
50	12.56	0.1	1.46	11.46	1100
100	11.65	0.1	1.44	11.98	798
200	2.66	0.1	1.63	11.65	264
500	2.01	0.1	2.01	12.13	201
MPC in soil (US Environmental Protection Agency 2017), mg/kg	32	2.1	3	23	1000

of the regression analysis are presented in Table 3, highlighting cells with the highest correlation coefficients (R) for each paired dependence by shading them in grey. Therefore, based on the results of the regression analysis utilizing the data from Table 2, the following regression models were ultimately endorsed as the most fitting:

$$C_{Hg} = \frac{1}{10 - 8e^{-x}} \text{ [mg/kg]} \quad (3)$$

$$C_{Cu} = 1.747 + 0.001723\,x - 0.095 \ln x \text{ [mg/kg]} \quad (4)$$

$$C_{Zn} = 14.15 + 0.004073\,x - 0.641 \ln x \text{ [mg/kg]} \quad (5)$$

$$C_{PP} = \frac{1}{7.633 \cdot 10^{-4} + 9.147 \cdot 10^{-6} x} \text{ [mg/kg]} \quad (6)$$

where: x – the distance from the municipal solid waste disposal site, m; C_{Hg}, C_{Cu}, C_{Zn}, C_{PP} – the concentration of mercury, copper, zinc, petroleum products in the soil, respectively, mg/kg.

Figure 1 shows graphical dependences, describing the change in the concentrations of individual soil pollutants with the distance from the MSW disposal site, constructed using regression equations (3–6), these endorsed regression models confirm the previously established satisfactory convergence of the theoretical dependencies with the data presented in (Pisarenko et al., 2022).

After substituting dependencies (1, 3–6) and *MPC* values for each of the pollutants into the formula (1), we will obtain the level regularity of multicomponent ground contamination around the municipal solid waste disposal site:

$$K_k = 1.815 + 7.514 \cdot 10^{-4} x - 0.08628\,x^{0.3} - 0.05954 \ln x + \frac{1}{21 - 16.8e^{-x}} + \frac{1}{0.7633 + 9.147 \cdot 10^{-3} x} \quad (7)$$

Based on the regularity (7), we will obtain the iterative formula for determining the dimentions of the zones of multicomponent soil contamination around the MSW disposal site, Eq. (8). Using the iterative formula (8), at $K_k = 2.5$ and the initial value of $x_0 = 20$ m, after the 11th iteration, we will obtain the size of the zone of very heavy multicomponent soil contamination around the municipal solid waste disposal site of 22.93 m, at $K_k = 2$ and the initial value of $x_0 = 80$ m, after the 6th iteration, we will get the size of the zone of heavy multicomponent contamination – 81.77 m, at $K_k = 1.5$ and the initial value of $x_0 = 480$ m, after the 13th iteration, we will get the size of the zone of

$$x = \frac{1}{9.147 \cdot 10^{-3} K_k - 0.0166 - 6.873 \cdot 10^{-6} x + 7.892 \cdot 10^{-4} x^{0.3} + 5.446 \cdot 10^{-4} \ln x - \left(2296 - 1837e^{-x}\right)^{-1}} - 83.45. \quad (8)$$

Table 3. Results of the regression analysis of the concentrations of heavy metals and petroleum products in the soils around the solid waste disposal site

No	Regression type	Coefficient of correlation R			
		$C_{Hg} = f(x)$	$C_{Cu} = f(x)$	$C_{Zn} = f(x)$	$C_{PP} = f(x)$
1	$y = a + bx$	0.47816	0.05759	0.42228	0.83877
2	$y = 1 / (a + bx)$	0.47816	0.17852	0.38929	0.93673
3	$y = a + b / x$	1.00000	0.84700	0.98627	0.73559
4	$y = x / (a + bx)$	0.99999	0.99407	0.98985	0.92958
5	$y = ab^x$	0.47816	0.12005	0.40709	0.89781
6	$y = ae^{bx}$	0.47816	0.12005	0.40709	0.89781
7	$y = a \cdot 10^{bx}$	0.47816	0.12005	0.40709	0.89781
8	$y = 1 / (a + be^{-x})$	0.99999	0.77300	0.99078	0.47575
9	$y = ax^b$	0.98746	0.71478	0.96904	0.59076
10	$y = a + b \cdot \lg x$	0.98746	0.75872	0.97388	0.73611
11	$y = ax / (b + x)$	0.99999	0.77300	0.99078	0.47576
12	$y = a + b \cdot \ln x$	0.98746	0.75872	0.97388	0.73679
13	$y = ax / (b + x)$	0.99999	0.77300	0.99078	0.47576
14	$y = ae^{b/x}$	0.99999	0.81095	0.99403	0.59013
15	$y = a \cdot 10^{b/x}$	0.99999	0.81095	0.99403	0.59013
16	$y = a + bx^n$	0.31570	0.22699	0.25668	0.68462
17	$y = a + bx + c \cdot \ln x$	0.98746	0.99732	0.99596	0.73679

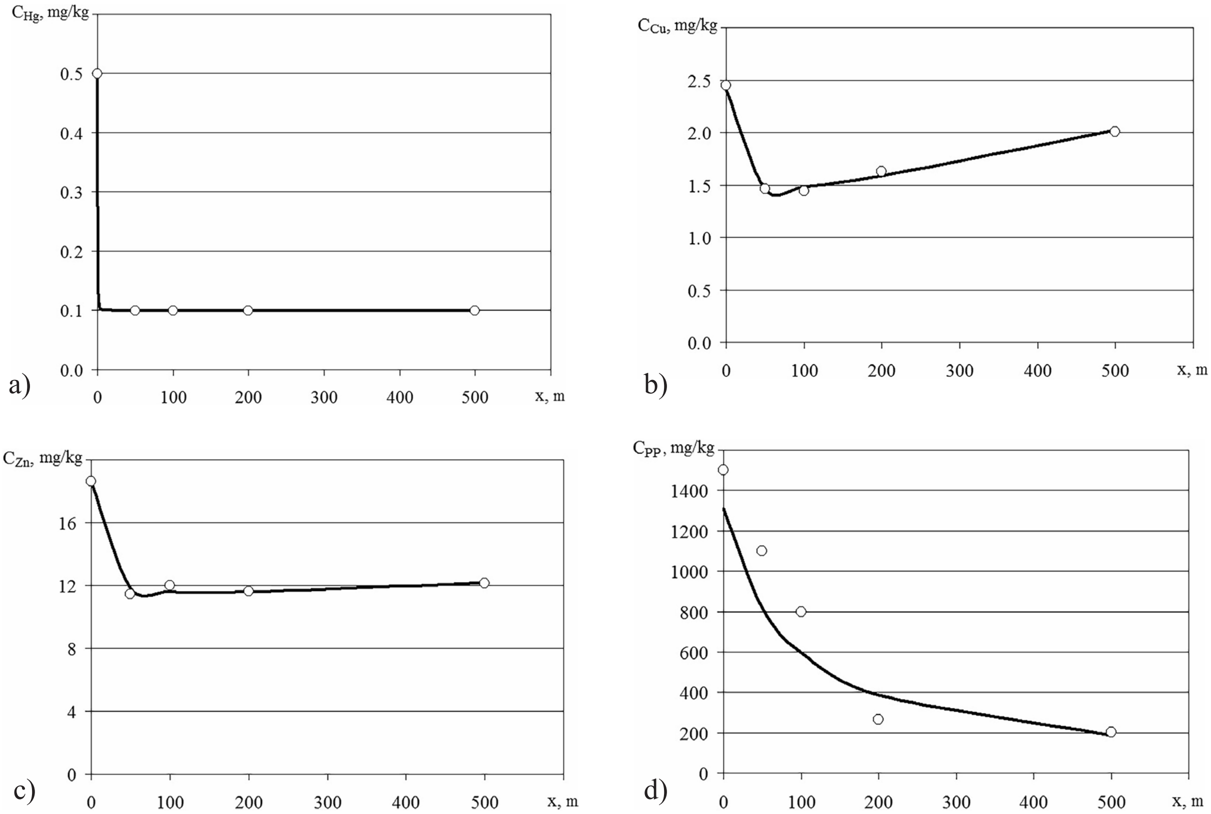

Figure 1. Dependencies, describing the actual (○ data of the paper authors (Kanmani et al., 2013) and theoretical (— own data) changes in the concentrations of individual soil pollutants with distance from the MSW disposal site: (a) $C_{Hg} = f(x)$, (b) $C_{Cu} = f(x)$, (c) $C_{Zn} = f(x)$, (d) $C_{PP} = f(x)$

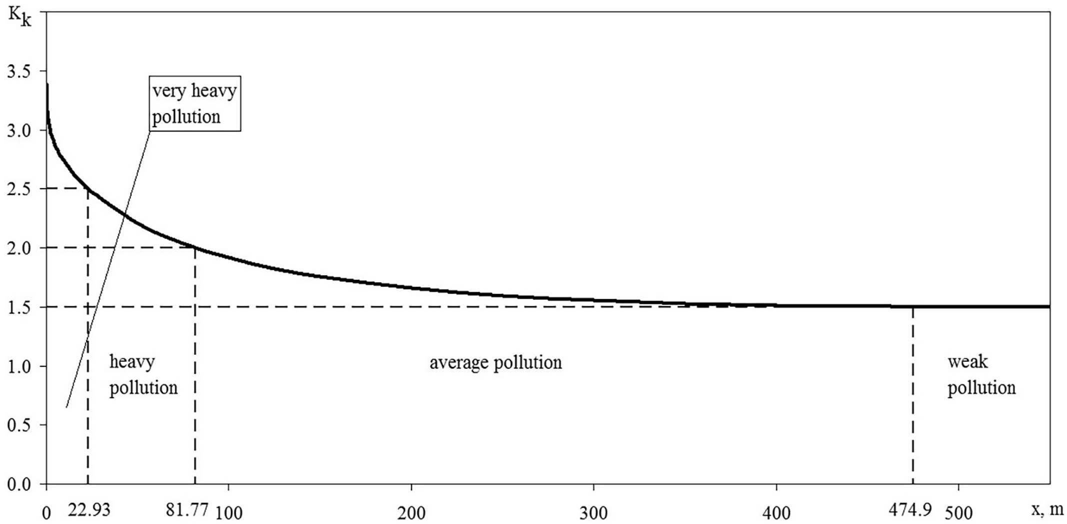

Figure 2. Dependency describing the change in the level of multicomponent contamination (heavy metals and petroleum products) of soils with the distance from the MSW disposal site

medium multicomponent contamination – 474.9 m from the foot of the landfill. Figure 2 present the graphic dependence describing the change in the level of the multicomponent soil contamination with distance from the MSW disposal site, built using the regularity (7), which facilitates the visual representation of the specified relationship. Figure 2 shows the multicomponent contamination zones (heavy metals and petroleum products) of the soils around the MSW disposal site. It is seen from Figure 2, that at the distance from the MSW disposal site from 0 to 500 m, the multicomponent contamination level (with petroleum products and heavy metals) of the adjacent soils decreases from 3.4 to 1.5.

CONCLUSIONS

The authors employed the method of regression analysis to establish the relationship between mercury, copper, and zinc concentrations in the soil and the distance from the municipal solid waste landfill. Additionally, a similar dependence was specified for petroleum products within a distance of up to 500 meters. This information was utilized to determine the pattern governing the extent and dimensions of multicomponent pollution zones in these soils.

Graphical representations depicting the variation in concentrations of individual soil pollutants with distance from the municipal solid waste disposal site were generated. These graphics provide a visual illustration of these dependencies, effectively demonstrating the satisfactory convergence of theoretical results with actual observations. Authors have obtained the regularity of the level of the multicomponent soil contamination (with heavy metals and petroleum products) when moving away from the landfill of municipal solid waste, which is necessary for determining the dimensions of the zones of multicomponent soil contamination.

The dimensions of the multicomponent pollution zones (with oil products and heavy metals) of the grounds, adjacent to the landfill of municipal solid waste were determined: very heavy polluted – 22.93 m, heavily polluted – 81.77 m, moderately polluted – 474.9 m from the foot of the landfill, these data are expedient to use for the return of a part of moderately polluted agricultural lands into circulation, in particular: moderately polluted soils can be used for any crops subject to quality control of crop production, and heavily polluted can be used for technical crops without obtaining food and fodder from them.

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