7.15 FUNCTIONAL OF RECEPTOR SENSITIVITY TO SPATIAL PROXIMITY OF EMISSIONS SOURCES AND CONJUGATE PROBLEM

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INTRODUCTION

Contemporary investigations indicate that atmospheric pollution contributes to morbidity and premature mortality (*Reshetin V.P. and V.I. Kazazyan,* 2004; *Reshetin V.P. and J.L. Regens,* 2002; *Dockery D. et al,* 1993; *Kunzli N. et al,* 2000; *Arutyunyan R.V. et al*, 2001; *Reshetin V.P. et al,* 2000). As an example, mention can be made of unique epidemiological investigations (*Dockery D. et al,* 1993) in which a coherent and statistically reliable relationship is established between contamination of the atmosphere by fine suspended particles of size less than 10 μm and mortality. Assessments of a number of attributable deaths indicate that about 6% of all the mortality cases in France, Austria, and Switzerland are due to the pollution of the atmosphere by fine particles of size less than 10 μm (*Kunzli N. et al,* 2000). Taking into account a higher exposure level in Russia, the number of attributable deaths caused by the atmospheric pollution can be much higher and attain 16 – 17 % of the total mortality number (*Reshetin V.P. and V.I. Kazazyan,* 2004). In this connection, the problem of population health risk reduction becomes especially urgent. One of the ways of its solution is optimization of the sitting of new industrial enterprises and complexes. Of no less importance is also the problem of an optimal decrease in the level of emission of harmful chemicals on pre-existing industrial enterprises. In view of the fact that laboratory resources have been distributed no uniformly, these enterprises are usually sited in densely populated regions or in close vicinity of them. The benefit for health and environment derived from reduction of the emission level will depend substantially on the location of emissions sources.
The problem of optimal sitting of new industrial enterprises and effective reduction of emissions on pre-existing ones can be solved by calculating the receptor sensitivity functional (*Reshetin V.P. and R.V. Arutyunyan,* 2002). The functional of the receptor sensitivity of a territory to sitting an emission object makes it possible to quantitatively assess a change in the population health risk depending on the location of an emission source. New possibilities of calculating the receptor sensitivity are afforded by the mathematical apparatus of conjugate problems (*Marchuk G.I.,* 1992). In the present work, the results obtained in (*Reshetin and Arutyunyan,* 2002; *Marchuk G.I.*, 1992) were applied to investigation of the problem of optimal sitting of enterprises and mathematical models of the most typical situations are considered.

STATEMENT OF THE PROBLEM AND MODELS

Suppose it is required to site a new industrial enterprise near populated localities or directly on the territory of a large populated area so that the population health risk over the entire region Σ_0 due to the pollution of the latter be minimal or not higher than certain permissible standards. Let us assume that an aerosol source *f(r)* is located at the point $\vec{\mathbf{r}}_\mathbf{0} = (x_0, y_0, z_0)$ and its intensity is *Q*:

$$f(\vec{\mathbf{r}}) = Q\,\delta(\vec{\mathbf{r}} - \vec{\mathbf{r}}_\mathbf{0}) \qquad (1)$$

Under the action of the wind, the impurity is transferred by air masses and diffuses as affected by low-scale convention. In the simplest statement, impurity transfer in the atmosphere can be described by the equation:

$$\frac{\partial C}{\partial t} + \mathrm{div}(\vec{\mathbf{U}}\,C) + \lambda\,C - K_x\,\frac{\partial^2 C}{\partial x^2} - K_y\,\frac{\partial^2 C}{\partial y^2} - \frac{\partial}{\partial z}K_z\,\frac{\partial C}{\partial z} = Q\,\delta(\vec{\mathbf{r}} - \vec{\mathbf{r}}_0) \quad (2)$$

where C is the impurity concentration in the atmosphere; $\vec{\mathbf{U}}$ is the wind velocity; K_x, K_y, and K_z are the coefficients of diffusion in the direction of the x, y, and z axes; λ is a constant determining the decomposition of the impurity with time; δ(r)- Dirac delta function.

The solution of the problem will be determined in the cylindrical region, in which the boundary conditions taken are

$$\mathrm{C}\big|_{\Sigma} = 0, \qquad \left.\frac{\partial \mathrm{C}}{\partial \mathrm{z}}\right|_{\Sigma_0} = \alpha\,\mathrm{C}, \qquad \left.\frac{\partial \mathrm{C}}{\partial \mathrm{z}}\right|_{\Sigma_H} = 0 \quad (3)$$

where Σ is the lateral cylindrical surface; Σ_0 is the section of the cylindrical surface at the level z = 0; Σ_H is the section of the cylindrical surface at the level z = H; α - constant determining the interaction between the impurity and the ground surface.

We also assume that function C is periodic, with the period T

$$C(\vec{\mathbf{r}}, T) = C(\vec{\mathbf{r}}, 0) \quad (4)$$

To assess the health risk for the residents of the region Σ_0, the ground-level aerosol concentration is multiplied by the population density *P(r)* and the resulting function is integrated over the area of the region and the time period T

$$F = a\int_0^T dt \int_{\Sigma_0} P\,C\,d\Sigma \quad (5)$$

Here $a = b/T$; the constant b reflects the dose - response relationship. The numerical values of this constant were found, e.g., in *Dockery D. et al* (1993). Correct to within a multiplier, equation (5) determines the collective exposure, averaged over the time period T, that will affect the population of the region due to the emission of aerosols by source (1). The value of term (5) at a given location of the emission source represents assessment of the effect exerted by the aerosol source on the population. Moreover, if, to obtain this assessment, the dose - response function established earlier in epidemiological investigations (*Dockery D. et al,* 1993) is used, it determines the relationship between exposure and premature mortality, whereas term (5) represents the assessment of the number of premature deaths caused by the atmospheric pollution. Carrying out calculations of term (5) for the emission sources located at different points of the region, it is possible to assess in which way the number of premature deaths caused by atmospheric pollution can change depending on the location of the source. In work (*ReshetinV.P. and R.V. Arutyunyan,* 2002) term (5) is called the receptor sensitivity of the territory to the sitting of emissions sources.

We note that at the existing level of exposure for many harmful effects to health and an environment, the relationship between exposure and response is linear. Thus, the distribution of the term (5) over the territory of the region represents the assessment of the receptor sensitivity of the territory to sitting of an emission source (*ReshetinV.P. and R.V. Arutyunyan,* 2002). At the given intensity and location of the emission source, the value of term (5) depends on the wind rose typical of this locality, lay of the ground, and the special features of distribution of population over the territory of the region. Due to the dose - response function linearity, the effect exerted by several emission sources on the population and environment is an additive quantity. Thus, the receptor sensitivity of the territory is independent of the location of the pre-existing emission sources in the region. The distribution of the receptor sensitivity function over the region makes it possible, in particular, to analyze the extent to which a decrease in emission at a certain industrial enterprise will be efficient from the viewpoint of risk reduction; moreover, at the same decrease in the level of emission the risk

reduction will be the greatest for the enterprises which are located on the territory with a high value of the receptor sensitivity term (*ReshetinV.P. and R.V. Arutyunyan,* 2002).
The term similar to that used above, (5), can be introduced to assess an environment risk. However, depending on the priorities selected, as the function *P(r)* one should select the distribution of these or other parameters significant for assessing the environment risk. Since, in assessing the environment risk, the effects are usually considered at the level of population of community or of an ecosystem, the dynamics of the population, the structure of the community, and the processes occurring in the ecosystem are those end points on which the risk assessment is usually concentrated. In the absence of universal environmental assessment of end points, the risk assessment and the calculation based on the territory receptor sensitivity must rather be restricted by a particular situation. In determining the function *P(r)*, those resources must be considered in the first place which potentially are exposed to emission products. In identifying the end points of risk assessment and determining the function *P(r)* conceptual models, environmental effects, and other factors must be analyzed. Trough the focus of the work reported here was on human health, the approach developed in this study can be extended readily to ecological receptors to provide better estimates of exposure to airborne discharges across complex landscapes.
With the main term of the problem being selected in the form of (5), the problem conjugate to the principal one is formulated as follows:

$$-\frac{\partial C^*}{\partial t} - \mathrm{div}(\vec{U} C^*) + \lambda C^* - K_x \frac{\partial^2 C^*}{\partial x^2} - K_y \frac{\partial^2 C^*}{\partial y^2} - \frac{\partial}{\partial z} K_z \frac{\partial C^*}{\partial z} = P(r)\,\delta(z)$$

$$C^*\Big|_{\Sigma} = 0, \qquad \frac{\partial C^*}{\partial z}\Big|_{\Sigma_0} = \alpha C^*, \qquad \frac{\partial C^*}{\partial z}\Big|_{\Sigma_H} = 0 \qquad (6)$$

$$C^*(r,T) = C^*(r,0)$$

By virtue of the fact that the problems are conjugate, equation (5) may be written in the following form (double representation of the term (*Marchuk G.I.*, 1992)):

$$F = a\,Q \int_0^T C^*(r_0, t)\,dt \qquad (7)$$

Term (7) depends parametrically on the location of the source of aerosols. When $z = 0$, solution of a conjugate problem determines the time dependence of the collective exposure of the population of the region C^* on the location of the emission source of unit intensity. Thus, the attractive side of the solution of a conjugate problem becomes evident: its solution makes it possible to determine collective exposure, whereas, to calculate the receptor sensitivity of the territory of the region, it is necessary simply to average this exposure for a certain interval of time and multiply by the coefficient which is determined by the dose – effect relation. Unlike the principal problem, where, to calculate term (5), it is required to find the distribution of the aerosol concentration for each location of the emission source, in a conjugate problem term (5) can be calculated by performing only one variant of calculation.
In some cases term (5), which apart from a factor, is equal to the exposure average for the period *T*, can be calculated as superposition of stationary solutions of conjugate problem (6):

$$F = a\,Q \sum_{i=1}^{n} C_i^* \Delta t_i\,, \text{ where } \sum_{i=1}^{n} \Delta t_i = T \qquad (8)$$

where Δt_i is the time of a stable regime of air masses.

Stationary solutions of the conjugate problem can be used to average the exposure *C** over the wind directions with allowance for the wind rose in the region. The averaging over stationary solutions allows one to calculate, with a sufficient accuracy, the receptor sensitivity for a situation in which the contribution of transient processes is insignificant.

An example of calculation of the receptor sensitivity term for the territory of the city of Minsk with the use of the "Nostradamus" code (*Arutyunyan R. V., V. V. Belikov, G. V. Belikova, et al.*, 1995) is presented in Fig. 1. The data (*Gidromet,* 1987) on the wind rose averaged over the period of many years of observation were used. As expected, different regions of Minsk are not equivalent from the viewpoint of their sensitivity to the emission sources. It is especially interesting that the sensitivity term differs for different regions of the city by more than an order of magnitude. This means that if there are two identical emission objects, the impaired health of the residents may differ more than tenfold depending on the location of a source. For a source located near the ground the value of the receptor sensitivity term at the given point on the territory of Minsk depends substantially on the number of people living in the region of size $K_y^{-1/2}$, where the concentration of aerosols decreases due to convective diffusion. The higher the elevation of the emission source, considerably greater is the contribution of more distant territories. In this case, the asymmetry in the directions and strengths of winds substantially influences the distribution of the term (5).

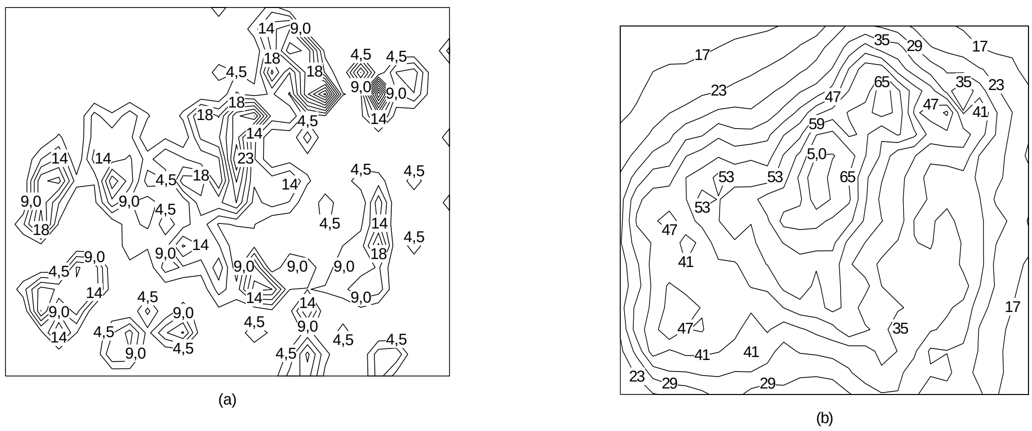

Figure 1. Population density distribution, thousand people/km^2 (a) receptor sensitivity functional (b) (relative units) for Minsk. Computational domain is 21 x 16 km, h=0 m.

CONCLUSIONS

The term of receptor sensitivity of the territory to sitting of an emission source can be calculated efficiently with the aid of the mathematical apparatus of conjugate problems.

To reduce the risk to health and environment, it may well be that for each region a program can be composed for sitting of industrial enterprises that release harmful aerosols and gases into the atmosphere. For each region, with allowance for climatic conditions, fields of winds, and specific features of the terrain, maps could be prepared which would reflect the distribution of the receptor sensitivity over their territory. This work should be done in the first place when planning the building of objects in economic development regions, where decisions rational from the viewpoint of protecting the environment and population could be made.

Mapping of the territory of the region by the magnitude of the receptor sensitivity would also be useful in drawing a plan of measures intended for decreasing the emission by industrial enterprises and vehicles. The distribution of the receptor sensitivity term over the region would make it possible to assess the efficiency of the measures suggested from the viewpoint of health risk reduction.

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