Spatial Modeling of the Processes of Spreading of Emissions from Thermal Plants and Boiler Houses

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***Abstract* - Geographic information systems allow to solve the complex and multifactorial tasks in creating models of pollution of the air basin from the pipes of thermal power plants and boiler-houses. They make it possible to collect and process together table, textual and cartographic data. GIS analyzes and visualizes the results of modeling. Automation of information processing and analysis led to the adoption of effective administrative decisions in the shortest possible time.**

***Keywords*: average "reference" function of distribution of polluting substances, models of spatial influence, pollution of air pool, technique of geomodeling.**

At the location of power facilities one of the main problems is the air pollution in the vicinity of thermal power stations and boiler-houses. So urgent is the problem of estimating the levels of pollution in the operation and design of these objects and the objects of urban development. It is important to increase the quality of design solutions through the use of accurate media pollution assessment. The problem usually lies in the lack of precise estimates of the joint action of a large number of pollution sources, their integration effect. A number of studies confirm that the normative methodology used in Russia does not take into account the combined impact of existing pollution sources in modern cities. This problem has a complex multi-factor system character, and its distinctive feature is a need to take into account the territorial (geographical) distribution and interaction of the sources of pollution.

Therefore, an effective solution can be obtained only through the use of geoinformation technologies. Geographic information system (GIS) combines the spatial and attributive databases. Due to the visibility of spatial analysis GIS provides a significant effect during the decision making on placement of industrial and energy facilities, the optimization of transport and engineering networks, for the conservation and improvement of the ecological situation around industrial enterprises. Spatial modeling or geomodelling allows the automation of the process of decision making in the information systems of the city or the region due to “play scenarios” of allocation of industrial, energy and other facilities and consideration of a large number of alternative project goals and search of optimal variants [1].

In order to take into account a number of factors there are various methods of spatial analysis and modeling, and they are constantly evolved and improved. Common for all these methods is the fact that the properties of the territory are determined mainly those objects, which are on the territory or close to it. This rather obvious fact allows us to consider a technique of definition of the various properties of the territory by means of calculation and visual cartographic representation of integral impact of objects on this territory.

For the determining the properties of an arbitrary point through the function of spatial influence on this point from the objects on this territory, it is advisable to use raster and vector formats spatial data. The spatial position of objects is given in the structural (vector) format, and the valuation properties of the territory are in a position (bitmap) format. Such integration is achieved through the influence function of objects on the basic sections of the set *W*, covering the territory.

Influence function can be represented analytically or as an array of numbers setting this feature in a tabular form. For point and linear objects the influence function is determined by four variables:

$$S_{ij} = f(S_i, R_i, r_{ij}, \alpha_{ij}), \qquad (1)$$

where S_{ij} is the property of the i-th element of *W* from the influence of the j-th object; S_i - value (weighting factor) of the property of the object at the point or points of its spatial position; R_i - impact range of the j-th object, i.e. the distance beyond which the influence of an object can be neglected; r_{ij} and α_{ij} - distance and direction between the i-th point and the j-th object.

Essentially, the current value of the S_{ij} depends on r_{ij} and αij, as the S_i and R_i are the parameters of the function *f*. This feature is used in a geographical model of spatial influence (SIM). SIM can be specified in several ways:

1) analytically, i.e. the analytical expression (1) or through the coordinates of the point of the territory (*x*, *y*), namely $S_{ij} = f(x,y)$;

2) numerically, the model is described in the form of a table (matrix) of influence values in the considered points of the territory. This view is in the processing of information obtained by direct measurements or the various numerical methods;

3) graphically, as a set of lines of equal level. It is a form of presentation, in which the spatial information is described on the plane in the form of borders of the sections, corresponding to the specific values of influence function. Usually cross-section is produced with equal step;

4) graphically, as a spatial relief - a form of three-dimensional presentation.

For example, in the case if the object is a spot, SIM is presented in the hills or depression.

The developed principles of construction of models of spatial influence allow to generate the library of the models for their operational use in getting the properties of the territory as a combination of models of influence of the objects located on this territory.

Each of the forms of presentation of models is suitable for different forms of analysis of the territory properties. In this case we consider the task of assessing the pollution of air basin in the vicinity of the industrial enterprises from point sources (pipes).

For the decision of ecological problems the most suitable model of spatial impact, defined by the normal distribution law:

$$S_{ij} = \frac{1}{\sigma_j \sqrt{2\pi}} e^{\frac{(r_{ij}\ \mu_j)^2}{2\sigma_j^2}}, \qquad (2)$$

where σ_j, μ_j - respectively the mean square deviation and the value of the mathematical expectation.

The normal distribution law describes the spatial influence in the most accurate way, due to the large number of poorly correlated factors. For the formation of models of influence of point objects equation (2) can be represented in the following form:

$$S_{ij} = S_j e^{-k_j^2 r_{ij}^2}, \qquad (3)$$

Theoretically the radius of influence is equal to infinity. Therefore, the value of R is determined with the size S_{ij}, in which the influence of the object can be neglected. Set this value as

$$S_{ij}^{*} = \nu S_j, \qquad (4)$$

where $\nu < 1$ is an admissible part of the maximum value S_{ij}.

Substituting formula (4) in expression (3), we get:

$$\nu S_j = S_j e^{-k_j^2 R_j^2}$$

or the value of the radius of influence will be determined as

$$R_j = \frac{1}{k_j}\sqrt{-\ln \nu}.$$

In practice the most convenient reference of models of the spatial influence is carried out with the following characteristics: S_j, R_j, f, defined analytically or in table. This is due to the fact that the values S_j and R_j are the most suitable and clear for expert assessments interpretation.

The next level of complexity is the models of point objects, reflecting unbalanced spatial effect. Typical examples of such influence are the models of the distribution of emissions from the pipe of thermal power plant with the wind rose; spilling water from the well with account of the terrain, etc. In these models, the effect of influence S_{ij} depends not only on the distance from the current point to the territory to the object of influence, but also from the direction:

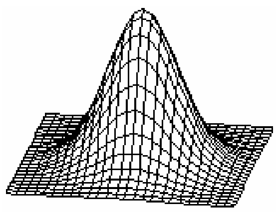
$$S_{ij} = f(r_{ij}, \alpha_{ij}), \qquad (5)$$

where r_{ij} is the distance between the i-th point and the j-th subject, α_{ij} is the angle between, for example, the positive direction of the X-axis and the line connecting the i-th point and j-th object.

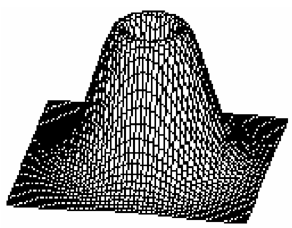
Radius of influence (or in this case more exactly – influence range) of model of such object will depend on the angle of influence direction

$$R_{ij} = f_R(\alpha_{ij}), \qquad (6)$$

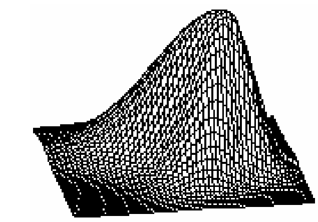
The most difficult are the models reflected the contradictory (opposite properties) of the factors of influence of objects, the size of which depends on the distance r_{ij} and angle of α_{ij}. An example of this is the extent of pollution of the adjacent territory around the pipes of boiler-houses: the pollution is small next to the pipe, the pollution increases far away from the pipe, and then it gradually decreases. The creation of such kind of combined models are encouraged by adding the simple models, reflecting the effect of each of opposing factors or effect of individual components having different functions of influence (fig. 2).



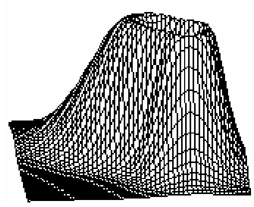
A simple model with the symmetric law of influence.



Combining model with the symmetric law of influence.



Simple model with the asymmetric law of influence.



Combinative model with asymmetric effects of the law.

Fig. 2. Class of point objects models of spatial influence.

All the considered models are a three-level hierarchy (see fig. 2) based on the principle "from simple to complex". The structure serves as the basis for the library of models of the spatial effects and for the generation of these models by methods of object-oriented design.

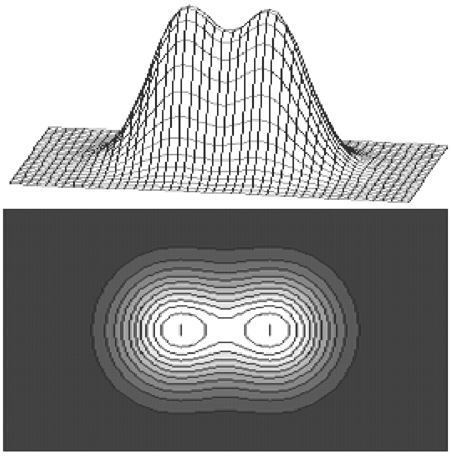


Fig. 3. Integration of spatial influence models.

The resulting assessment relief of the pollution is association (summation) of spatial influence models of the two (see fig. 3) or more objects.

Analytical methods of pollution estimate are used for the preliminary assessment, since they have low accuracy. To increase the accuracy of calculations it is advisable to use a tabular method for definition of spatial influence models, using for this adopted in Russia of "Methods of calculation of concentrations in the atmospheric air of harmful substances contained in the emissions of enterprises" [2].

The maximum surface concentration of harmful substances C_m (mg/m^3) with the release of the air-gas mixture out of a single point source with a round mouth is achieved under adverse meteorological conditions at a distance $x_m(M)$ of the source and is determined by the formula:

$$C_м = \frac{A \cdot M \cdot F \cdot m \cdot n \cdot d}{H^2 \sqrt{V_1 \cdot \Delta T}}\,, \qquad (7)$$

where A – coefficient, depending on the temperature stratification of the atmosphere;

M (g/s) is the mass of harmful substances emitted to the atmosphere per unit of time;

F is a dimensionless coefficient, taking into account the speed of sedimentation of harmful substances in the atmospheric air;

m and n – coefficients, taking into account the conditions of exit of the air-gas mixture out of the mouth of the source;

H (m) – height of the source of release above ground level (for land-based sources in the calculation shall be equal to 2 m);

d – dimensionless coefficient, taking into account the relief of terrain. In the case of a smooth or rugged terrain with difference of heights not exceeding 50 m to 1 km is equal to 1;

ΔT – the difference between the temperature of discarded air and the temperature of the ambient air;

V_1 (m^3/s) – the consumption of air-gas mixtures, defined by the formula:

$$V_1 = \frac{\pi \cdot D^2}{4} \cdot \omega_0\,, \qquad (8)$$

where D (m) – diameter of the mouth of the source of release; ω_0 (m/s) – is the speed of the gas mixture output from the mouth of the release source.

We need to know the type of distribution of the concentration of pollutants in the low layer of the atmosphere from the emission of all sources of pollution to build a thematic relief of the pollution of the air basin. The above described technique was implemented in the form of the original software module that is integrated in the environment of GIS ArcInfo.

Software module meets the following requirements:

- has an available interface;
- is universal, i.e. gives the possibility to calculate the surface concentration of various pollutants;
- saves the results of the calculation in a file;
- you can record in a stored image file attribute information about the source of pollution;
- visually presents the results of simulation in the form of thematic maps.

We obtained the data on the distribution of pollutants: nitrogen dioxide, carbon monoxide, soot, benzopyrene for the quarterly gas-fired boiler houses using this software module. As a result, it was determined that the concentration of carbon monoxide and soot emissions from individual boiler-houses on the order below of maximum permissible concentration, while the emissions of nitrogen dioxide and benzopyrene had concentrations of the same order that maximum permissible concentration.

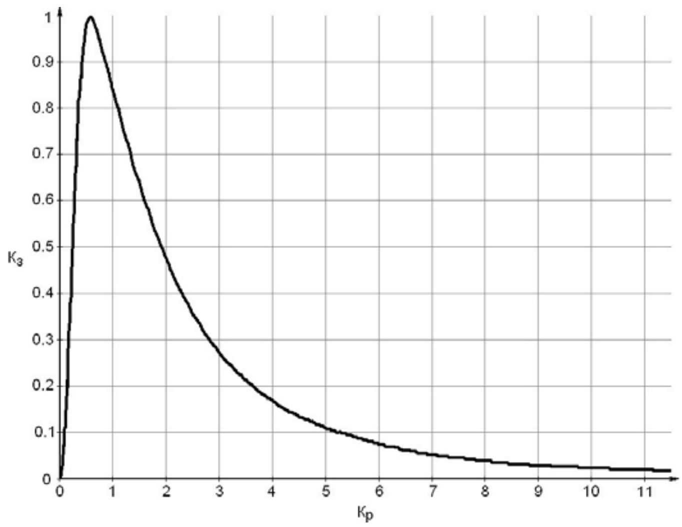


Fig.4. Schedule of the spread of pollutions in relative units.

To put all boiler-houses with their unique SIM in one thematic layer of a map has been used average "reference" distribution function of a pollutant, as calculated graphics of distribution of emissions have a similar appearance. On the basis of this, the SIM in relative units was developed (fig. 4).

The values of the coefficient of the relative distance of pollution are postponed on the X-axis on the graph: $K_P=x/x_{max}$, where x is the current distance; x_{max} - distance to the point of maximum pollution, which is almost the same for all similar sources of pollution for the investigated territory.

The values of the coefficient of relative pollution are postponed on the Y-axis: $K_3=C/C_{max}$, where C is the value of the emissions from the source of pollution; C_{max} is the value of the emissions from the source of maximal contamination in the area.

The method of calculation is the following:

1. The object with the maximum high emissions is determined for each pollutant substance;
2. The normalized (standard) model of the spatial distribution of pollution is built for the selected object;
3. For all other sources a similar model is defined through the weighting coefficients relative to the reference model.

Thus, the thematic layer is built for each type of pollution. Then virtual contamination relief of the territory is calculated. In accordance with this procedure pollution of benzopyrene and nitrogen dioxide from the boiler plants of the city of Kostroma (Russia) have been investigated.

The following data for solving the problem of modeling the properties of urbanized territory were used:

- The map from GIS "Sity";
- The accounting log of stationary pollution sources and their characteristics (data from the municipal heat and power engineering company):

1. the address of an object
2. place and point of sampling measurement
3. gas consumption cu. m per hour
4. coefficient of air excess
5. sectional area of the pipe
6. parameters of air-gas mixtures at the exit of the source
7. volume of air mixture
8. the amount of harmful emissions from the source.

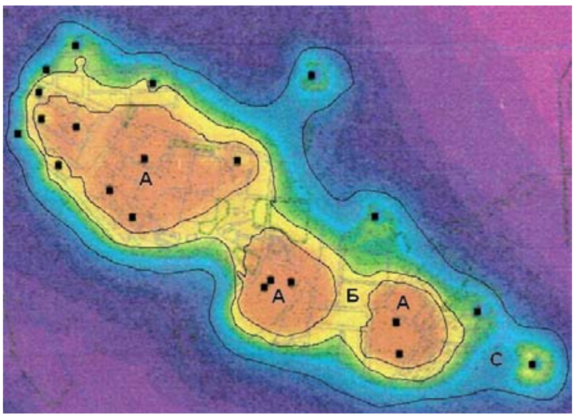


Fig.5. The resulting pollution of nitrogen dioxide from the city gas boiler houses (■- identification of sources of pollution).

Measurement of the concentration of harmful substances in emissions of the city boilers are carried out with the help of gas-analyzers. The special "Methods of calculation of concentrations in the atmospheric air of harmful substances contained in the emissions of enterprises" are used to determine the concentration of the pollution at a distance of X meters from the source.

Fig. 5 shows the calculated pollution area of nitrogen dioxide. In the zone A pollution exceeds maximum permissible concentration (MPC) in 5 times, in the area B pollution corresponds to the allowable level (0,85 mg/m^3), in the zone C - in 2 times lower than the permissible limit. Thus, in spite of the fact that pollution from individual sources of pollution urban air basin do not exceed the permissible norms, data of spatial modeling show that, because of their cumulative effect level of pollution exceeds MPC in several times.

Even more impressive results are obtained on benzopyrene. Its total concentration exceeded MPC in more than 20 times in some areas of the city.

CONCLUSIONS

The problem of the pollution of the air basin from a number of sources has a complex multi-factor, territorial character. Therefore, an effective solution can be obtained only through the use of geoinformation technologies. The methodology of spatial modeling of the pollution of air basin is based on library of models of spatial impact of the sources of pollution on the adjacent territory. The averaged "reference" distribution function of the pollutants: nitrogen dioxide, carbon monoxide, soot, benzopyrene is developed. In assessing the ecological situation it is necessary to define the cumulative effect of all sources of pollution.

The law of distribution of the concentration of pollutants from point source (pipes) can be modeled accurately enough. Therefore to automate the assessment of the pollution of air basin it is advisable to use method of a spatial modeling operating in the functions of the spatial influence of objects.

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Anna Gnatjuk, Boris Staroverov. Termoelektrostaciju un katlumāju emisijas izplatīšasnās procesa telpiskā modelēšana

Ģeogrāfiskās informācijas sistēmas risina sarežģītas un multifaktoriālas problēmas, kuras jārada modelējot gaisa piesārņojumu no termoelektrostaciju un katlu māju caurulēm. Tas ļauj, lai ievākt un apstrādāt tabulas, tekstus un datus par kartēm. ĢIS analizē un vizualizē modelēšanas rezultātus. Automatizēta datu apstrāde un analīze ir novedusi līdz efektīvu administratīvo lēmumu pielāgošanai samērā īsā laikā.
Metode telpiskās gaisa piesārņojuma modelēšanu balstīta uz bibliotēku modeļu telpiskās ietekmes piesārņojuma avotu par piekrastes teritorijā. Iegūta vidēji spēcīga funkcija piemaisījumu sadale: NO2, CO, kvēpi, C20H12. Novērtējot situāciju vides, ir svarīgi noteikt kumulatīvo efektu visiem piesārņojuma avotiem.
Sadalījuma likums koncentrācijas piemaisījumiem no centrālā punktveida avota (caurules), kuru iespējams modelēt precīzi. Tāpēc, lai automatizētu aprēķinu gaisa piesārņojumam, ir ieteicams izmantot telpisko modelēšanu, kas izmanto telpisko ietekmi objektiem.

Анна Гнатюк, Борис Староверов. Пространственное моделирование процессов распространения эмиссий от теплоэлектростанций и бойлерных домов

Системы географической информации позволяют решать сложные и полифакториальные задачи в создании моделей загрязнения воздушного бассейна от труб теплоэлектростанций и бойлерных домов. Они позволяют собрать и обработать табличные, текстовые и картографические данные. ГИС анализирует и визуализирует результаты моделирования. Автоматизация обработки и анализа привела к адаптации эффективных административных решений в самое короткое время.
Метод пространственного моделирования загрязнения воздушного бассейна основан на библиотеке моделей пространственного влияния источников загрязнения на смежные территории. Получена средняя ссылочная функция распределения примесей: NO_2, CO, сажи, $C_{20}H_{12}$. В оценивании экологической ситуации важно определить кумулятивный эффект всех источников загрязнения.
Закон распределения концентрации примесей от точечного источника (трубы) может быть смоделирован достаточно точно. Следовательно, автоматизировать расчёт загрязнения воздушного бассейна рекомендуется использовать метод пространственного моделирования, который использует функцию пространственного влияния объектов.