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REGRESSION ANALYSIS OF THE LEAD CONCENTRATION IN THE SOIL AT THE DISTANCE FROM THE LANDFILLS OF SOLID MUNICIPAL WASTE

In recent years the total area of the solid municipal waste landfills and dumpsites, including the overloaded ones, which violate the norms of ecological safety and are the objects of intensive ecological loading, that may cause the pollution of the environment with chemical substances, contaminating soil, in particular with the lead has greatly increased. Determination of the regression dependence of lead concentration in the soil on the distance to solid municipal waste landfills is an important scientific-technical problem.

Objective of the research is to determine the regressive dependence of lead concentration in the soil on the distance to solid municipal waste landfills. During the research the method of regressive analysis of the results of single-factor experiments and other pair dependences with the selection of the rational type of function from sixteen most widely spread variants by the criterion of maximum value of the correlation factor has been used. Regression was performed on the base of the linearizing transformations, which enable to reduce the nonlinear dependence in to linear one. Determination of the coefficients of the regression equations was carried out by means of the least squares method, applying the developed computer program "RegAnaliz", protected by the Certificate of the State registration of the rights to the copyright object.

Adequate regressive power dependence of the lead concentration in the soil on the distance to solid municipal waste landfills was obtained, the dependence can be used for the determination of the level of chemical pollution of the soil with lead. Graphic interpretation of the lead concentration dependence in the soil on the distance to solid municipal waste landfill was constructed, it enables to illustrate this dependence and show the coincidence of the theoretical results with actual results on the level of 0.93493. It is established that the distance from the landfill of solid municipal waste, where the lead pollution of the soil does not exceed the background level (boundary of mild contamination area), is 526 m.

Key words: *garbage dump, landfill, solid municipal waste, chemical contamination, concentration, lead, soil, regression analysis.*

Introduction

Solid municipal waste produce long-lasting negative impact on human health and environment [1, 2], as the characteristic feature of SMW is that it is heterogeneous multicomponent mixture of the complex morphological composition unlike the waste of the construction industry [3, 4] or industrial waste, which are mainly homogeneous and can be rather easily recycled. Annual volume of SMW formation on the territory of Ukraine exceeds 54 mil. m^3, greater part of solid municipal waste is buried on 6107 landfills and dumps, their total area is 7700 ha, the waste is only partially recycled or disposed at waste incineration plants, unlike the developed countries, where modern technologies of recycling and disposing of SMW are widely used [6].

During the period of 1999-2014 the total area of the landfills and dumps increased three times. The area of the overloaded landfills and dumps increased almost two times and the area of the landfills and dumps where the norms of ecological safety are violated, creating the danger of the pollution of the environment (air, water, soil), particularly chemical contamination of soil with heavy metals, for instance, lead, which causes the diseases of living organisms [7], pollution of the adjacent plots of land increased almost three times. That is why, to avoid the growth of the landfills area and their negative impact on the environment, the dust-carts in the process of waste loading perform the technological operation of the SMW compaction [9, 10]. Dehydration of SMW [11] also will help to decrease the growth of the landfills area.

Problem set-up

According to the Resolution of the Cabinet of Ministers of Ukraine № 265, among the priority

directions of SMW management in Ukraine is the organisation of the monitoring over the closed and operating landfills to avoid harmful impact on the environment and human health [12]. That is why, the determination of the regressive dependence of the lead concentration in the soil on the distance to the landfill of solid municipal waste, which can be used for the determination of the level of chemical contamination of the soil with lead, is an important scientific-technical problem.

Analysis of the recent studies and publications

Mathematical prediction models of SMW volumes formation and areas of the landfills in Ukraine are suggested in the materials of the paper [13], these studies show that the total area of the landfills as well as the dumps that do not correspond to the norms of ecological safety increases by the exponential law, and the area of the overloaded landfills and dumps, both corresponding and not corresponding to the norms of ecological safety annually increases almost linearly. To decrease the rate of the landfills area increase, technological operation of SMW compaction during waste loading in the dump-cart is performed [9, 10]. High coefficient of the SMW compaction promotes more efficient usage of the waste landfills deposit [14, 15].

Studies [16 - 19] consider the problem of soil contamination with heavy metals as a result of SMW burial. The paper [20] contains data regarding the impact of heavy metals on microbiota of soddy-weak podzolic soil.

The review of the most widely spread methods of heavy metals remediation in the soil is presented in [21]. Paper [22] contains the data, regarding the specific energy consumption for the reduction of heavy metals (cadmium, lead and zink) concentration in the soil of SMW landfills, applying the method of electrochemical remediation, based on the usage of electric current for the extraction of the corresponding polluting substances. Using this method it is possible to renovate soil directly on the surface without taking it into special vessels that makes the process less energy-consuming. The regression dependence of the specific energy consumption needed for cleaning the soil of SMW landfills from the pollution with such heavy metals as cadmium, lead and zink on their actual and limited admissible concentrations is determined in the paper [23]. Studies, aimed at improvement of the mathematical model of the specific energy consumption, needed for cleaning soil of SMW landfills from the pollution with such heavy metals as cobalt, copper, nickel, chrome, vanadium and manganese, that enable to evaluate energy expenses for cleaning the contaminated soil from the above-mentioned harmful substances are performed in [24].

Authors of the paper [25] underline that traditionally urban community solves the problem of waste accumulation at the expense of the rural territories, as a result the problem of rural territories pollution as a result of worsening the quality of soil, water, air arises, also it was established that the SMW landfill may become a reason of the degradation of drinking water quality and sanitary-hygienic state of the adjacent agricultural lands. Adequate regression power dependence of the petroleum products concentration in the soil on the distance to solid municipal waste landfills is determined in the study [26], the dependence is used for the determination of the safe distance for the location of the solid municipal waste landfills from the agricultural lands by the index of the level of soil chemical contamination with petroleum products.

Lead pollution of the soil emerges as a result of the manufacturing of the lead storage batteries, formation, accumulation and recycling of their waste, as well as in the process of using ethylated petrol as the engine oil [27]. It is noted in the paper [28] that greater part of water-soluble compounds of lead, entering the soil are fixed in it and pass into insoluble state.

Materials of the paper [29] contain chemical characteristic of the soil of SMW landfill in the village of Sencha, Lokhvitsia District, Poltava Region, in particular level of lead contamination at different distances from the landfill. However, the authors did not revealed any specific mathematical dependences of the lead concentration in soil on the distance to the landfill of solid municipal waste as a result of the analysis of the known publications.

Objective and tasks of the paper

Objective of the paper is the usage of the regression analysis method for the determination of the dependence of lead concentration in the soil on the distance to the landfill of solid municipal waste, that can be used for the determination of chemical contamination level of soil with the lead.

Methods and materials

For the determination of the regressive dependence of lead concentration in soil on the distance to SMW landfill the following methods are used: analysis of the literature sources, regression analysis of the results of single-factor experiments and other pair dependences, computer simulation.

Results of the research

Table 1 shows the concentrations of lead in the soil of SMW landfill in the village of Sencha, Lokhvitsia District, Poltava Region, obtained by means of the atomic-absorption method, using atomic-absorption spectrophotometer C-115 У [29]. On the base of the data from Table 1 it was planned to obtain pair regression dependence of lead concentration in the soil on the distance to SMW landfills.

Table 1

Lead concentration in the soil of SMW landfill [29]

Distance to SMW landfill	0	50	100	200	500
Lead concentration in the soil, mg/kg	18.65	12.56	11.65	2.66	2.01

Regression was carried out on the base of the linearizing transformations, enabling to reduce non-linear dependence to linear one. Determination on the coefficients of the regression equationa was performed, applying the method of the least squares [30], using the developed computer program "RegAnaliz" [31], protected by the Certificate of the State Registration of the right to the copyright object, the program is described in details in the work [32].

Program "RegAnaliz" allows to perform the regression analysis of the results of single-factor experiments and other pair dependences with the selection of the rational type of function from sixteen most widely used variants by the criterion of the maximum value of the correlation coefficient, saving the results in MS Excel and Bitmap format.

Results of the regression analysis are presented in Table 2, where the grey color indicates the cell with the maximum value of the correlation coefficient *R*, that corresponds to the power function №16.

Thus, by the results of the regression analysis on the base of the data of Table 1 the following regression dependence can be taken as the most adequate:

$$C_{Pb} = 19{,}76 - 2{,}761x^{0{,}3} \text{ [mg/kg]}, \quad (1)$$

where C_{Pb} – is lead concentration in the soil, mg/kg; x – is the distance to SMW landfill, m.

Fig. 1 shows actual and theoretical graphic dependence of lead concentration in the soil on the distance to SMW landfill.

Table 2

Results of the regression analysis of the dependence of lead concentration in the soil on the distance to SMW landfill

№	Type of regression	Correlation coefficient R	№	Type of regression	Correlation coefficient R
1	$y = a + bx$	0.84375	9	$y = ax^b$	0.56071
2	$y = 1 / (a + bx)$	0.92904	10	$y = a + b \cdot \lg x$	0.72235
3	$y = a + b / x$	0.72183	11	$y = a + b \cdot \ln x$	0.72302
4	$y = x / (a + bx)$	0.92777	12	$y = a / (b + x)$	0.92904
5	$y = ab^x$	0.89149	13	$y = ax / (b + x)$	0.45151
6	$y = ae^{bx}$	0.89149	14	$y = ae^{b / x}$	0.56009
7	$y = a \cdot 10^{bx}$	0.89149	15	$y = a \cdot 10^{b / x}$	0.56009
8	$y = 1 / (a + be^{-x})$	0.45150	16	$y = a + bx^n$	0.93493

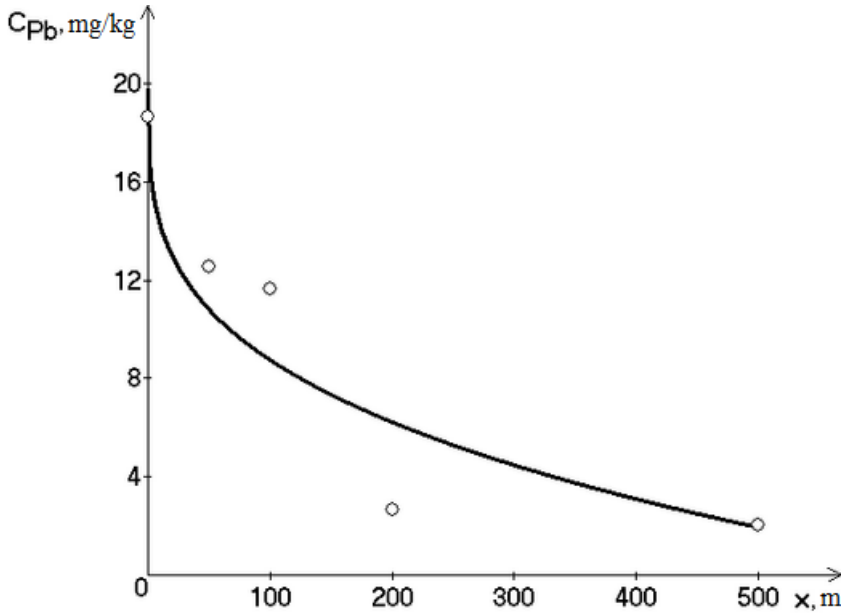

Fig. 1. Change of lead concentration in the soil on the distance to SMW landfill

Comparison of actual and theoretical data showed that theoretical concentrations of lead in the soil, depending on the distance to SMW landfill, calculated by means of the regression equation (1), do not differ greatly from the data, presented in the study [29], this proves the accuracy of preciously obtained dependence at the level of 0.93493.

As MPC(maximum permissible concentration) of lead in the soil is *MPC* = 32 mg/kg, that is higher than the levels of contamination, determined in [29], then it is expedient to determine the boundary of the weak pollution zone, where lead concentration in the soil does not exceed MPC but higher than the natural background level. Having substituted the value of the background lead concentration in the soil of Poltava Region P_b = = 1.615 mg/kg [33] in the regression equation (1), the distance from SMW landfill can be determined at which soil contamination does not exceed the background level (boundary of the zone of weak contamination)

$$x = \left(\frac{19{,}76 - C_{Pb}}{2{,}761}\right)^{\frac{1}{0{,}3}} = \left(\frac{19{,}76 - 1{,}615}{2{,}761}\right)^{\frac{1}{0{,}3}} \approx 526 \text{ (м)}.$$

Conclusions

1. Method of regression analysis for the determination of the dependence of lead concentration in the soil on the distance to the landfill of solid municipal waste, is used for the determination of the level of chemical contamination of the soil with lead.
2. Graphic change of lead concentration in the soil on the distance to SMW landfill has been constructed, it enables to illustrate the given regression dependence and show the coincidence of the theoretical results with actual on the level of 0.93493.
3. It is established that the lead concentration in the soil with the increase of the of the distance to the landfill of solid municipal waste coincides by power dependence.
4. It is determined that the distance from SMW landfill, at which soil contamination with lead does not exceed the background level (boundary of the weak contamination zone) is 526 m.

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