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Assessment of the risk of dust influence on human health in urban built-up areas

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Abstract. The non-carcinogenic risk of chronic effects Rch and immediate effects Rn caused by human exposure to dust depending on the urban development density was determined. The equation was obtained which sets the relation between the concentration of dust in the atmospheric air and the air temperature, humidity, wind velocity, the coefficient of housing development density, the specific load of dust pollution on the atmosphere. It can be used in practice in the course of dispersion calculation and risk assessment, including the forecasting ones.

Nomenclature

R_{ch}- non-carcinogenic risk of chronic effects
R_{n}- non-carcinogenic risk of immediate effects
C- daily average concentration of polluting substance
C_1, C_2- concentration of $PM_{2,5}$ and PM_{10} fractions

Introduction

The atmospheric pollution with solid particles plays a major role among the factors influencing the ecological safety of urban environment. According to the data [1], 66% of urban citizens are exposed to dust, which amounts to about 71,6 million people.

Recent investigations allow revealing a significant dependence of the incidence of diseases of the respiratory system among townspeople on the degree of atmospheric air pollution. It is established that micro particles PM10 and PM2,5 are the most hazardous for human health, which can easily penetrate into a human organism and deposit in various divisions of respiratory tract. In addition, it should be noted that such particles have large specific surface area, they can absorb a considerable amount of various substances from the environment and transport them into human organisms [2-4].

At the present time in Russia, the evaluation of the hazard of polluting substances for human beings and the choice of relevant protective measures are conducted through the comparison of the level of atmospheric pollution with the maximum permissible concentration (MPC) of the substance in the air. In accordance with [4], the MPC for suspended particles PM10 and PM2,5 are specified.

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The risk of any possible negative consequences is not determinant. However, it should be noted that the awareness of the risk level allows justifying the choice of protective measures as early as at the design stage even when the sanitary hygiene standards are observed.

Objective and tasks of research

The assessment of the risk of dust influence on human beings was carried out in accordance with the non-threshold model of exposure [5], through which the non-carcinogenic risk of chronic effects R_{ch} (1) and of immediate effects R_n (2) were determined:

$$R_{ch}=1\text{-}\exp\left[\frac{\ln 0{,}84}{K_3}\left(\frac{C}{PDK}\right)b\right], \quad (1)$$

where *R*- is the non-carcinogenic risk of chronic effects; *C*- is the daily average concentration of polluting substance, mg/m^3; PDK_{cc}= MPC_{da}- is the maximum permissible daily average concentration, mg/m^3; K_3- is the depreciation factor; *b*- is the isoefficiency coefficient,

$$R_n \; \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Prob} \exp\left(-\frac{C^2}{2}\right) dx\,, \quad (2)$$

where P_{rob}- is the probability of occurrence of undesirable outcome which is determined depending on the class of hazard of the substance, *C*- is the daily average concentration of the polluting substance, mg/m^3.

For the purpose of the evaluation of the amount of particles $PM_{2,5}$ and PM_{10}, it is possible to use the calculation dependences [6] in the course of risk assessment. However, dust dispersion is a very complex process, which is determined by both meteorological factors and the characteristic features of built-up areas. In order to make the calculation dependences more specific for the evaluation of the amount of particles $PM_{2,5}$ and PM_{10} in urban districts with various housing development density, the particle size distribution of dust was analyzed through the method [7,8].

The method developed by the authors [7,8] and aimed at determining the particle size distribution of dust through microscopical method is based on the measurement of particle size of the dust under investigation by means of photographing the samples magnified by 200-2000 times under a microscope applying an attachment.

In order to carry out the analysis, samples of dust were collected in various districts of Volgograd where the housing development is characterized by some specific features. For the purpose of general evaluation of housing development influence on the dispersion of hazardous substances in urban localities, it seems to be reasonable to use the existing regulatory indices of housing development density of territorial zones, to which the coefficient of housing development density i.e. the ratio of the area of all the buildings and constructions to the area of the city block or the site belongs [9]. For the purpose of the investigation of pollutants transfer under the conditions of urban built-up areas, the zoning method is rather often used, which implies representing a non-homogeneous urban territory as a set of “quasi-homogeneous zones” with each of those having certain characteristics [10]. In the present case, they are the equal values of the coefficient of housing development density.

In the territory of Volgograd, the authors singled out “quasi-homogeneous zones” with the coefficient of housing development density: K_d= 0,5 (the housing development zone with low-rise multi-apartment residential buildings of 4 storeys or lower), K_d= 0,8 (the housing development zone with low-rise multi-apartment residential buildings of 4 storeys or lower in the territories intended for reorganization), K_d= 1,0 (the housing development zone with high-rise multi-apartment residential buildings of 5 storeys or higher), K_d= 1,4 (the mixed housing development zone with residential buildings). The sampling was carried out at 8 points of each zone once a week throughout 6 months. Altogether, 14 series of the tests were carried out. The given number of measurements was chosen according to [11] in such a way as to ensure the confidence level of the sample to be 95%.

The median integral functions of the particle mass distribution according to diameters are given in Fig. 1.

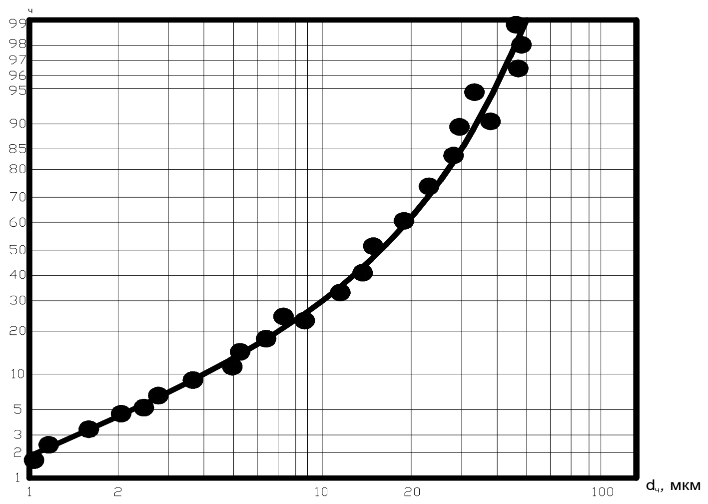


Fig. 1. Median integral functions of particle mass distribution according to diameters. 1- K_d= 1; 2- K_d= 0,5; 3- K_d= 1,4; 4- K_d= 0,8

Based on the analysis of the dust particle size distribution, the dependences which allow determining the concentration of fine particles $PM_{2,5}$ and PM_{10} were obtained with regard to the coefficient of housing development density:

For the zones with the coefficient of housing development density K_d= 0,5

$$C_1=D(2,5\ \mu m)C = 0,03C \quad (3)$$

$$C_2= D(10\ \mu m)\ C = 0,85\ C \quad (4)$$

For the zones with the coefficient of housing development density K_d= 1

$$C_1=D(2,5\ \mu m)C = 0,032C \quad (5)$$

$$C_2=D(10\ \mu m)\ C = 0,9\ C \quad (6)$$

For the zones with the coefficient of housing development density K_d = 0,8

$$C_1=D(2,5\mu m)C = 0,02C \quad (7)$$

$$C_2=D(10\ \mu m)\ C = 0,15\ C \quad (8)$$

For the zones with the coefficient of housing development density K_d = 1,0

$$C_1=D(2,5\mu m)C = 0,028C \quad (9)$$

$$C_2=D(10\ \mu m)\ C\ = 0,8\ C \tag{10}$$

For the zones with the coefficient of housing development density K_d = 1,4

$$C_1=D(2,5\mu m)C\ = 0,03C \tag{11}$$

$$C_2=D(10\ \mu m)\ C\ = 0,25\ C\ , \tag{12}$$

where C_1, C_2 - are the concentrations of the $PM_{2,5}$ and PM_{10} fractions, respectively, mg/m^3; D(2,5 µm), D(10 µm) - are the proportions of the particles $PM_{2,5}$ and PM_{10}.

The obtained values are given in table 1. Taking into account the obtained values and based on the equations (1,2), the assessment of the risk of human exposure to dust was carried out.

Table 1. Assessment of the ecological risk of dust influence.

Coefficient of housing development density	***1,4***	***1,0***	***0,8***	***0,5***
1	***2***	***3***	***4***	***5***
Warm period of year				
C , [mg/m^3]	*1.1*	*1.0*	*0.8*	*0.4*
C_1 , [mg/m^3]	*0.286*	*0.26*	*0.208*	*0.104*
C_2, [mg/m^3]	*0.605*	*0.55*	*0.44*	*0.22*
R_{ch}	*0.236*	*0.162*	*0.143*	*0.176*
R_n	*0.229*	*0.20*	*0.133*	*0.083*
Transition period of year				
C , [mg/m^3]	*0.85*	*0.7*	*0.4*	*0.2*
C_1 , [mg/m^3]	*0.22*	*0.20*	*0.18*	*0.15*
C_2, [mg/m^3]	*0.56*	*0.48*	*0.35*	*0.12*
R_{ch}	*0.346*	*0.32*	*0.143*	*0.074*
R_n	*0.162*	*0.134*	*0.077*	*0.037*
Cold period of year				
C , [mg/m^3]	*0.75*	*0.45*	*0.2*	*0.1*
C_1 , [mg/m^3]	*0.195*	*0.117*	*0.052*	*0.026*
C_2, [mg/m^3]	*0.412*	*0.248*	*0.11*	*0.055*
R_{ch}	*0.251*	*0.160*	*0.074*	*0.04*
R_n	*0.144*	*0.086*	*0.038*	*0.004*

Note: The $MPC_{max.sing.}$ for suspended particles PM_{10} is 0,3 mg/m^3, for $PM_{2,5}$ it is 0,16 mg/m^3 [2].

In order to forecast the ecological risk at the stage of design through the method of correlation and regression analysis, a mathematical dependence of dust concentration in urban atmospheric air was obtained, which takes into account the influence of the air temperature (T), humidity (W), wind velocity (V), the coefficient of housing development density of the "quasi-homogeneous zone" under consideration (K_d), and the specific load of dust pollution on the atmosphere of the "quasi-homogeneous zone" under consideration P.

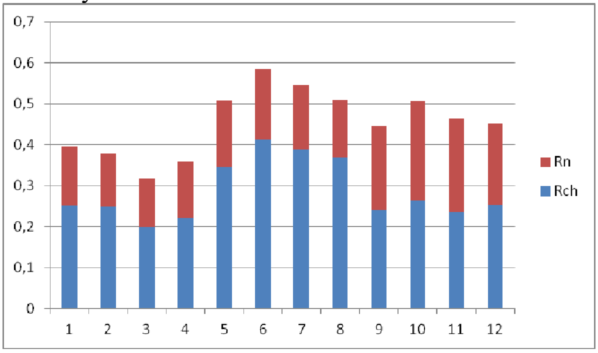
The specific load of dust pollution on the atmosphere of the "quasi-homogeneous zone" P was assessed according to the method [12].

In the natural scale, the equation has the form:

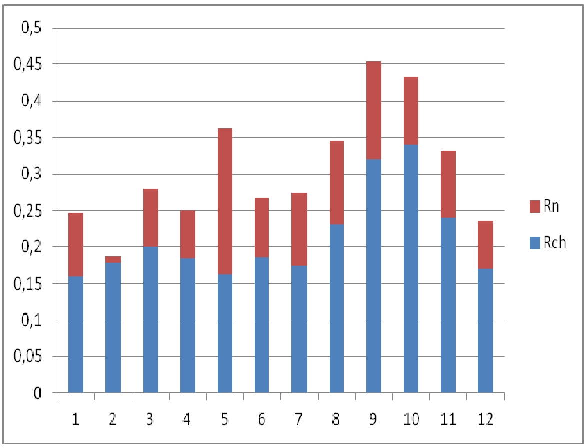
$$C = 1,706 - 0,006T + 0,067\ W - 0,212\ V\ - 0,0002\ K_d + 0,15P\ . \tag{13}$$

Checking the obtained equation through the Fisher criterion showed its adequacy (the table value of the Fisher criterion for the significance level of 0,05 is 5,15, the calculated value is 9,4).

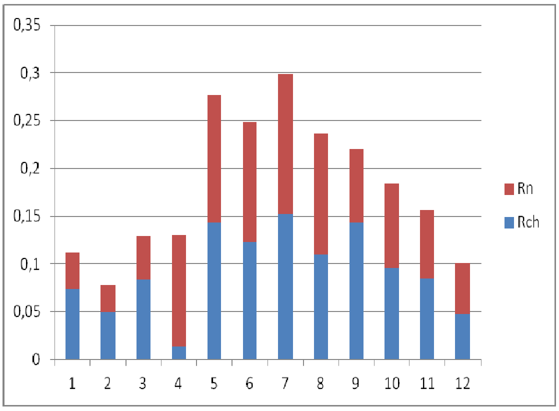
Based on the obtained dependence (13), it is possible to forecast the non-carcinogenic risk of immediate and chronic effects with regard to the housing development density and meteorological factors. Figure 2 shows the forecast of non-carcinogenic risk of chronic and immediate effects for the year of 2020.



a



K=1 b



c

K=1,2

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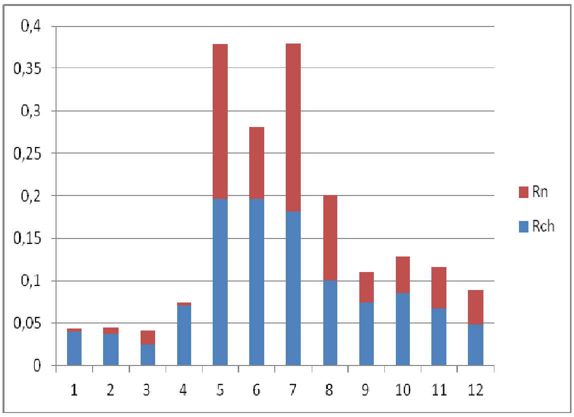

d

Fig. 2. Forecast of non-carcinogenic risk of chronic effects (R_{ch}) and immediate effects (R_n) for the year of 2020 at the coefficient of housing development density K_d= 1,2(a), K_d = 0,8(b), K_d = 0,6(c), K_d = 0,4(d).

The analysis of the data from table 1 and figure 2 shows that the winter period is characterized by a higher stability of the risk values, which can be explained by a rather constant amount of solid particles in the atmosphere. During the spring period, the parameter under control varies within a wider range, which can be explained by a large scatter of the values of solid particles concentration in the air as well as by variations in air temperature and humidity. The housing development with the density coefficient of K= 1,2-1,4 is subjected to the largest risk. The risk value lies within the range of 0,05-0,4, which is assessed as a moderate risk. In this case, measures aimed at organizing permanent monitoring and developing activities intended for the reduction of emissions into the atmosphere are recommended [13].

Conclusion

1. The dust particle size distribution is analized for the city districts which differ in man-induced load and the specifics of housing developemt. The authors obtained the dependences which allow determining the concentration of fine particles PM2,5 and PM10 in the air of urban environments with various coefficients of housing development density.
2. Through the method of multiple correlation, an equation is obtained, which sets the relation between the dust concentration in the air of urban environment and the climatic parameters and the coefficient of housing development density, on the basis of which the calculations of dispersion can be carried out, including the forecasting ones.
3. The non-carcinogenic risk of chronic effects Rch and immediate effects Rn caused by human exposure to dust depending on the housing development density in the territory was determined. A forecast of the ecological risk of exposure to dust depending on the housing development density, was conducted for the year of 2020.

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