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STUDY OF THE SPREADING DYNAMICS OF THE SOLID MUNICIPAL WASTE MANAGEMENT METHODS IN UKRAINE

Aim of the research is the determination of the regressive dependences, which describe the dynamics of the spreading of the methods of solid municipal waste management in Ukraine. Among the main methods of solid municipal waste management the following ones were considered: waste burial, burning, processing, recycling, composting. In the course of the research the method of regression analysis of the results of single-factor experiments and other pair dependences with the selection of the best kind of function from the most widely-spread variants by the criterion of maximum correlation factor is used. Regression was carried out on the base of the linearized transformations, which enable to reduce the non-linear dependence to the linear one. Determination of the regression equations coefficients was carried out by the developed computer program "RegAnaliz", protected by the certificate of state registration of the rights to the copyright object. Adequate regression dependences, describing the spreading dynamics of the methods of solid municipal waste management in Ukraine and allow to forecast the spreading of such methods of waste management as waste burial, burning, processing, recycling, composting, have been obtained. Graphic dependences, describing the spreading dynamics of the methods of solid municipal waste management and allow to illustrate the dynamics and show the sufficient coincidence of the theoretical and actual results have been constructed. It is established that in Ukraine the spreading of the solid municipal waste burial drops hyperbolically, burning – changes according to the quadratic dependence, processing and recycling – grows hyperbolically and composting – grows according to the power – law dependence. The spreading of solid municipal waste composting increases most intensively. The following spreading of the methods of solid municipal waste management in Ukraine in 2021 is forecast: waste burial – 93.68%, burning – 0.41%, processing and recycling – 4.02%, composting – 0.121%.

Key words: *dust cart, solid municipal waste, burial, burning, processing, recycling, composting, dynamics, regression analysis.*

Introduction

Nowadays the problem of solid municipal waste (SMW) management is of great importance [1], annual volume of municipal waste in the communities of Ukraine exceeds 54 mil. m^3, greater part of the waste is transported to the disposal sites and landfills [2], total area of these sites is almost 7700 ha, such volume of waste presents threat for human health and environmental security [3]. Waste is only partially processed and recovered at waste incineration plants [4]. During 1999 - 2014 the total area of the landfills and disposal sites in Ukraine increased 3 times. The area of the overloaded landfills and disposal sites increased almost 2 times and the area of the landfills and disposal sites, where the norms of ecological safety are violated, increased more than 3.1 times. For the transportation of solid municipal waste (SMW) by 4000 dust carts to the site of the utilization outside the territory of 30 km sanitary zone, more than 45 ths tons of fuel is needed [5, 6]. Wear of the dust carts fleet of the municipal enterprises of Ukraine reaches almost 70 %. Resolution of the Cabinet of Ministers of Ukraine № 265 [7] became the base for the development of National Strategy of solid municipal waste management on the territory of Ukraine. In such developed countries of the EU as Sweden, Denmark, spreading of the solid waste burning, using the energy, reaches more than 50% of the methods of solid waste management [8, 9]. Actuality of the study of solid waste management system stipulates one of the articles of the Agreement on the Association between the EU and Ukraine [10].

Problem set-up

One of the priority directions of solid waste management in Ukraine, according to the Resolution of the Cabinet of Ministers of Ukraine № 265 is the provision of the application of modern high

efficient dust carts [7], that is why, the determination of the regression dependences, describing the levels of spreading of SMW management methods in Ukraine and can be used for the determination of the necessary number of dust carts for the collection and transport of the solid waste is an important scientific-engineering task, as one of the components for the solution of the problem, aimed at the creation of scientific-engineering fundamentals for the design of the efficient working organs of the machines, intended for the collection and primary processing of the solid municipal waste.

Analysis of the recent studies and publications

The works [8, 9, 11] contain statistical data, regarding the spreading of the SMW management methods in different countries of the world. In [12] the regression models of such methods of SMW management as burial and burning are presented. The spreading of the composting as the method of SMW management has been modeled in [13]. Paper [14] is devoted to the modelling of landfill gas utilization method. The paper [15] considers the assessment of the hazardous municipal waste creation in the Eastern Europe. The research [16] studies the dynamics of SMW management methods spreading in the countries of EU, the corresponding regression dependences, enabling to forecast the dynamics of these methods spreading are determined. In the study [17] the regression dependences, describing the dynamics of the reduction of the number of the landfills in the USA and Ukraine are suggested, also the comparison of the reduction of the landfills dynamics in these countries is proposed. Spreading of SMW burning with energy utilization is studies in [18]. Statistic data, regarding the dispersion of the SMW management methods in Ukraine can be found at the site [19]. However, the author did not find as a result of the analysis of the known publications, the specific mathematic dependences, describing the dynamics of SMW management methods spreading in Ukraine.

Aim and task of the research

Aim of the research is the construction by means of regression analysis the regression dependences, which describe the dynamics of SMW management methods spreading in Ukraine and can be used for the determination of the needed quantity of the dust carts for the collection and transport of the solid municipal waste.

Methods and materials

For the determination of the regression dependences, which describe the dynamics of SMW management methods spreading in Ukraine the following methods are used: regression analysis of the results of single-factor experiments and other pair dependences, computer modelling.

Results of the research

Table 1 contains the dynamics of SMW management methods spreading in Ukraine [19]. Pair regression dependences, describing the dynamics of these methods in Ukraine were planned to be obtained on the base of the data from the Table 1.

Regressions were carried out on the basis of the linearized transformations, which enable to reduce the non-linear dependence to linear one. Determination of the coefficients of the regression equations was carried out by means of the least square methods, applying the developed computer program "RegAnaliz", protected by the certificate of state registration of the copyright object and is described in details in [20].

The results of the regression analysis are given in Table 2, where the cell with the maximum value of correlation factor R is market by the grey color.

Table 1

Spreading of the methods of SMW management in Ukraine in different years [19]

Year	Spreading of the methods of SMW management in Ukraine, %			
	burial	Burning	processing + recycling	composting
2013	96.34	1.15	2.51	0.00000
2014	95.80	1.66	2.54	0.00000
2015	93.46	2.98	3.52	0.00390
2016	94.20	2.71	3.09	0.00410
2017	93.35	2.48	4.17	0.00721
2018	94.23	2.02	3.72	0.02457

Thus, by the results of the regression analysis, based on the data of Table 1, as the most adequate, finally such regressive dependences are taken:

$$П_{burial} = \frac{t-2012}{0,01071(t-2012)-0,0003134}\ [\%]; \quad (1)$$

$$П_{burning} = -0,3302+1,569(t-2012)-0,1974(t-2012)^2\ [\%]; \quad (2)$$

$$П_{prec} = \frac{t-2012}{0,2496+0,2212(t-2012)}\ [\%]; \quad (3)$$

$$П_{comp} = 3,934\cdot10^{-6}+1,479\cdot10^{-5}(t-2012)^{4,1}\ [\%], \quad (4)$$

where $П_{burial}$, $П_{burning}$, $П_{prec}$, $П_{comp}$ – spreading of the burial, burning, processing and recycling, composting of SMW, correspondingly, %; t –year .

Table 2

Results of the regression analysis of the spreading dynamics of SMW management methods in Ukraine

№	Type of regression	Correlation factor R			
		$П_{burial} = f(t-2012)$	$П_{burninq} = f(t-2012)$	$П_{prec} = f(t-2012)$	$П_{comp} = f(t-2012)$
1	$y = a + bx$	0.74292	0.50802	0.84480	0.83975
2	$y = 1 / (a + bx)$	0.73975	0.65219	0.86505	0.90697
3	$y = a + b / x$	0.84724	0.76506	0.77090	0.58082
4	$y = x / (a + bx)$	0.99992	0.90912	0.96185	0.81876
5	$y = ab^x$	0.74134	0.59024	0.85708	0.82835
6	$y = ae^{bx}$	0.74134	0.59024	0.85708	0.82871
7	$y = a \cdot 10^{bx}$	0.74134	0.59024	0.85708	0.82835
8	$y = 1 / (a + be^{-x})$	0.85500	0.92793	0.80227	0.84954
9	$y = ax^b$	0.83180	0.75370	0.85907	0.87685
10	$y = a + b\cdot\lg x$	0.83347	0.67414	0.83991	0.72019
11	$y = a + b\cdot\ln x$	0.83347	0.67414	0.83991	0.72019
12	$y = a / (b + x)$	0.73975	0.65219	0.86505	0.90697
13	$y = ax / (b + x)$	0.84371	0.90241	0.81474	0.85946
14	$y = ae^{b/x}$	0.84548	0.84297	0.79473	0.84476
15	$y = a \cdot 10^{b/x}$	0.84548	0.84297	0.79473	0.84465
16	$y = a + bx^n$	0.62171	0.33742	0.79728	0.97284
17	$y = a + bx + cx^2$	–	0.93322	–	–

Fig. 1 shows actual and theoretical graphic dependences, which describe the spreading dynamics of SMW management methods in Ukraine.

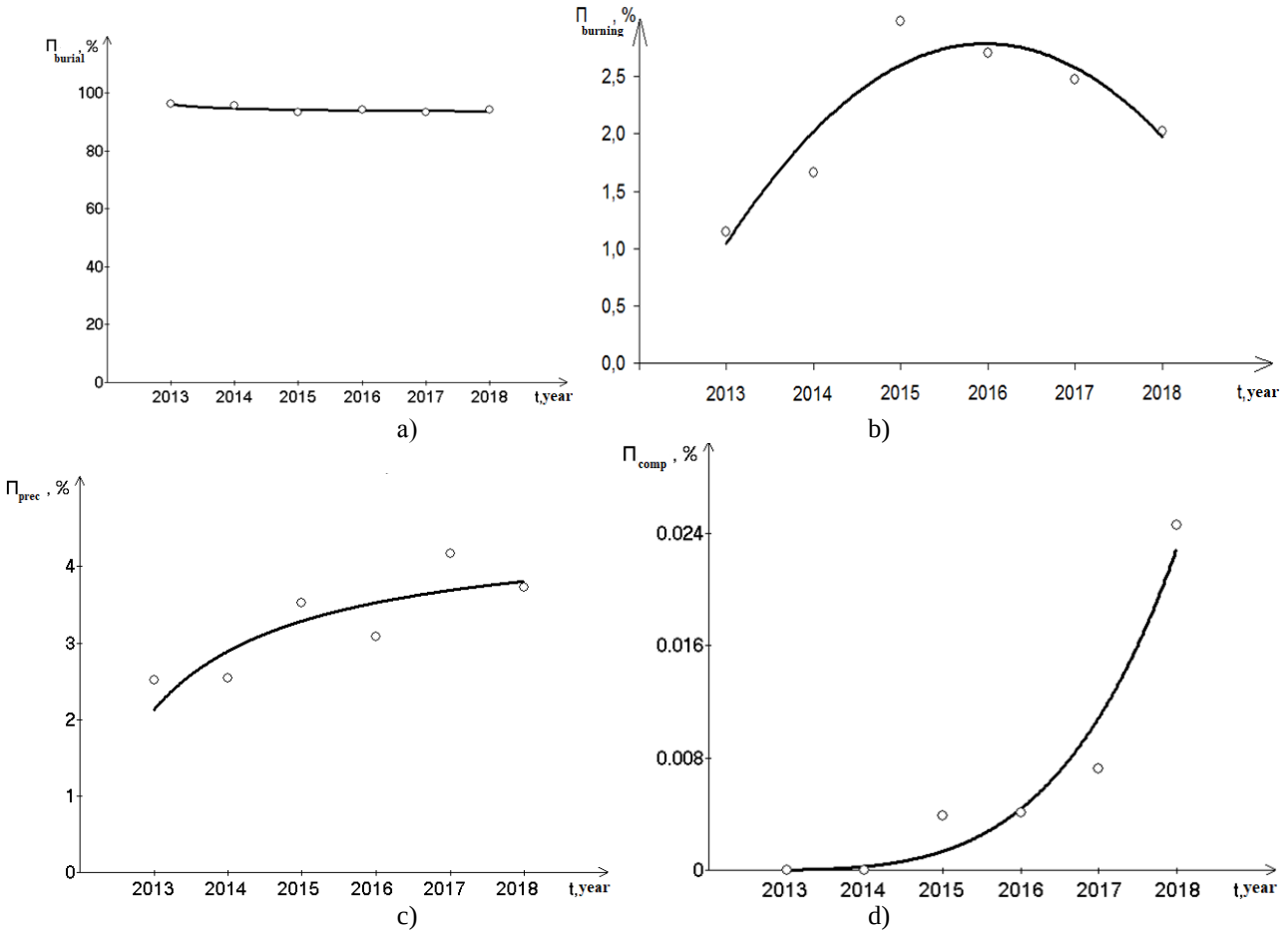

Fig. 1. Dependences, which describe the spreading dynamics of SMW management methods: (a) burial, (b) burning, (c) processing and recycling, (d) composting in Ukraine in the period of 2013 - 2018: actual ○, theoretical —

Comparison of actual and theoretical data showed that the theoretical dynamics of spreading the SMW management methods in Ukraine, calculated by means of regression equations (1) – (4) slightly differs from the data, given in [19], that proves the sufficient accuracy of the obtained dependences, determined previously.

As it is seen from Fig. 1, in Ukraine in the period of 2013 – 2018, the spreading of SMW burial drops hyperbolically, burning changes according to quadratic dependence, processing and recycling grows hyperbolically, and composting grows according to power law dependence. The spreading of the SMW composting grows most intensively.

Using the dependences (1) – (4) the following spreading of SMW management methods can be forecast in Ukraine in 2021: burial – 93.68%, burning – 0.41%, processing and recycling – 4.02%, composting – 0.121%. Even at such growth of the method of SMW composting spreading in Ukraine it is possible, in accordance with the dependence (4), to keep up with the present spreading of the composting method, used in the countries of EU only in 2043 , that proves the necessity of the large-scale implementation of modern technologies for the treatment and disposal of SMW in Ukraine.

Conclusions

1. Regression dependences, describing the dynamics of solid municipal waste management methods spreading in Ukraine are determined, they can be used in the process of determination of the needed amount of dust carts for waste collection and transport.

2. Graphic dependences, describing the dynamics of the SMW management methods spreading in Ukraine are constructed, these dependences allow to illustrate the given dynamics and show the

sufficient coincidence of the theoretical results with actual ones.

3. Results of the application of the suggested forecasting model of solid municipal waste management methods spreading in Ukraine prove the necessity of the large-scale implementation in our country of modern technologies for the treatment and disposal of the solid municipal waste.

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