

## Responses of the Human Body to the Effect from Exposure to Anthropogenic Increase of Ambient Air Pollution

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In modern urbanized conditions, the human population is experiencing a constant effect of various exogenous factors - social, economic, environmental. That is quite a challenge to determine the leading or dominant influence factor of the current total. At the same time, there is no doubt that environmental impacts on the human population adversely affect the population health. Human habitation in highly polluted ambient air leads to the diseases of respiratory, nervous and circulatory system, and may contribute to the exacerbations of existing diseases and shorten the life. The health of population residing under the continuous long-term negative environmental impact is progressively worsening. This study considers biogas formed in landfill mass of municipal solid wastelands as an environmental impact. We created ecological pyramids with characteristics dependencies of the anthropogenic factor and human population in the biogas dispersion areas. The study gives a mathematical description of the human body response to effect from exposure to high levels of pollutants in ambient air.

**Keywords:** Human populations, Public health, Ambient air, Biogas, Ecological pyramid, Environmental impact, Population characteristics.

Throughout the ontogenesis, the human body has been under the constant effect of various environmental impacts<sup>1-5</sup>. This effect can be healthy and restorative<sup>6,7</sup> and can have a negative impact<sup>8,9</sup>, contributing to the formation of dysfunctions in all body systems<sup>10,11</sup>.

In modern urbanized conditions, the human population is experiencing a constant effect of various exogenous factors - social, economic, environmental<sup>12,13</sup>. That is quite a challenge to determine the leading or dominant impact of the current total<sup>14</sup>. At the same time, there is no doubt that environmental impacts on the human population adversely affect the population health<sup>15</sup>. Human habitation in highly polluted ambient air leads to the diseases of respiratory, nervous and circulatory system, and may contribute to the

exacerbations of existing diseases and shorten the life<sup>16,17</sup>.

It is known that human long exposure to low doses of methane (20–25%) leads to asphyxiation; acute poisoning may occur with methane concentration in the air over 30%, when vomiting, headache, weakness, pallor, muffled heart sounds, low blood pressure, weakening or increased muscle tone, reduction of abdominal reflexes, loss of consciousness are observed. When the pressure increases by 1–2 atmospheres, the toxic effect of methane raises<sup>18</sup>. People who are constantly working in mines or in industries where methane and other hydrocarbons methane series are present in the air show noticeable shifts in the vegetative nervous system: a decrease in heart rate by 5-12 beats per minute, hypotension, nystagmus



(involuntary oscillatory movements of eye with frequency up to several hundred per minute)<sup>19</sup>.

Carbon dioxide causes acidosis or impaired acid-base balance in the body. More than 10% concentration of carbon dioxide in the air is dangerous for humans, because it promotes the blood pressure and heart rate decrease, causes respiration difficulty, headache, hearing impairment, weakness and fatigue<sup>18</sup>. The established fact was that a high content of carbon dioxide in the air adversely affected the metabolism of pregnant women: it can cause fetal development abnormalities and reduce the fertility<sup>20</sup>.

Settlements located near places of open storage of municipal solid waste are under the permanent adverse effect of the increased content of biogas components, emitted from landfills mass of municipal solid waste (MSW) landfills into the ambient air and forming a halo of dispersion<sup>21,22</sup>. The biogas includes: macrocomponents – methane ( $CH_4$ ) and carbon dioxide ( $CO_2$ ); microcomponents – sulfur dioxide ( $SO_2$ ), nitrogen oxide ( $NO$ ), hydrogen fluoride ( $HF$ ), ammonia ( $NH_3$ ), hydrogen sulfide ( $H_2S$ ), nitrogen ( $N_2$ ), hydrogen ( $H_2$ ), oxygen ( $O_2$ ), benzene ( $C_6H_6$ ), trichloromethane ( $CHCl_3$ ), carbon tetrachloride ( $CCl_4$ ), chlorobenzene ( $C_6H_5Cl$ ), and other chemical compounds<sup>23,24,25</sup>.

To obtain a mathematical description of the human population response to an increased content of biogas in ambient air, the following goal has been set: to evaluate the anthropogenic impact on the human habitation under continued exposure to landfill gas.

## MATERIALS AND METHODS

We used data on the volumes of biogas emission from the “Samosyrovo” MSW landfills (Vysokogorsky municipal district of the Republic of Tatarstan) and “Korgashino” (Mytishchi district of the Moscow region), as well as population characteristics of Zvanka and Konstantinovka villages inhabitants, and Samosyrovo village falling into the biogas dispersion zone of the Samosyrovo landfill, and the villages of Vysokovo, Svinoedovo, and Korgashino, Kardo-Lenta settlement, located within the halo of biogas dispersion of the Korgashino landfill.

Parameters of the anthropogenic environmental factor – the annual volumes of

biogas emission from the “Samosyrovo” and “Korgashino” MSW landfills were determined based on the results of a gas-chemical survey of landfill masses and application of the methodology for determining the total volume and mass of biogas produced by the solid household and industrial waste landfill.

The published statistical materials gave information characterizing the human population (size, density, fertility, mortality, natural growth and morbidity of the population).

We used a correlation analysis to determine the statistical relationship between empirical data characterizing the human population and the anthropogenic environmental factor; the correlation coefficients were calculated using K. Pearson formula<sup>26</sup>.

A factor analysis was carried out with the purpose of grouping the considered features and finding such complex homogeneous groups (factors) that best explain the observed relationships between the variables under study. Method of principal components was used for factorization, according to the H.F. Kaiser criterion. The obtained values of factor loadings served as the basis for constructing an ecological pyramid<sup>26</sup>. The calculations were performed using the SPSS software package (version 12.0).

The least square method applied to describe graphic images of characteristics dependency of human population on the anthropogenic impact factor<sup>26</sup> - the biogas as functions of the type  $y = f(x)$ .

## RESULTS AND DISCUSSION

The total population of Samosyrovo, Konstantinovka and Zvanka villages is 4190 people or 9% of Vysokogorsky municipal district population (46,300 people); the number of residents of Kardo-Lenta settlement, Vysokovo, Korgashino and Svinoedovo villages is 301 people or 5% of the number of inhabitants of Pirogovsky urban settlement (6531 people). Thus, the total number of people residing within the halo of biogas dispersion from the “Samosyrovo” and “Korgashino” landfills was 4,491 people on 5267 sq. km.

Over the past four years, the total population in two districts has decreased by 250 people or by 5%, the mortality was 103 people

or 2% of the population. The human population of both districts increased by 129 newborns, i.e. the natural population growth was 26 people; 44 cases of pregnancy complications were noted. The number of recorded diseases increased by 18%. The number of respiratory diseases increased from 888 cases to 1021. The number of visits with circulatory system diseases increased from 121 to 169. The number of diagnosed diseases of the nervous system increased from 50 to 65.

According to the International Classification of Diseases, the respiratory diseases include the acute respiratory diseases, bronchitis, pneumonia, bronchial asthma, pulmonary emphysema, chronic nonspecific lung diseases; the circulatory system diseases include arrhythmia, atherosclerosis, hypertension, vasoneurosis, myocardial infarction, ischemic heart disease, cardiosclerosis, pericarditis, congenital and acquired heart diseases, angina, endocarditis; the diseases of nervous system include extrapyramidal and other motor disorders, degenerative diseases of nervous system, demyelinating diseases of central nervous system, episodic and paroxysmal disorders, polyneuropathies and other lesions of peripheral nervous system, diseases of the myoneural junction and muscles, cerebral palsy and other paralytic syndromes<sup>27,28</sup>.

The overall dynamics of decline in population, fertility and population density over a four-year period is confirmed by positive values of the correlation coefficients between the indicators: population and density ( $r = 0.99$ , when  $p < 0.01$ ), population and fertility ( $r = 0.65$ ;  $p < 0.05$ ), fertility and population density

Negative values of the correlation coefficients between morbidity and number of inhabitants ( $r = -0.98$ ;  $p < 0.01$ ), morbidity and population density ( $r = -0.97$  when  $p < 0.01$ ), morbidity and fertility ( $r = -0.68$ ;  $p < 0.01$ ) indicate a tendency to increase the number of diseases with a general decrease in the number, density and fertility of the population. Positive material correlation coefficients also indicate a deterioration in the population health status:  $r = 0.94$  ( $p < 0.01$ ) between the indices of the number of diseases of the respiratory organs and the circulatory system;  $r = 0.90$  ( $p < 0.05$ ) –between the respiratory and nervous system;  $r = 0.71$  ( $p < 0.05$ ) –between the nervous system and circulatory system

Public health depends on various factors, including socio-economic and ecological living conditions, psychological comfort, efficiency of the health care system, etc. The additional research requires identifying these factors and studying the contribution of each of them. However, in this paper we will focus on one environmental factor - the impact of biogas emitted by landfill masses, since the permanent residence in conditions of elevated concentrations of toxic gaseous substances in ambient air cannot but affect the human body.

The operation of the Korgashino landfill started in 1987, the Samosyovo landfill has been operating since 1960. Such period is essential for people living near the landfills location. This is confirmed by the state statistical reports, according to which the average life expectancy in Russia is 67 years. For the period from 1987 to 2084, the calculated total emission of biogas to ambient air from the Korgashino landfill will be 530,021 tons, namely 153,048 tons of methane, 333,988 tons of carbon dioxide, 42,985 tons of microcomponents of biogas. For the period from 1960 to 2092, the estimated total biogas emission to ambient air from the Samosyovo landfill is estimated at 1,935,815 tons, of which 557,619 tons of methane, 12,227,909 tons of carbon dioxide, 150,287 tons of micro-components of biogas<sup>29,30</sup>.

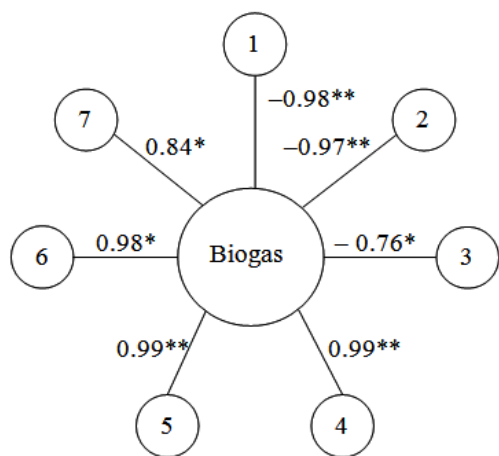
With increasing volumes of biogas emission in the ambient air, there are tendencies of reduction of population ( $r = -0.98$ , when  $p < 0.01$ ), density ( $r = -0.97$ , when  $p < 0.01$ ), fertility ( $r = -0.76$ , when  $p < 0.05$ ) and rise of morbidity of the population ( $r = 0.99$ , when  $p < 0.01$ ), in particular, an increase in the number of diseases of circulatory system ( $r = 0.99$ , when  $p < 0.01$ ), nervous system ( $r = 0.98$ , when  $p < 0.01$ ) and respiratory system ( $r = 0.84$ , when  $p < 0.05$ ). The obtained correlation dependencies (Fig. 1) show a pronounced impact of the environmental factor on the human population in settlements located in the area of biogas dispersion.

Correlation pleiade of human population parameters and anthropogenic environmental factor. *Note:* biogas - annual volumes of biogas emission, t / year; 1 - population, persons per annum; 2 - population density, persons / km<sup>2</sup>; 3 - fertility, persons per annum; 4 - morbidity or number of reported cases, persons per annum; 5 - circulatory system diseases, persons per annum; 6

- diseases of nervous system, persons per annum;  
7 - respiratory diseases, persons per annum; \* - correlation is significant at the level of 0.05; \*\* - correlation is significant at the level of 0.01.

A factor analysis was applied to determine the homogeneous complex groups (factors) of variables with the closest relationship between them. The grouping of data showed that, regardless of the municipal solid wastelands location, all indicators are combined into two identical groups (factors). However, the exception are the indicators of the number of circulatory system diseases and fertility. All selected factors are bipolar, since the factor loadings of the desired indicators fall into positive and negative values, that is, the indicators are divided into two subgroups within each group (factor). Table 1 shows the factor analysis results and factor loadings of the variables in the identified groups (factors). The total share of all factors in the area of the Samosyrovo landfill was 86.3%, and in the area of the Korgashino landfill - 75.3%.

As a result, the first group of indicators, combining the characteristics of biogas emission,



**Fig. 1.** Correlation pleiade of human population parameters and anthropogenic environmental factor. Note: biogas - annual volumes of biogas emission, t / year; 1 - population, persons per annum; 2 - population density, persons / km<sup>2</sup>; 3 - fertility, persons per annum; 4 - morbidity or number of reported cases, persons per annum; 5 - circulatory system diseases, persons per annum; 6 - diseases of nervous system, persons per annum; 7 - respiratory diseases, persons per annum; \* - correlation is significant at the level of 0.05; \*\* - correlation is significant at the level of 0.01

population morbidity and population characteristics was determined to be the most significant or having a large share. The most significant factor has a share of 56.6% in the area of the “Samosyrovo” landfill location; the weight of the first group of indicators in the area of the “Korgashino” landfill location is 55.8%.

The first group (factor 1) falls into two subgroups. The first subgroup includes the indicators that have the most significant factor loadings: the volume of biogas emission from the Samosyrovo landfill (0.99), the volume of methane emission from the Samosyrovo landfill (0.99), the number of respiratory diseases recorded within the halo of biogas dispersion from the landfill (0.98), the number of recorded nervous system diseases (0.94) and circulatory system diseases (0.94). The second subgroup of the first factor is represented by indicators of population (-0.98) and density (-0.98).

In the area of the Korgashino landfill location, the indicators are as follows. The first subgroup of the first factor is formed by indicators of the volume of biogas emission from the Korgashino landfill (0.96), the volume of methane emission from the Korgashino solid waste landfill (0.96), the number of respiratory diseases recorded (0.94) and the nervous system diseases (0.81); the second subgroup combines population (-0.98), density (-0.97), and fertility (-0.87).

The second group or the second factor is less significant and has a share of less than 30%. This factor includes two subgroups for each of the territories under consideration. In the area of the Samosyrovo landfill, the first subgroup is represented by one indicator - the number of deaths per year (0.99), the second subgroup combines the fertility (-0.96), population natural growth (-0.99) and the number of pregnancy complications (-0.87). In the region where the Korgashino landfill is located, the first subgroup consists of the population growth (0.92) and the number of circulatory system diseases (0.95); the second is mortality (-0.85), and pregnancy complications (-0.87).

Figure 2 shows the hierarchy or pyramids of the considered indicators for the two areas, where all the pyramids are shaped like an hourglass. The bases for the most significant factors (factor 1 in both areas) are the indicators characterizing

the anthropogenic (exogenous) impact factor – the biogas, namely, the emission of biogas and methane from municipal solid waste landfills. Indicators characterizing the population morbidity form the central part of the pyramids. For the “Samosyrovo” landfill area, these are the diseases of respiratory, circulatory and nervous systems. For the “Korgashino” landfill area, these are the diseases of respiratory and nervous systems. The indicators characterizing a human population represent the upper part of the pyramids: for the “Samosyrovo” landfill area, these are the population density and number (Fig. 2a, factor 1); for the “Korgashino” landfill area, there are the fertility, population density and number (Fig. 2b, factor 1).

Thus, the toxic properties of gaseous emissions cause the morbidity of the population residing near the landfills. The negative factor loadings of the population and population density indicators in the areas of location of the “Samosyrovo” and “Korgashino” municipal waste landfills are explained as follows. During the period under review, biogas emission from the Samosyrovo landfill doubled, and biogas emission from the Korgashino landfill increased by one and a half. This could not but affect the demographic tension, expressed in a reduction of the number and density of the population in the studied locations.

Indicators that are not associated with the anthropogenic (exogenous) impact factor also form the hourglass pyramid (factor 2 in both

**Table 1.** Groups (factors) of characteristics of biogas and human population according to MSWlandfills locations

Variables	Factor loadings	
	1 Factor	2 Factor
Vysokogorsky municipal district (Samosyrovo, Konstantinovka, Zvankavillages), "Samosyrovo" landfill		
Volume of biogas emission, t/year	0.99*	0.14
Methane emission, t/year	0.99*	0.14
Population, pers. per annum	-0.98*	0.14
Population density, pers./km <sup>2</sup>	-0.98*	0.19
Fertility, pers. per annum	0.04	-0.96*
Mortality, pers. per annum	0.11	0.99*
Natural growth, pers. per annum	-0.07	-0.99*
Respiratory system diseases, pers. per annum	0.98*	0.06
Nervous system diseases, pers. per annum	0.94*	0.32
Circulatory system diseases, pers. per annum	0.94*	0.33
Complications during pregnancy, pers. per annum	-0.21	-0.87*
Total share of factors, %	56.6	29.7
City settlement Pirogovsky (Kardo-Lenta, Vysokovo, Korgashino, Svinoedovovillages), Korgashino landfill		
Volume of biogas emission, t/year	0.96*	0.17
Methane emission, t/year	0.96*	0.17
Population, pers. per annum	-0.98*	0.16
Population density, pers./km <sup>2</sup>	-0.97*	0.19
Fertility, pers. per annum	-0.87*	0.38
Mortality, pers. per annum	-0.47	-0.85*
Natural growth, pers. per annum	-0.38	0.92*
Respiratory system diseases, pers. per annum	0.94*	0.31
Nervous system diseases, pers. per annum	0.81*	-0.58
Circulatory system diseases, pers. per annum	0.01	0.95*
Complications during pregnancy, pers. per annum	0.43	-0.87*
Total share of factors, %	55.8	29.5

Note:\* –major factor loadings

areas). These pyramids characterize the specificity or particular features of the human population of each of the areas under consideration.

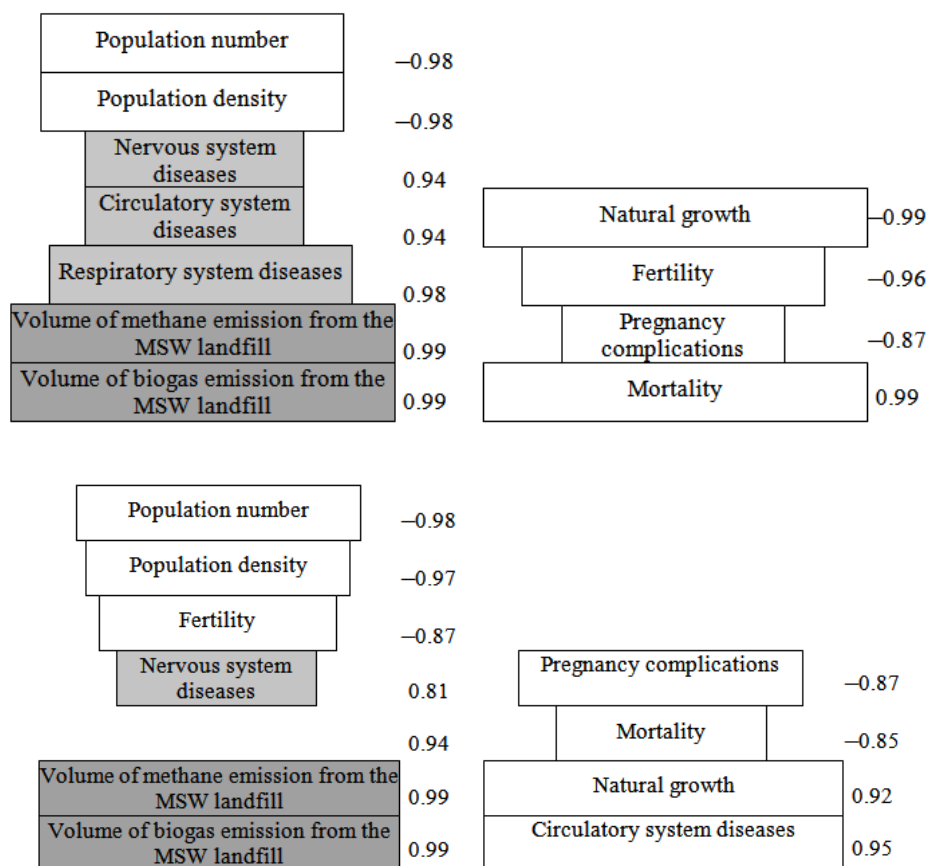
For the area of the Samosyrovo landfill location, the population indicators are distributed in the order of decreasing factor loadings as follows: mortality rate, pregnancy complications, fertility and natural growth (Fig. 2a, factor 2); for the area of the Korgashinolandfill, they will be the circulatory system, natural growth, mortality and pregnancy complications (Fig. 2 b, factor 2).

We describe the given data as a functional relationship  $y = f(x)$ , using the least squares method. As a result, we obtain a series of mathematical descriptions. The nonlinear regression equations described the response of a human body to the anthropogenic factor impact – the landfills biogas (factor 1).

Thus, the response of the human body to the continuous long-term impact of the increased content of biogas in the ambient air from the “Samosyrovo” and “Korgashino” MSW landfills has the following mathematical description.

For Vysokogorsky municipal district Zvanka, Konstantinovka, and Samosyrovo villages):

- Population number is determined by the formula:  $f(x) = 46 \cdot 10^{-8}x^2 - 0,07x + 7041$ ;
- Population density:  $f(\delta) = 15 \cdot 10^{-11}x^2 - 2 \cdot 10^{-5}x + 1,82$ ;
- Number of nervous system diseases:  $f(x) = 3 \cdot 10^{-8}x^2 - 0,004x + 151$ ;
- Number of respiratory system diseases:  $f(x) = -6 \cdot 10^{-8}x^2 + 0,01x + 260$ ;
- Number of circulatory system diseases:  $f(x) = 8 \cdot 10^{-8}x^2 - 0,01x + 329$ .



**Fig. 2.** Ecological pyramids of the characteristics dependencies of biogas and human population by the location of the “Samosyrovo” and “Korgashino” landfills.

Note: the numbers to the right of the pyramids indicate the factor loadings

For Pirogovsky urban settlement (Kardo-Lenta settlement, Vysokovo, Korgashino, and Svinoedovo villages):

• Population number is determined by the formula:

$$f(x)=4\cdot 10^{-7}x^2-4\cdot 10^{-5}x+579;$$

• population density:  $f(x)=-4\cdot 10^{-10}x^2-10^{-7}x+0,6;$

• Number of nervous system diseases:

$$f(x)=3\cdot 10^{-9}x^2-10^{-5}x+0,8;$$

• Number of respiratory system diseases:

$$f(x)=2\cdot 10^{-7}x^2+10^{-5}x-39;$$

• Number of circulatory system diseases:

$$f(x)=-2\cdot 10^{-8}x^2-4\cdot 10^{-6}x+25.$$

### CONCLUSION

In modern urbanized conditions, the human population is experiencing a constant effect of various exogenous factors - social, economic, environmental. Now, that is quite a challenge to single out the leading or dominant impact factor of the current total. At the same time, there is no doubt that the environmental impacts on the human population adversely affect the population health. Human habitation in highly polluted ambient air leads to the diseases of respiratory, nervous and circulatory system, and may contribute to the pregnancy complications. The discovered response of the human body to the impact of anthropogenic factor - the increased content of pollutants in the ambient air - reflects a tendency to oppress it if the person resides near the waste landfills. This is manifested by a reduction of the population, density, fertility and an increase in the population morbidity.

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