INFLUENCE OF ANTHROPOGENIC ENVIRONMENTAL POLLUTION ON INCIDENCE INDICATORS OF THE CIRCULATORY SYSTEM DISEASES

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In industrial regions, air pollution poses a serious threat to the natural environment and public health. Emissions of dust substances also significantly worsen the ecological state of the environment, cause premature failure of industrial equipment and objects of housing and communal services [1]. From the point of view of sanitary and epidemiological well-being of the population, the health risks associated with fine particles with a diameter of less than 10 and 2.5 μm are of particular interest, as they are able to penetrate deep into the lungs, but particles with a diameter of less than 2.5 μm can even enter into the bloodstream, which primarily leads to diseases of the cardiovascular and respiratory systems [2-4], and also causes damage to other organs. The main source of air pollution with fine particles is the burning of fuel in various sectors of the economy, including transport, energy, industry, construction, communal services and agriculture, as well as in everyday life.

The World Health Organization (WHO) has determined that fine particulate matter affects more people worldwide than any other pollutant, and air pollution leads to increased morbidity and mortality worldwide.

In work [5], it is stated that one of the most dangerous of the entire nomenclature of pollutants is fine dust with a particle diameter of up to 10 μm. Such dust is solid particles that can remain suspended in the air for a long time, is not effectively captured by existing cleaning devices and spreads in the atmosphere over considerable distances [6].

According to the recommendations of the WHO, threshold exposure limits for fine dust with a diameter of less than 10 microns have been established in EU countries. For the average daily concentration, it is not allowed to exceed the threshold level of 50 μg/m^3 more than 35 times during the year, the average annual concentration should not exceed the level of 40 μg/m^3 [7]. However, in the countries of Eastern Europe, the Caucasus, and Central Asia, the monitoring of suspended particles with a diameter of less than 10 μm is very limited: only a small number of monitoring stations are available in Belarus and Uzbekistan (Tashkent, Nukus), and there are none at all in Ukraine [8].

In the atmospheric air of populated areas there are large volumes of fine dust consisting of soot, cement crumb and other fine particles [9]. Narrowing of blood vessels and deterioration of blood circulation in the body due to the effect of dust leads to disruption of the normal functioning of the human circulatory system [10].

By themselves, toxic fine dust emissions under the influence of sunlight and ozone can form new, even more toxic compounds in the atmosphere [11].

The paper [12] determined the regression hyperbolic dependence of the concentration of benz[a]pyrene in the soils of the municipal solid waste landfill [13-17] on the measurement depth. In works [18, 19], regression dependences of the concentration of petroleum products and lead in soils on the distance to the municipal solid waste landfill are proposed.

In the article [20, 21], the regression dependence of the incidence of respiratory diseases on the productivity of the waste incineration plant is given.

The materials of the article [22] are devoted to the determination of regression power dependences of the prevalence of diseases of various classes in the adult population of settlements adjacent to the MSW disposal site and the distance to the landfill.

In [23], the following two-factor linear mathematical models of the incidence of the circulatory system diseases are proposed, each of which takes into account the influence of fine dust emissions of only the total volume or only of a certain dispersion:

$$Y = -47.4665 + 0.02318N + 104.6041X_1; \quad (1)$$

$$Y = 1864.977 - 0.01372N + 364.5516X_2; \quad (2)$$

$$Y = -3477.74 + 0.1188N + 394.5634X_3, \quad (3)$$

where Y – the number of cases of diseases, persons; N – the total population in the country, persons; X_1 – total volumes of emissions of fine dust into atmospheric air, kg/person; X_2 – volumes of emissions of fine dust into atmospheric air with a size of 2.5...10 microns, kg/person; X_3 – volumes of emissions of fine dust into atmospheric air with a size of less than 2.5 microns, kg/person.

At the same time, the coefficient of determination R^2 for dependencies (1-3) was 0.9248; 0.9365; 0.8022, respectively, which when used to predict the incidence of the circulatory system diseases leads to significant errors, and therefore, in our opinion, these mathematical models need to be improved.

Among the parameters on which the incidence of the circulatory system diseases depends, the following were considered: the total population in the country, the volume of emissions of fine dust into the atmospheric air, the values of which are given in the table 1.

Table 1

Morbidity of the circulatory system depending on influencing factors [23]

Year	Cases of the circulatory system diseases, thousands of cases	Factors of influence		
		Population, thousands of people	Volumes of emissions of solid particles, kg/person	
			2.5…10 mkm	< 2.5 mkm
2012	2390	45633.6	2.910	0.889
2013	2346	45553	3.118	0.927
2014	2318	45426.2	2.966	0.757
2015	2256	42929.3	2.767	0.597
2016	1880	42760.5	1.971	0.559
2017	1844	42584.5	1.588	0.461
2018	1826	42386.4	1.717	0.801
2019	1781	42153.2	1.104	0.319

According to the table 1, a regression equation was obtained that describes the incidence of the circulatory system diseases from the main parameters of influence [24]

$$C_d = 1.088N + 14491m_2 - 280m_3 - 0.3801Nm_2 - 237.1m_2m_3 + 494m_2^2 + 753.9m_3^2 - 42900, \quad (4)$$

where C_d – the cases number of the circulatory system diseases, persons; N – the total population in the country, persons; m_2 – volumes of emissions of fine dust into atmospheric air with a size of 2.5...10 microns, kg/person; m_3 – volumes of emissions of fine dust into atmospheric air with a size of less than 2.5 microns, kg/person.

The improvement of the mathematical model was carried out using the rotatable central composite planning of the 2nd order experiment by the Box-Wilson method [25]. The coefficients of the regression equation were determined using the developed computer program "PlanExp", which is protected by a certificate of copyright registration for the work [26] and is described in detail in the work [27].

According to the Student's test, it was found that: all factors, their paired interaction effects, except for Nm_3, and quadratic effects, except for N^2, were found to be significant; the number of cases of the circulatory system diseases depends more on the volume of emissions of fine dust into the atmospheric air with a size of 2.5...10 microns than on emissions of less than 2.5 microns, which is consistent with the conclusions of the authors of the paper [23].

It was established that according to Fisher's test, the hypothesis about the adequacy of the regression model (4) can be considered correct with 95% confidence. The correlation coefficient was 0.99865, which indicates sufficient reliability of the obtained results.

A comparison of the actual and theoretical number of cases of the circulatory system diseases, simulated with the help of mathematical models (1-4), is shown in fig. 1.

From fig. 1 shows that the theoretical prevalence of the number of cases of the circulatory system diseases, calculated using the regression model (4), does not significantly differ from the actual data [23], which confirms the previously determined sufficient reliability of the obtained dependence, which can be used to predict the indicators of such morbidity. In addition, the improved mathematical model (4) with the coefficient of determination R^2 = 0.9973 allows more accurate prediction of the number of cases of the circulatory system diseases compared to the well-known models (1-3) obtained by the authors of the work [23], for which R^2 is 0.9248; 0.9365; 0.8022, respectively.

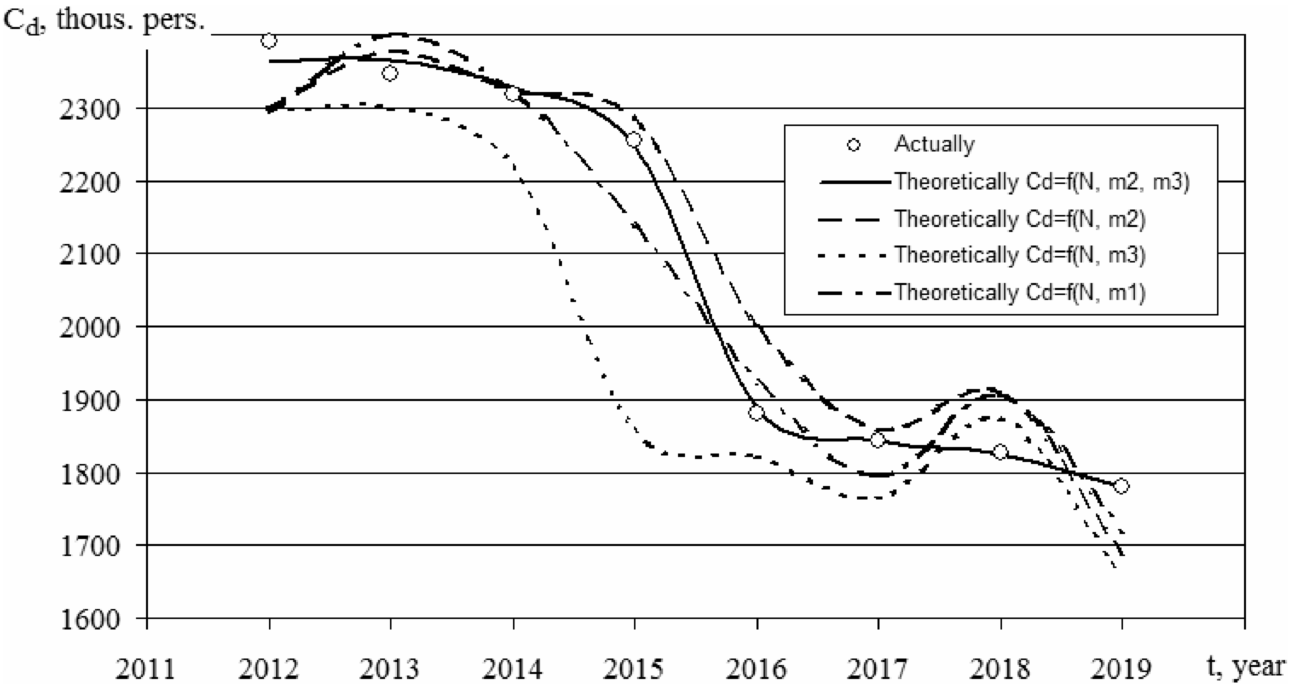
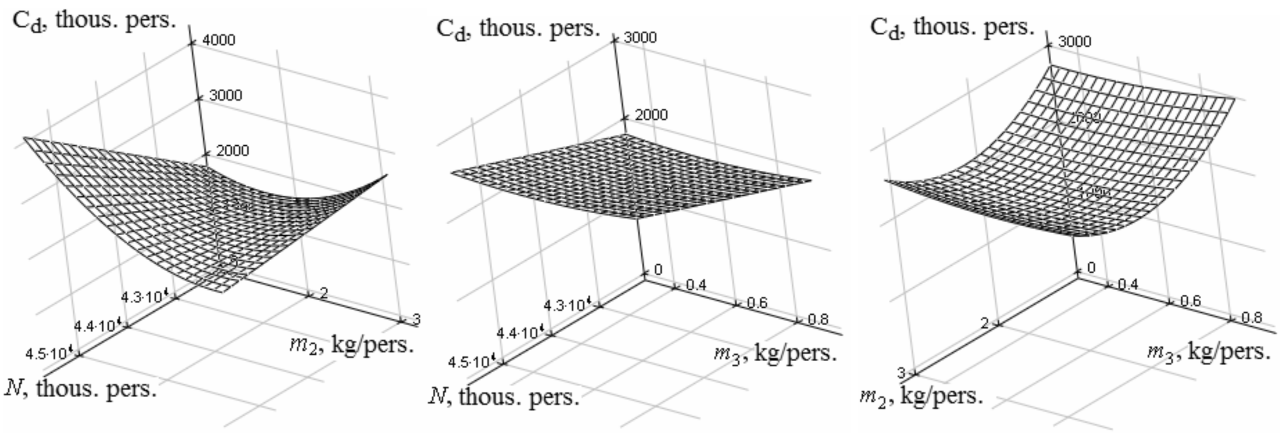


Figure. 1. Comparison of the actual and theoretical cases number of the circulatory system diseases, simulated using known (1-3) and improved (4) mathematical models

In fig. 2 shows the response surfaces of the target function – the number of cases of the circulatory system diseases and their two-dimensional sections in the planes of influence parameters, which allow you to visually display the dependence (4) and the nature of the simultaneous influence of several factors on the target function.

In the table 2 shows the average prevalence of the circulatory system diseases in the adult population of settlements adjacent to the site of municipal solid waste disposal, determined by the author of the work [28], depending on the distance between the border of the settlement and the landfill of municipal solid waste.

Regression was carried out on the basis of linearizing transformations, which allow to reduce the non-linear dependence to a linear one. The regression coefficients of the equations were determined by the method of least squares using the developed computer program "RegAnalyz", which is protected by a certificate of copyright registration for the work [29], and is described in detail in the works [30, 31].



a) b) c)

Figure. 2. Response surfaces of the target function – the cases number of the circulatory system diseases and their two-dimensional sections in planes of influence parameters: a) – $C_d = f(N, m_2)$; b) – $C_d = f(N, m_3)$; c) – $C_d = f(m_2, m_3)$

Table 2

The prevalence of the circulatory system diseases in the adult population of settlements adjacent to the site of municipal solid waste disposal [28]

Distance to the landfill, m	490	750	900
Prevalence of the circulatory system diseases, vol. per 10,000 people.	7394	5455	4121

The "RegAnalyz" program allows you to carry out regression analysis of the results of univariate experiments and other pairwise dependencies with the selection of the best type of function from the 16 most common options according to the criterion of the maximum correlation coefficient with saving the results in MS Excel and Bitmap format.

The results of the regression analysis are shown in the table 3, where cells with the maximum value of the correlation coefficient R are marked in gray.

So, according to the results of the regression analysis based on the data in the table 2, the following regression dependence was finally accepted as the most adequate [22]

$$P_{CSD} = 9596 - 0.2024x^{1.5} \text{ [vol. for 10 thous. people]} \quad (5)$$

where P_{CSD} – the prevalence of the circulatory system diseases, vol. for 10 thousand people; x – the distance from the settlement to the municipal solid waste landfill, m.

Table 3

The results of the regression analysis of the prevalence dependence of the circulatory system diseases on the ways of handling municipal solid waste

No	Regression type	Correlation coefficient R	No	Regression type	Correlation coefficient R
1	$y = a + bx$	0.99888	9	$y = ax^{b}$	0.97933
2	$y = 1 / (a + bx)$	0.97715	10	$y = a + b \cdot \lg x$	0.99272
3	$y = a + b / x$	0.98268	11	$y = a + b \cdot \ln x$	0.99272
4	$y = x / (a + bx)$	0.98192	12	$y = a / (b + x)$	0.97715
5	$y = ab^{x}$	0.99153	13	$y = ax / (b + x)$	0.93828
6	$y = ae^{bx}$	0.99153	14	$y = ae^{b/x}$	0.96396
7	$y = a \cdot 10^{bx}$	0.99153	15	$y = a \cdot 10^{b/x}$	0.96396
8	$y = 1 / (a + be^{-x})$	0.98272	16	$y = a + bx^{n}$	0.99996

Figure 3 shows the actual and theoretical graphical dependence of the prevalence of the circulatory system diseases in the adult population of settlements adjacent to the MSW disposal site on the distance to the landfill.

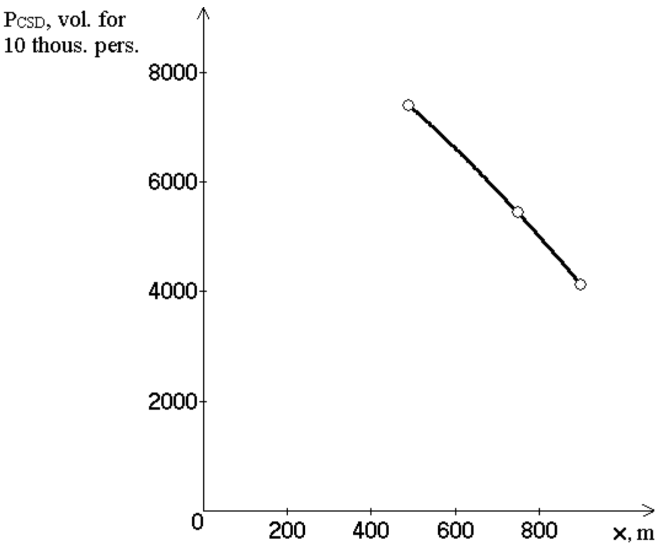


Figure. 3. Dependence of the prevalence of the circulatory system diseases in the adult population of settlements adjacent to the MSW disposal site on the distance to the landfill: actual ○, theoretical —

A comparison of actual and theoretical data showed that the theoretical prevalence of the circulatory system diseases, calculated using the regression equation (5), do not significantly differ from the data given in [28], which confirms the previously determined sufficient accuracy of the obtained dependence.

In 2017, for the adult population (18-100 years) of Ukraine, the average statistical indicators of the incidence of the circulatory system diseases amounted to 495.74 per 10 thousand [32]. By substituting the average statistical (background) data on the prevalence of the circulatory system diseases into the regression equation (5), we will determine the safe distance of landfill sites from the borders of settlements based on the prevalence of the circulatory system diseases

$$x_{CSD} = \left(\frac{9596 - P_{CSD}}{0.2024} \right)^{2/3} = \left(\frac{9596 - 495.74}{0.2024} \right)^{2/3} = 1264 \text{ (m)}.$$

So, regression dependences of the prevalence of the circulatory system diseases of the population on anthropogenic environmental pollution have been determined, which can be used to predict indicators of such morbidity, in particular, to determine the safe distance of placement of municipal solid waste landfills from settlements based on the prevalence of the circulatory system diseases.

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