O. V. Bereziuk, Cand. Sc. (Eng.), Assistant Professor; V. O. Kraevskyi, Cand. Sc. (Eng.), Assistasnt Professor; L. L. Bereziuk

WORLD TRENDS OF THE REDUCTION OF THE MUNICIPAL WASTE LANDFILLS NUMBER ON THE EXAMPLE OF THE USA

Over the last years the total area of the municipal solid waste landfills and waste dumping grounds has considerably increased, many of these landfills and waste dumping grounds are overloaded, as a result norms of ecological safety are violated and the landfills become the objects of the intensive ecological loading that may lead to the contamination of the environment with harmful substances: heavy metals, microorganisms (colibacilli, streptococci, staphylococci and ascarids), toxic filtrate, landfill gas, etc. The urgent scientific-engineering problem is the determination of the regressive dependences, which describe the dynamics of the number of municipal waste landfills decrease. The aim of the research is the determination of the regressive dependences, which describe the dynamics of the number of the municipal waste landfills decrease. In the process of the research the method of the regressive analysis of the result of the single factor experiments and other pair dependences with the selection of the best type of the function from the sixteen most widely spread variants by the criterion of the maximum value of the correlation factor was used. The regression was performed on the base of the linearized transforms, which enable to reduce the non-linear dependence to the linear one. Determination of the coefficients of the regression equations was carried out, applying the method of least squares, by means of the developed program "RegAnaliz", the program is protected by the certificate of the state registration of the rights to the copyright object. Adequate regression dependences, describing the dynamics of the number of municipal waste landfills decrease are obtained, they can be used for the determination of the necessary number of the dust-carts for the collection and transport of the solid household waste and machines needed for the execution of the technological operations of the compaction on the map of the waste dumping ground. Graphic dependences, describing the dynamics of the number of the municipal waste landfills decrease and allow to illustrate this dynamics and show the sufficient coincidence of the theoretical results with the actual data are constructed.

Key words: *dust-cart, landfill, solid household waste, dynamics, regression analysis.*

Introduction

Solid household waste (SHW) present serious threat for the health of people and security of the environment [1, 2], every year more than 54 million cubic meters of SHW are accumulated in Ukraine. Greater part of the domestic waste is buried in 6107 waste landfills and waste dumping grounds, their total area is almost 7700 ha, but only small part of waste is partially processed or handled at waste-to-energy facilities, unlike developed countries, where modern technologies of the processing and handling of SHW are widely used [3]. Only in 1999 – 2014 the total area of the landfills and waste dumping grounds in Ukraine increased three times. The area of the overloaded landfills increased almost two times, the number of landfills where the norms of ecological safety are violated increased 3.1 times, this may cause the pollution of the environment with the harmful substances, in particular, as a result of the soil pollution with heavy metals, which together with the filtrate may penetrate into the ground waters, polluting them, it may represent the threat for the life safety and human activity. Waste landfills are also the objects of the intensive ecological load on the environment and may pollute with the microorganisms the adjacent plots of land: colibacills, streptococci, staphylococci and ascarids [4]. Waste landfills are the sources of the constant negative impact on the environment of high toxic filtrate [5, 6] and landfill gas that contains the greenhouse gases and toxic substances [7]. For the reduction of the waste landfills growth rates the technological operation of SHW compaction in the process of dust-cart loading is performed [8]. High compaction coefficient of SHW promotes the efficient usage of the waste landfill area [9]. Waste transportation to the site of the processing at minimal distance of 30 km, that corresponds to the dimensions of the

sanitary norms of Ukraine, is connected with considerable financial expenditures, as annually, the municipal services spend more than 45 thousand tons of fuel [10]. The wear of the dust-carts of the municipal enterprises of Ukraine is almost 70 % [11], that stipulates the necessity of manufacturing of new dust-carts. Nowadays, in the USA, for the assessment of the technical state of the dust-carts other index is used Percent Good Factor, PGF, the value of this factor is defined depending on the age (or the efficient age) of the dust cart according to the special Tables or formulas [12].

Problem set-up

According to the Decree of the Cabinet of Ministers of Ukraine № 265 the usage of modern high efficient dust carts is among the priority directions of the solid waste management [13], that is why, the determination of the regressive dependences, which describe the dynamics of the number of the waste landfills decrease and can be used for the determination of the number of the dust cars for the collection and transport of the solid household waste and machines for carrying out technological operations of their compaction on the map of the landfills is important scientific-engineering task.

Analysis of the recent research and publications

The paper [14] suggests the mathematical models for the forecast of the volumes of SHW formation and the areas of the waste landfills in Ukraine. As the result of the studies, carried out, it is established that the total area of the landfills and areas that do not correspond to the norms of the ecological safety, increase exponentially and area of the overloaded landfills which correspond to the norms of ecological safety and areas of the landfills which do not correspond to these norms annually increases almost linearly. The research [4] reveals wider nomenclature of the sanitary-bacteriological composition of SHW in spring (colibacills, streptococci, staphylococci and ascarids _) due to available staphylococcus and ascarids, missing in SHW during the summer composting. Modeling of the specific energy expenditures for cleaning the soil of the landfills from heavy metals pollution is carried out in the research [15], as a result of the studies logarithmic regression dependencies of the specific energy expenditures of landfills soil cleaning from heavy metals pollution on the decrease of the concentration of cadmium, lead, zinc, used for the construction of the mathematical model of the specific energy expenditures for cleaning of the landfills soil from heavy metals pollution are suggested . The paper [16] contains statistic data regarding the occurrence of such methods of SHW management as waste burial, burning, recycling, composting in EU in 1995-201yy. Paper [17] presents the improved mathematical model in the form of the logarithmic dependence of the concentrations of the polluting substances in the filtrate of SHW landfalls. The research [18] describes the constructed mathematical models of the dependence of saprophytic bacteria concentration in the soil on the distance to the SHW burial landfills, the models enabled to establish that with the approaching of the landfall the concentration of the saprophytic aerobic bacteria, necessary for biochemical reactions of the SHW organic fraction decomposition in the sites of their burial and self-cleaning of the soil from the foreign organic substances decreases. In the research [19] hyperbolic regression dependence of SHW compaction coefficient on the height of the landfall is suggested. However, as a result of the analysis of the known publications the authors did not reveal the specific mathematical dependences, describing the decrease of the number of the landfills.

Aim and task of the research

Aim of the given paper is the construction, by means of the regressive analysis, the regression dependence, which describes the dynamics of the number of the landfills decrease and can be used in the process of the determination of the necessary number of the dust carts for the collection and transport of the solid household waste and machines for the execution of the technological operations for waste compaction on the map of the landfill.

Methods and materials

For the determination of the regressive dependence which describes the dynamics of the number of landfills reduction such methods are used: regression analysis of the results of the single-factor experiments and other pair dependences, computer modelling.

Results of the research

Table 1 contains the dynamics of the decrease of the number of landfalls on the example of USA [20, 21] and in Ukraine [22]. On the base of the data from Table1 pair regressive dependences are to be obtain which describe the dynamics of the number of the landfills decrease on the example of the USA and Ukraine

Table 1

Number of the landfills in the USA and Ukraine in different years [20 – 22]

Year	Number of landfills, q-ty.	Year	Number of landfills, q-ty	Year	Number of landfills, q-ty	
	USA		USA		USA	Ukraine
1988	7924	1997	2514	2010	1908	
1989	7379	1998	2314	2011	1908	
1990	6326	1999	2216	2012	1908	
1991	5812	2000	1967	2013	1908	6682
1992	5386	2001	1858	2014	1956	5978
1993	4482	2002	1767	2015	1738	6064
1994	3558	2005	1754	2016	1267	5470
1995	3197	2006	1754	2017	1269	5434
1996	3091	2007	1754	2018		6107

Regression was carried out on the base of linearized transformations which enable to reduce the nonlinear dependence to linear one. Determination of the coefficient of the regression equations was carried out applying the method of the least squares [23] and by means of the developed computer program “RegAnaliz”, the program is protected by the certificate of the state registration of the rights to the copyright object and is described in details in the paper [19].

Program “RegAnaliz” allows to perform the regressive analysis of the result of the single-factor experiments and other pair dependences with the selection of the best kind of function from 16 most common variants by criterion of the maximum correlation coefficient saving the results in MSExcel and Bitmap formats.

The results of the regressive analysis are shown in Table 2, where the grey color indicates the cell with maximum value of the correlation coefficient *R*.

Thus, by the results of the regressive analysis on the base of the data from the Table 1 as the most adequate such regressive dependences are ultimately chosen

$$n_{сзв.США} = 10461(t - 1987)^{-0,5759} \text{ [units];} \quad (1)$$

$$n_{ñçâÓêð.} = \frac{t - 2012}{1,759 \cdot 10^{-4}(t - 2012) - 1,36 \cdot 10^{-5}} \text{ [units.].} \quad (2)$$

Table 2

Results of the regressive analysis of the dynamics of the number of the landfills reduction on the example of the USA and Ukraine

№	Type of regression	Correlation factor R		№	Type of regression	Correlation factor R	
		USA	Ukraine			USA	Ukraine
1	$y = a + bx$	0,80970	0,58921	9	$y = ax^b$	0,95482	0,71089
2	$y = 1 / (a + bx)$	0,90163	0,57235	10	$y = a + b \cdot \lg x$	0,95473	0,72287
3	$y = a + b / x$	0,86912	0,78985	11	$y = a + b \cdot \ln x$	0,95473	0,72287
4	$y = x / (a + bx)$	0,95255	0,99205	12	$y = a / (b + x)$	0,90163	0,57235
5	$y = ab^x$	0,87540	0,58094	13	$y = ax / (b + x)$	0,68458	0,75660
6	$y = ae^{bx}$	0,87540	0,58094	14	$y = ae^{b / x}$	0,78885	0,77347
7	$y = a \cdot 10^{bx}$	0,87540	0,58094	15	$y = a \cdot 10^{b / x}$	0,78885	0,77347
8	$y = 1 / (a + be^{-x})$	0,48946	0,76999	16	$y = a + bx^n$	0,66737	0,43901

Fig. 1 shows actual and theoretical graphic dependences, which describe the dynamics of the number of the landfills reduction on the example of the USA and Ukraine.

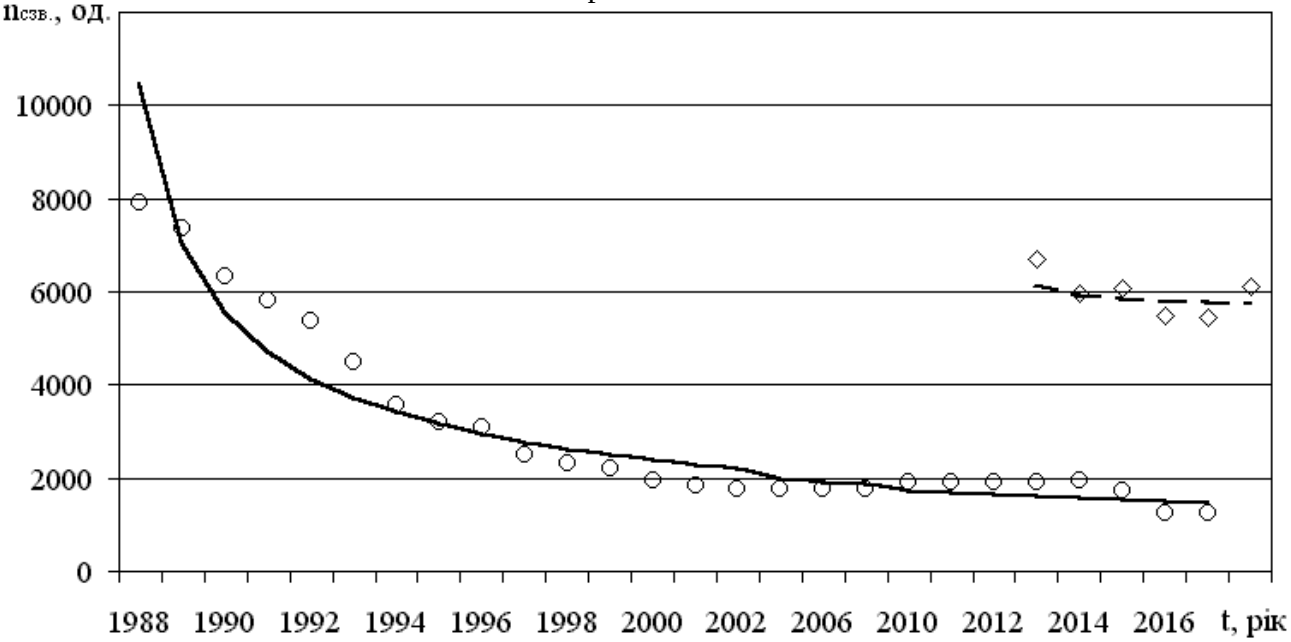

Fig.1 Dependences, which describe the dynamics of the number of the landfills reduction on the example of the USA during 1988-2017; actual ○, theoretical—and in Ukraine during 2013-2018; actual ◊, theoretical – – –

Comparison of the actual and theoretical data showed that the theoretical dynamics of the reduction of the number of landfills, calculated by means of regression equations (1,2) slightly differ from the data, presented in [20 – 22], this proves the sufficient accuracy of the obtained dependences.

As it is seen from Fig.1 the number of the landfills in the USA in 1988-2017 decreased more than 6 times. Such drastic reduction can be explained by the large-scale introduction of modern technologies of the recycling and treatment of SHW. At the same time in Ukraine the reduction of the number of the landfills during 2013-2017 is not great.Using the dependence [9], we may forecast that the number of the landfills in the USA in 2017 will reduce to 1250 and in 2032 – to 1168. Taking into account Euro Atlantic aspirations of Ukraine and having recalculated these results with the quantity of the population of the USA on the quantity of the population of Ukraine we can forecast that the number of the landfills in Ukraine in 2027must not exceed 161 and in 2032 – 150. This proves the necessity of the introduction in Ukraine modern technologies of recycling

and treatment of SHW.

Conclusions

1. Regression dependences, which describe the dynamics of the landfills number reduction are determined and can be used for the determination of the quantity of the dust carts, needed for the collection and transport of the solid household waste and machines for the execution of the technological operations for their compaction on the map of the landfill.

2. , Graphic dependences, describing the dynamics of the landfills number reduction are constructed, they enable to illustrate the described dynamics and show the sufficient convergence of the theoretical results and actual results.

3. The results of application of the suggested forecast model of the landfills number reduction on the example of the USA in projection on Ukraine prove the necessity of the introduction in our country modern technologies of the recycling and treatment of the solid household waste.

REFERENCES

1. Hamer G. Solid waste treatment and disposal : effects on public health and environmental safety / G. Hamer // Biotechnology advances. – 2003. – Vol. 22, № 1-2. – P. 71 – 79. – DOI: 10.1016/j.biotechadv.2003.08.007.

2. Qdais Abu H. Kinetics of solid waste biodegradation in laboratory lysimeters / H. Abu Qdais, A. Alsheraideh // Jordan Journal of Civil Engineering. – 2008. – Vol. 2, № 1. – P. 45 – 52.

3. Moroz O. V. Economic aspects of solving ecological problems of the solid household waste treatment : monograph / O. V. Moroz, A. O. Sventukh, O. T. Sventukh. – Vinnytsia : Universum-Vinnytsia, 2003. – 110 p. (Ukr).

4. Bereziuk O. V. Modeling of sanitary bacteriolological content of the solid waste during summer composting / O. V. Bereziuk, S. M. Gorbatiuk, L. L. Bereziuk // Bulletin of Vinnytsia Polytechnic Instituter. – 2013. – № 4. – P. 17 – 20. (Ukr).

5. Voronkova T. V. System of the filtrate formation management on SMW landfills / T. V. Voronkova, S. Yu. Chudinov // Solid municipal waste. – 2013. – № 8. – P. 36 – 40. (Rus).

6. Popovych V. V. Ecological danger of the filtrate from the landfills / V. V. Popovych // Material of the 2hd International Scientific-Practical conference «Ecological safety as the basis of the sustainable development of the society. European Experience and perspective», November 4-6, 2015. – Lviv, 2015. – P. 165 – 166. (Ukr).

7. Ratushniak G. S. Energy saving in the systems of bioconversian : manual / G. S. Ratushniak, V. V. Dzhedzhula. – Vinnytsia: VNTU, 2006. – 83 p. (Ukr).

8. Berezyuk O. V. Dynamics of hydraulic drive of hanging sweeping equipment of dust-cart with extended functional possibilities / O. V. Berezyuk, V. I. Savulyak // TEHNOMUS – New Technologies and Products in Machine Manufacturing Technologies. – Suceava, Romania, 2015. – № 22. – P. 345 – 351.

9. Berezyuk O. Approximated mathematical model of hydraulic drive of container upturning during loading of solid domestic wastes into a dustcart / O. Berezyuk, V. Savulyak // Technical Sciences. – 2017. – № 20 (3). – P. 259 – 273.

10. Savuliak V. I. Technical support of the collection, transport and preparation for the treaetment of the solid municipal waste : monograph / V. I. Savuliak, O. V. Bereziuk. – Vinnytsia : Universum-Vinnytsia, 2006. – 217 p. (Ukr).

11. Popovych V. V. Efficiency of the dust-cars operation in the environment "city-landfill" / V.V. Popovych, O. V. Prydatko, M. I. Sychevskyi // Scientific bulletin of National Forest Engineering University (NFEU) of Ukraine. – 2017. – V. 27, № 10. – P. 111 – 116. (Ukr).

12. Smoliak S. A. Models for the assessment of the low-sided cars cost / S. A. Smoliak // Bulletin of the transport information. – 2015. – № 3. – P. 37 – 40. – DOI: 10.2139/ssrn.2763710. (Rus).

13. Cabinet of Ministers of Ukraine. Decree № 265 “On the approval of the Program of solid household waste management” [Electronic resource] March 4, 2004. Access mode : http://zakon1.rada.gov.ua/laws/show/265-2004-%D0%BF. (Ukr).

14. Bereziuk O. V. Mathematical modeling of the forecast of the solid household waste formation volumes and areas of the landfills and waste dumping grounds in Ukraine / O. V. Bereziuk // Modern technologies, materials and constructions in the building sphere: Scientific-engineering collection. – Vinnytsia: Universum-Vinnytsia, 2009. – № 2. – P. 88 – 91. (Ukr).

15. Bereziuk O. V. Modeling of the specific energy expenses for the treatment of the solid waste landfills soil from the heavy metals pollution / O. V. Bereziuk // Community facilities of the city. Library: Vital activity security – education, science, practice. – 2015. – № 1 (120). – P. 240 – 242. (Ukr).

16. Perspectives of SHW usage for the generation of the thermal energy in Ukraine [Electronic resources] / N. Yu. Pavliuk // Materials of the XXVI International conference «Problems of ecology and operation of the enterprises of energy sector», September 20-24, 2016. – Odesa: Institute of the industrial ecology, 2016. – Access mode:

http://engecology.com/wp-content/uploads/2015/08/19-pavljuk_tpv-v-teplo_odesa_2016.pdf. (Ukr).

17. Bereziuk O. V. Improvement of the mathematical model of the polluting substances concentration in the filtrate of the solid waste landfills / O. V. Bereziuk // Bulletin of Vinnytsia polytechnic Institute. – 2016. – № 4. – P. 28 – 31. (Ukr).

18. Bereziuk O. V. Construction of the models of saphrophitic bacteria concentration in the soil of the distance to the solid waste landfill / O. V. Bereziuk, L. L. Bereziuk // Bulletin of Vinnytsia Polytechnic Institute. – 2017. – № 1. – P. 36 – 39. (Ukr).

19. Bereziuk O. V. Determination of the waste disposal parameters regression and need in the compaction mechanisms on the base of the computer program "RegAnaliz" / O. V. Bereziuk // Bulletin of Vinnytsia Polytechnic Institute. – 2014. – № 1. – P. 40 – 45. (Ukr).

20. Municipal solid waste in the United States : 2007 facts and figures [Electronic resource]. – US Environmental Protection Agency, 2007. – Access mode: https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/msw07-rpt.pdf.

21. Number of municipal waste landfills in the U.S. from 1990 to 2017 [Electronic resource]. Access mode: https://www.statista.com/statistics/193813/number-of-municipal-solid-waste-landfills-in-the-us-since-1990/.

22. Ministry of Regional Development. State of solid waste management sphere in Ukraine in 2018 [Electronic resource]. Access mode: http://www.minregion.gov.ua/napryamki-diyalnosti/zhkh/terretory/stan-sferi-povodzhennya-z-pobutovimi-vidhodami-v-ukrayini-za-2018-rik/. (Ukr).

23. Khomiuk I. V. Probability theory and mathematical statistics. Manual / I. V. Khomiuk, V. V. Khomiuk, V. O. Kraevskyi. – Vinnytsia: VNTU, 2009. – 189 p. (Ukr).

Editorial office received the paper 02.03.2020.
The paper was reviewed 18.03.2020.

Bereziuk Oleg – Cand. Sc. (Eng), Asssist. Professor with the Department the Life Safety and Pedagogy of Safety.

Kraevskyi Volodymyr – Cand. Sc. (Eng), Asssist. Professor with the Department of Higher Mathematics. Vinnytsia national technical university.

Bereziuk Ludmila – Senior Assistant with the Department of Geography. Vinnytsia Kotsubinsyi State Pedogogocal University.