

RIVER WATER CONTROL AND SEWAGE DISPOSAL DETECTION

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Abstract: The condition of water quality in the rivers of most countries deteriorate with each year, despite of rigid demands of environment laws in legislation of many countries. There are three main reasons for such a state – increasing of non-registered sewage disposals of polluting substances in the rivers, the lack of reliable methods and tools for definition of coordinates of sources of these sewage disposals, insufficient spatially-temporal control over processes which take place in the rivers. The paper presents the mathematical models, methods and tools for the solution of the above mention problems for the small and middle flat rivers. The efficiency of the suggested approach is shown on the example of water quality estimation problem solving in the river Southern Boog in Vinnytsia. The comparison of outcomes obtained by the authors with those obtained by the known methods for solving similar problems is realized.

Keywords: river water quality control, sewage disposal detection, river processes

The condition of rivers water in the majority of countries worsens each year despite the toughening of the legislation in the sphere of environment protection. It in its turn leads to the shortage of fresh water for home and economic objectives. And the water we have must undergo thorough and expensive clearance. The low quality of river water also tells on river ecosystem state. Natural ecosystem, the selfclearance processes of which do not cope with acting at it polluting impacts is on the way to destruction. Thus, the arisen now problem of river water quality deterioration owing to pernicious man's influence has large negative economic and ecological consequences and requires the prompt solving.

At present there are good and efficient methods against contamination [1]. The application of new technologies in economy allows essentially to reduce its polluting impact on rivers water quality – receivers of sewage. It should be noted, however, that the improvement of a situation is connected not with the rise of ecological understanding in industry, but with toughening of the ecological legislation and control over the environment.

Now the greatest danger to environment is not so much the stationary and known sources of contamination, which tend to reduce the negative impact on the environment in order to avoid heavy fines, but non-registered sources [1, 2].

The *non-registered sources of contamination* (NSC) are not afraid of the fines owing to their being anonymous and it allows them to drop heavy polluted sewage in an unlimited amount any time. As such sources act the ones which are absolutely unknown in the given region, for example machine with toxic liquid waste from adjacent region, as well as the ones which are the well-known, but which have hidden the fact of the sewage disposals.

The detection of such sources is usually carried out by special investigations. But at first it is necessary to reveal the fact of non-registered sewage disposals, its location and, whenever possible, the magnitude of disposal – it is the difficult problem because it does undergo direct measurements as it is impossible to measure the quality of all rivers through each meter every second – it is expensive for any country.

Thus the problem of detection of non-registered sources, the coordinates of their location and quality of water coming from those sources is at present a very important problem which requires immediate solution.

The paper presents the mathematical models, methods and tools of solution of this problem for the small and average flat rivers.

The limitation as to small and average rivers is imposed in connection with the fact that the processes which take place in the river, are considered only in stream averaged on width and depth of the river,

instead of being considered in each point of the river cross-section. The limitation as to flat rivers is connected with neglect of features of thresholds, waterfalls, swirls and other areas of river current, where the river processes proceed not so as in their areas – the equal current relatively homogeneous by a character is considered only.

For the characteristic of water quality we will use the known chemical and bacteriological *water quality indices* (WQI) [1, 2].

When forming the mathematical models of WQI dynamics and influenced the WQI river processes, there are usually a number of difficulties:

- 1) necessity of the registration of the large number of drains;
- 2) the change of a character of river processes connected with change of hydraulic parameters of stream;
- 3) the complexity of the registration of all processes which influence the simulated concentration of a substance, as well as neglect the processes, nature of which is still investigated insufficiently;
- 4) the distribution of processes in space.

To overcoming the first difficulty, the authors of the article [2] suggest to consider the reach of the river which undergoes analysis, as many-dimensional cybernetic system. And various impacts in the kind of manufacturing water, household sewage, natural flows, atmospheric precipitation, etc., which influence the quality of water in the river, arrive on the entrances of the river. The output characteristic of the system is quality of water in places of water consumption and usage. The input, output and state variables are WQI and their derivatives.

To overcome the second difficulty it is offered to divide the simulated reach of the river into N of more small-sized elementary reaches according to two criterions:

- 1) on each elementary reach there should be no more than one source of water in addition to water which comes from the river reaches located upstream;
- 2) values of the basic characteristics of the river, which influence the dynamics of river processes, for example the hydraulic characteristics of the river (current speed, geometrical sizes of a river-bed, turbulent diffusion factor, etc.), should be approximately constant on each elementary reach.

To facilitate the registration of impacts of natural and artificial flows it is recommended to divide the river so that each new elementary reach of the river begins in a place of arrival of these flows. In this case the arriving flows are taken into account in the initial conditions of a model.

The coordination of elementary reaches should be done according to the chain principle: the output of each of them is the entrance for the following.

To overcome the third difficulty the authors of the articles [3, 4] suggest all possible processes impacting on simulated WQI to divide into groups. When doing this, for example to concentrate the polluting substances, all processes immediately acting on substances, which comes in the river are referred to the first group. To the second – processes which influence only the outcomes of action of processes of the first group, and to the third – processes which influence the outcomes of action of processes of the second group. Further, we suppose that the polluting substances are completely deleted from river water already after action of processes of the third group (sedimentation, evaporation, absorption by water life etc.).

But for example in a case of large chemical activity of substances they can be deleted due to action of processes of the second or the first group and then total amount of such groups will accordingly make only, 2 or 1. For the other WQI the division of river processes on groups is made by analogy.

As the mathematical description of such processes it is offered to use a model

$$\frac{dx(t)}{dt} = -G_l(t)x(t), \quad x(0) = x_0, \quad t = [0, T], \quad (1)$$

where $x(t)$ – value of WQI; t – time; T – period of simulation; x_0 – value of x in an initial time moment $t = 0$; $G_l(t)$ – function that takes into account the influence of the l -th (1, 2 or 3) quantity of groups of processes on change of value of WQI $x(t)$:

$$G_1(t) = -k_1,$$

$$G_2(t) = -k_2 \left(1 - e^{-k_1 t} \right), \quad (2)$$

$$G_3(t) = -k_3 \left[1 - e^{-k_2 \left(1 - e^{-k_1 t} \right) t} \right],$$

where k_1 , k_2 and k_3 – proportionality factors between the speeds of proceeding processes of the first, second and the third groups, accordingly (under the condition of their isolated passing), and the value of index, on which they act.

And it is not necessary to know perfectly what processes and how they influence the given WQI – their structure and dynamics are identified on experimental outcomes.

As it is seen, models (1), (2) describe the change of WQI values in time, while on each reach of the river we are interested in the change of these indices in space – along a coordinate axis passing along averaged river stream in the direction of current of the river. The overcoming of this last, the fourth difficulty is possible if to take into account that for the separate volume of river stream, limited by two neighboring river cross-sections, the coordinates of time t and spaces z – are interdependent. Proportionality factor between them is the speed of moving of volume – speed of the river current v :

$$z = vt. \quad (3)$$

Deciding the equations (1), (2) it is possible to write the equation of dynamics for WQI on an elementary river reach with the length L , with the constant hydraulic characteristics and one entrance:

$$x(z) = x_0 \cdot M(K_i, z), \quad z = [0, L], \quad (4)$$

where K_i – vector of k -parameters of a model:

$$K_1 = k_1, \quad K_2 = \begin{bmatrix} k_1 \\ k_2 \end{bmatrix}, \quad K_3 = \begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix}, \quad (5)$$

$M(K_i, z)$ – decision function:

$$M(K_i, z) = \begin{cases} e^{-k_1 \cdot z}, & i = 1, \quad z = [0, L]; \\ e^{-\frac{k_2}{k_1} \cdot (e^{-k_1 \cdot z} + k_1 \cdot z - 1)}, & i = 2, \quad z = [0, L]; \\ e^{-k_3 \cdot \left[z - \int_0^z e^{-k_2 \cdot q} (1 - e^{-k_1 \cdot q}) dq \right]}, & i = 3, \quad z = [0, L]; \\ 0, & z < 0. \end{cases} \quad (6)$$

The authors in paper [3] develop algorithms and methods of identification of models (5), (6) in practice on experimental data. The algorithms allow for each concrete WQI on the given river reach to receive an optimal model, which ensures a minimum of a sum of quadrate of an deviation error of simulation outcomes from an experimental data.

The model with the identified factors minimizes a difference between left and right members of the equations set:

$$\widehat{x}_0 \cdot M(K_i, z_j) = \widehat{x}_j, \quad i = \overline{1, N}, \quad (7)$$

where \widehat{x}_j , $i = \overline{0, N}$ – experimental values of WQI measured in river cross-sections with coordinates z_j (N – amount of river cross-sections, except a zero one, on the given elementary reach).

A peculiar property of the suggested model is the fact that it describes dynamics of river processes, which cause the change of WQI in space (time), irrespectively of initial values of WQI. It allows to predict response of the river ecosystem on impact of other values of WQI, than those, with which this model was identified.

Ideology of solution of the set problem on detection of non-registered sewage disposals on each elementary river reach for some WQI is: at first a series of single metering in a number of points (not less than 5 – this is the requirement of an algorithm of model identification) is made, then according to these points the model is identified, optimal for the given elementary reach and WQI – it is a preliminary stage. After that it is possible to decide the set problem: according to constructed model the distribution of values of WQI along the elementary reach of the river in the subsequent periods of time is predicted. In the same instants the regular metering of WQI in the river are conducted. If in any moment the distribution of WQI begins to differ from the experimental data, exceeding the limits of possible error of simulation, then it is possible to make a conclusion that somewhere on a reach a non-registered sewage disposal takes place. Further the algorithm of finding of a place of a sewage disposal and its magnitude is applied.

Before proceeding to algorithm of finding of a place of disposal and its magnitude, it is necessary to explain a problem of the taking into account the water discharge and what is meant by *magnitude of disposal* in this case.

If the simulation of WQI within only one elementary reach of the river is carried out, where a unique entrance is the water of the river coming from the reach, located upstream, then in the model (7) values x – it is simply the value of WQI. But, if the sequence of elementary reaches joint under the chain circuit is simulated, and each of them can have one entrance (inflow or stationary sewage disposal), then it is necessary to take into account the change of river water discharge from one reach to the other. In the theory of dilutions says [1]: in case if the sewage with WQI u and discharge q comes in the river with WQI x_0 and water discharge Q the value of WQI x_1 under the full merging river cross-section (we consider just such case) is calculated according to the formula:

$$x_1 = \frac{Q \cdot x_0 + q \cdot u}{Q + q}. \quad (9)$$

Such recalculation of WQI values at the beginning of each reach creates additional difficulties. But incomparably large difficulties are created by the search of non-registered sewage disposal, for which both the value of WQI w as well as water discharge q_w are known. To overcome these difficulties we offer to carry out simulation for products:

$$X = Q \cdot x, \quad U = q \cdot u, \quad W = q_w \cdot w. \quad (10)$$

We will name these values conditionally "*discharge water quality indices*" (DWQI) and we will mark them by capital letters.

For DWQI the expression (9) becomes extreme simple:

$$X_1 = X_0 + U. \quad (11)$$

It is obvious that the transition from WQI to DWQI should be made at once after measurements and carry out identification of a model for DWQI:

$$\widehat{X}_0 \cdot M(K_i, z_i) = \widehat{X}_i, \quad i = \overline{1, N}, \quad (12)$$

where

$$\widehat{X}_i = Q \cdot \widehat{x}_i, \quad i = \overline{0, N}. \quad (13)$$

The algorithm of finding of a place of a non-registered source of contamination and its W magnitude consists in solution of the equations set, which is the changed system (7):

$$X_0 \cdot M(K_1, z_i) + W \cdot M(K_1, z_i - \mathbf{m}) = \widehat{X}_i, \quad i = \overline{0, N}, \quad (14)$$

where \mathbf{m} – coordinate of location of NSC within elementary reach of the river: $0 \leq \mathbf{m} \leq L$; X_0 – value of DWQI directly ahead of initial river cross-section of the reach is the value of DWQI in the final river cross-section of the previous elementary reach and if it is known precisely that in zero river cross-section of this reach can not be the sewage disposal then this value coincides with \widehat{X}_0 .

While in the equations set (7) were unknown K -factors of the equations in the equations set (14) K -factors are considered to be known and the place of \mathbf{m} and magnitude W of sewage disposal are unknown.

It is necessary to mark that the offered model (14) should be applied only provided that the supposition about stationarity of dynamics of passing of river processes is executed. If this supposition is defaulted (there began sharp flowering of algae, flood, mean water etc., in the river), the model should be renewed for new conditions of stationarity of dynamics by carrying out model identification on measurements data anew.

After the calculating of the coordinate of the place of sewage disposal (within the limits of an error of simulation) it is easy to find a true place of sewage disposal by conducting a survey in a neighborhood of this coordinate of a coastal zone, coastal water vegetation, river silt, atmospheric contamination and other characteristics. And as a result of special investigation to specify true magnitude of this disposal.

Let's assume that the outcomes of our measuring method can be used as a reference point for special investigation, which is undertaken by organizations of ecological monitoring and control.

The authors has created the software package, which processes measurements of WQI in the river on described algorithm and allows to detect on each elementary reach of the river the coordinates \mathbf{m} sewage disposals and its W magnitudes.

The efficiency of the offered approach is checked on detection a NSC on the reach of the river Southern Boog located in the city of Vinnytsia. The obtained outcomes have satisfied interests of State administration of ecological safety of Vinnytsia area.

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