Geoinformation modelling of quotas distribution of technogenic load for water users

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Abstract. The method of redistributing the technogenic load according to various scenarios of combined impact for industrial enterprises of territorial natural-production complexes using the geoinformation online environmental management system and managing anthropogenic load quotas for water users is described. Proposed method allows to determine zonas of negative impact of existing industries and zonas with maximum pollution, to reduce negative impact from production to the aquatic environment of separate river basin due to optimization of the load level.

Stricter requirements for quality of environmental forecasts and problem solution of anthropogenic load distribution at intersectoral level and based on efficiency increasing of functioning of territorial natural-production complexes (TPPC) according to environmental and technological criteria determines the relevance of developing new methods and means of redistributing the load for the aggregate industrial production located in the boundaries of a separate water basin, within which it is necessary to ensure environmental and technological standards.

Simulation geoinformation modeling allows you to set standards and redistribute the anthropogenic load for subjects of TPPC using the geoinformation online system, depending on the accepted criteria for establishing load quotas. For various levels of organization of industrial production within the framework of TPPC, territorial, sectoral and resource standards of environmental safety are established [1].

The table shows typical mathematical models of the deterministic type, consisting of equations of motion and balance of matter, physico-chemical hydrodynamics in the form of turbulent diffusion or convective-diffusive transport and the conversion of non-conservative impurities (CDT and CI), which are the basis of geoinformation model of the TPPC (environmental block) [2].

In the general case, the semi-empirical equation of turbulent diffusion is written as a parabolic partial differential equation:

$$\frac{\partial C}{\partial t} + \frac{\partial U_a C}{\partial x_\alpha} = \frac{\partial}{\partial x_\alpha} K_{a\beta} \frac{\partial C}{\partial x_\beta} + M_c,$$  \hspace{1cm} (1)

where $U_a$ - projection of actual speed on axis $x_\alpha$ ($\alpha=1,2,3$); $K_{a\beta}$ - tensor of turbulent diffusion coefficients; $M_c$ – parameter characterizing the transformation of impurities.
In solving practical problems, as a rule, it is assumed that the inhomogeneity of the turbulence field is small and the principal axes of the tensor \( K_{\alpha\beta} \) coincide with the coordinate axes, i.e. \( K_{\alpha\beta} = 0 \) for \( \alpha \neq \beta \). In some cases, the off-diagonal components of \( K_{\alpha\beta} \) are not always negligibly small (for example, for pressureless flows).

We assume that the principal axes of the tensor coincide with the axes of the Cartesian coordinate system used. In this case, \( K_{xy} = K_{xz} = K_{yx} = K_{yz} = K_{zx} = K_{zy} = 0 \).

Then the CDT and CI equation will take the form:

\[
\frac{\partial C}{\partial t} + V_x \frac{\partial C}{\partial x} + V_y \frac{\partial C}{\partial y} + V_z \frac{\partial C}{\partial z} = \frac{\partial D_x}{\partial x} \frac{\partial C}{\partial x} + \frac{\partial D_y}{\partial y} \frac{\partial C}{\partial y} + \frac{\partial D_z}{\partial z} \frac{\partial C}{\partial z} + M_c. \tag{2}
\]

Equation (2) contains seven unknown variables: \( C, V_x, V_y, V_z, D_x, D_y, D_z \). The last six of them can be determined by solving hydrodynamic equations.

To obtain a solution to equation (2), it is necessary to specify boundary conditions (initial and boundary). The initial conditions for the desired function \( C \) are written in the form:

\[
C = C_0(x, y, z, 0) \text{ for } t = t_0, \tag{3}
\]

where \( C_0(x, y, z, 0) \) – a known coordinate function.

This means that at time \( t_0 \) the distribution of the impurity concentration in space is known.

Since equation (2) contains the second derivatives with respect to all three coordinates, it is necessary to specify two boundary conditions for each of the three coordinates as boundary conditions. For the calculation, we assume that the solution to equation (2) is sought in a rectangular region with lower and upper boundaries, which are horizontal planes \( z = z_1 \) and \( z = z_2 \), and for a reservoir the surface of the stream is \( z = 0 \) or \( z = z_0 \). For a reservoir, “lateral” boundaries can be set in a similar way on the banks of a river or in the form of a semi-infinity of the sea.

For the restrictions of the rectangular region, the boundary conditions in the most general form are written as follows:

when \( x = x_1 \) \( C = C_{x1} \), when \( x = x_2 \) \( C = C_{x2} \),

\[
y = y_1 \quad C = C_{y1}, \text{ when } y = y_2 \quad C = C_{y2},
\]

\[
z = z_1 \quad C = C_{z1}, \text{ when } z = z_2 \quad C = C_{z2}. \tag{4}
\]

In accordance with expressions (4), the values of the desired function are set at each of the boundaries. In the case of an unlimited computational domain, the desired function or its derivative is often set to zero at an unlimited distance from the origin.

\[
X \to \pm \infty, C \to 0
\]

\[
y \to \pm \infty, C \to 0
\]

When \( X \to \pm \infty, \frac{\partial C}{\partial X} \)

\[
y \to \pm \infty, \frac{\partial C}{\partial y}
\]

For the upper boundary of the water flow is set at \( z = 0 \) \( \frac{\partial C}{\partial z} = 0 \).

When calculating the distribution of impurities in a water body at the bottom and lateral boundaries, the impenetrability condition is set:

for \( z = H \) \( B > y > 0 \) \( \frac{\partial C}{\partial z} = 0 \)

\[
y = y_1 \ H > z > 0 \quad \frac{\partial C}{\partial z} = 0 \tag{6}
\]

where \( B \) – the body of the river or the sea.
\[ y = y_2 \text{ } H > z > 0 \quad \frac{\partial C}{\partial z} = 0 \]

In the case of boundary conditions of the first kind (Dirichlet problem) at the boundary of the computational domain of a water body \( x \), the distribution of the values of the initial function is specified:

\[ C|_i = f_i(x, y, z). \]  

This type includes conditions (4) and (5).

**Table 1.** The main types of CDTandCI models implemented in the “Geoinformation modelling system (GIoMS)-TPPC”.

| N  | Type of equation                                                                                                                                 |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | \( \frac{\partial C}{\partial t} + \nu \cdot \frac{\partial C}{\partial x} = f(x, t, C) \)                                                                 |
| 2  | \( \frac{dC_2}{dt} = \frac{dC_1}{dt} + k_2 \cdot \left( C_{2np} - C_2 \right) \)                                                                  |
| 3  | \( \frac{dC_1}{dt} = -\alpha \cdot C_1 \cdot C_2 \)                                                                                              |
| 4  | \( \frac{\partial C}{\partial t} + \nu_x \cdot \frac{\partial C}{\partial x} = D_x \cdot \frac{\partial^2 C}{\partial x^2} - k_1 \cdot C. \)       |
| 5  | \( \frac{\partial}{\partial x} (Q \cdot C) = \frac{\partial}{\partial y} \left( \omega \cdot D_y \cdot \frac{\partial C}{\partial y} \right) - k_1 \cdot \omega \cdot C \) |
| 6  | \( \frac{\partial (\omega \cdot \nabla T)}{\partial t} + \frac{\partial (Q \cdot C)}{\partial x} = \frac{\partial}{\partial x} \left[ \omega \cdot D_x \cdot \frac{\partial C}{\partial x} \right] - k_1 \cdot \omega \cdot (T - T_i) \) |
| 7  | \( \frac{\partial}{\partial t} \left( \omega \cdot C_i \right) + \frac{\partial (Q \cdot C_i)}{\partial x} = \frac{\partial}{\partial x} \left[ \omega \cdot D_x \cdot \frac{\partial C_i}{\partial x} \right] \) |
| 8  | \( B \cdot \frac{\partial z}{\partial t} + \frac{\partial Q}{\partial x} = q \)                                                                      |
| 9  | \( \frac{\partial}{\partial t} (\omega \cdot C) + \frac{\partial}{\partial x} (Q \cdot C) = \frac{\partial}{\partial x} \left( \omega \cdot D_x \cdot \frac{\partial C}{\partial x} \right) - k_1 \cdot \omega \cdot C \) |
| 10 | \( \nu_x \cdot \frac{\partial C}{\partial x} = D_y \cdot \frac{\partial^2 C}{\partial y^2} - k_1 \cdot C \)                                                                 |
| 11 | \( \nu \cdot \frac{\partial C}{\partial x} = D_y \cdot \frac{\partial^2 C}{\partial y^2} + D_z \cdot \frac{\partial^2 C}{\partial z^2} - k_1 \cdot C \)          |
| 12 | \( \nu_x \cdot \frac{\partial C}{\partial x} + \nu_y \cdot \frac{\partial C}{\partial y} + \nu_z \cdot \frac{\partial C}{\partial z} = D_x \cdot \frac{\partial^2 C}{\partial x^2} + D_y \cdot \frac{\partial^2 C}{\partial y^2} + D_z \cdot \frac{\partial^2 C}{\partial z^2} - k_1 \cdot C \) |
N  Type of equation

\[
\frac{\partial C}{\partial t} + V_x \frac{\partial C}{\partial x} + V_y \frac{\partial C}{\partial y} = D \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right)
\]

where \( Q \) – water consumption, \( m^3/\text{c} \); \( k_1 \) – coefficient of bio-chemical oxidation, \( 1/\text{day} \); \( \omega \) – cross-sectional area of the channel, \( m^2 \); \( \nu_x, \nu_y, \nu_z \) (\( \nu_x, \nu_y, \nu_z \)) – average flow speeds, \( \text{m/sec} \); \( D_x, D_y, D_z \) – coefficients of longitudinal, transverse diffusion and vertical diffusion, respectively, \( \text{m}^2/\text{sec} \); \( C \) – substance concentration, \( \text{mg/l} \); \( t \) – time, \( \text{sec} \); \( T \) – water temperature, \( ^\circ\text{C} \); \( x \) – longitudinal coordinate, \( \text{m} \); \( y \) – transverse coordinate, \( \text{m} \); \( z \) – vertical coordinate; \( B \) – coefficient; \( L \) – length of design section, \( \text{m} \).

The boundary conditions of the second kind (Neumann problem) are set on the boundary of the region in the form of the normal derivative (gradient) of the desired function:

\[
\frac{\partial C}{\partial n} = f_2(x, y, z),
\]

where \( n \) – the internal normal to the boundary.

This type includes conditions (8).

The boundary conditions of the third kind are a linear combination of the first two:

\[
\nu C - D \frac{\partial C}{\partial n} = f_3(x, y, z),
\]

where \( \nu, D, f_3 \) – known functions defined at each point of the flow boundary.

Mathematically, the boundary conditions are limit conditions in the sense that a given combination of a substance and its derivatives tends to a given value as the point approaches the surface.

In accordance with the proposed typification of geoinformation modeling tasks for industrial production as part of TPPC, as well as on the basis of schematization of CDTandCI processes, a system of partial differential equations is constructed that describe a wide class of typical problems with corresponding boundary conditions (see table) that underlies the method of redistributing the technogenic load for TPPC entities using an online geographic information system. For each type of model, mathematical and software have been developed.

The method of redistributing anthropogenic load for industrial productions within TPPC, which includes an algorithm for calculating the redistribution of load for enterprises using the created system for managing the distribution of load quotas between the subjects of “GIMS-TPPC” system according to complex attributive and spatial queries.

For effective management of emergency situations, strategic (long-term) and current (operational) tasks are set, for which the proposed geographic information modelling system is used. At the same time, the target function of the algorithm for managing the distribution of anthropogenic load between all nature users of a separate water basin is set to ensure the required quality of water taken and wastewater discharged with the most efficient use of environmental protection groupings within a specific TPPC [3].

In this case, the optimization task takes the form:

\[
\sum_{i=1}^{n} S_i^{\text{out}}(P_i) \rightarrow \min,
\]

with restrictions:

\[
\sum_{i=1}^{n} C_i^{\text{out}}(P_i) \rightarrow C_{K\text{C}}, P_{i,\text{min}} \leq P_i \leq P_{i,\text{max}},
\]
where \( S_i\) – reduced costs for wastewater treatment at the \( i\)-th control point;
\( C_{KC}\) – reduction of the concentration of impurities in the water body referred to the control site in accordance with established standards for permissible discharges (SPD);
\( C_{i}^{\text{re}}\) – reduction in the concentration of impurities in the control release as a result of wastewater treatment by the \( i\)-th water user;
\( P_i\), \( P_i^{\text{min}} \) and \( P_i^{\text{max}} \) - respectively min allowable and max possible degrees of wastewater treatment.

To increase the efficiency of environmental management system for inter-industry relations of TPPC production systems, the following criteria are proposed for establishing quotas for anthropogenic load and its distribution between TPPC subjects [4]:

- Implement the best available technology.
- The assignment of the object to socially significant.
- The ecological state of water bodies according to pollution indicators at the established control points of the TPPC.

The developed method for redistribution of anthropogenic load based on quotas for TPPC entities using an online geoinformation system allows:

- develop a feasibility study for projects of construction of new enterprises, modernization and reconstruction of existing industrial enterprises, taking into account heterogeneous production indicators within the boundaries of a separate TPPC;
- to optimize the technogenic load from individual water user enterprises to reduce the negative impact on the water bodies of the basin using the minimum amount of costs for achieving SPD by all entities (production systems) of a particular water management site or the entire TPPC;
- to simulate the processes of pollutants transfer in a water body under standard, emergency and planned conditions, as well as taking into account the composition of discharged wastewater and natural changes.

References
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