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EVALUATION OF ENVIRONMENTAL RISKS OF NATURAL ECOSYSTEMS, PRESENTED AS INFORMATION MODEL WITH GEOMETRIC NETWORKS

The analysis of the main existing approaches to the evaluation of ecological risks has been performed. Formalization of the rivers tracts coding in ramified river network has been realized .Relation for of the evaluation of expected environmental risk of locking river section has been deduced. The example of calculation of expected environmental risks is given.

Key words: *ecological risks, quality of surface waters, evaluation of ecological risks, modeling of ecorisks, ecological network.*

Nowadays problem of the environmental security becomes the problem of paramount importance. This is due to worsening of environmental situation in Ukraine and, as a consequence, the deterioration of living conditions, health status of the population. The improvement of models and capabilities of geoinformation technologies used for environmental safety, management of nature, measures, taken in emergency situations is very actual.

Problems of water pollution, water use, probability of various emergency situations related to these problems make various methods and technologies of optimal control of environmental safety by the objects of water network very important.

For ecological risk assessment it is necessary first of all to perform simulation of surface water state change processes in the river basin. To do this, the whole river system should be considered as geometric network.

Considering the river system (RS) as a geometric network (GN), such problems as determination of quality (quantity) of water change after installation of the discharge (intake) at certain section, definition of the impact of environmental factors (precipitation, evaporation) on the amount of water, consideration of the possibility of water intake construction on the section of the river depending on water quality, etc.

Thus, it is expedient to consider RS as GN, and for more rapid, comprehensive and visual data analysis for evaluation of environmental safety (ecological risks) to apply specialized GIS.

Problem set-up

Nowadays there are many approaches and methods for assessing environmental risks.

We will consider them according to the following criteria: those that take into account ecosystems state, areas of ecological emergency, levels of water objects contamination, overall index of contamination.

According to one of the techniques ecological risk for aquatic ecosystems is defined as [1]:

$$P_G^c = f(G_v\langle v=\overline{1,N_G}\rangle, H_{Gm}\langle m=\overline{1,N_{HG}}\rangle), \tag{1}$$

where: G_v – is current state of aquatic ecosystems; H_{Gm} – is integrated assessment of the present level of anthropogenic pressure under the influence of negative factors on the aquatic ecosystems by v^{th} parameter.

In [1] the definition of the notion "environmental risk for surface water" is determined as the probability of adverse consequences for aquatic ecosystems and their components as a result of anthropogenic and natural factors, including the deterioration of water quality. Ecological risk for aquatic ecosystems is determined by the formula (1). Such evaluation is generalized and is intended for determination of the states of regions, basins of rivers or their parts where there exists the danger for ecosystems, including their degradation, on condition of conservation of existing anthropogenic pressure(2).

One of the approaches to the assessment of environmental safety is to reveal already formed areas of emergency ecological situation and ecological disaster.. This procedure is carried out by chemical and environmental indices.

For aggregate evaluation of dangerous levels of water pollution while allocation of zones of ecological emergency and environmental disaster it is suggested to use formalized aggregate index of chemical pollution (ICP-10) [3]. This index is particularly important for areas where chemical pollution is observed by several substances simultaneously, each of which repeatedly exceeds the permissible level (maximum permissible concentration (MPC)).

Calculation of ICP-10 is performed by ten compounds that exceed the maximum MPC, by the formula [3]:

$$ICP-10=\left(\frac{C_1}{MPC_1}+\frac{C_2}{MPC_2}+...+\frac{C_{10}}{MPC_{10}}\right), \quad (2)$$

where: C_i – is the concentration of i^{th} contaminating substance in the water; MPCi is water handling facilities MPC of i^{th} CS in water.

Another common method of environmental safety assessment is determination of contamination level by generalized pollution index (I_p), that equals [3]:

$$I_p=\frac{1}{n}\sum_{1}^{n}\frac{C_i}{MPC_i}, \quad (3)$$

As it is seen, the formula (3) is converted into (2) if n = 10.

Let us consider another method of environmental risk *RISK* determination. Formula [4] is used for this purpose:

$$Risk=-\ln(P), \quad (4)$$

where

$$P=\frac{\sum n_i}{N}, \quad (5)$$

$$\sum n_i=\sum\frac{C_i}{MPC}, \quad (6)$$

where: C_i – is concentration of ith contaminating substance(CS), that exceeds MPCi (CS that do not exceed the MPC , are not substituted in the formula(6); N – is total number of CS, being analyzed (both those that exceed their MPC, and those – which do not).

These formulas are usually used for the analysis of the data in statics rather than in dynamics, based on processing of large amount of observations. For instance, if emergency discharge of sewage waste took place at a certain location of the river and level of river contamination increased this event must automatically increase ecological risk at this section of the river and on those areas located downstream, even if the contamination did not reach those locations. We suggest a special mathematical apparatus, based on the presentation of the river basin as a graph, i. e., in the form of geometric network. In fact, this apparatus must give the possibility of expected environmental risks evaluation in areas of the river in the dynamics as a result of significant changes in water quality upstream.

Formalization of the river sections coding in ramified river network

In [5] decomposition of the river into elementary sections (ES) by two criteria was suggested: 1) each ES has no more than one spatially concentrated input of sewage waters or inflow waters

(Fig. 1), 2) each ES has approximately the same characteristics of physical and biochemical processes of self-cleaning. Fig. 1 shows the i^{th} ES.

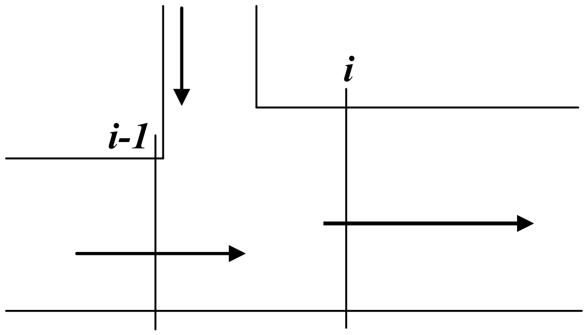

Fig. 1. Scheme of i^{th} elementary section of the river, where sewage and inflow water arrive

While assessing environmental risks the division of the river into ES is carried out in such a way that site of surface water quality control was at the beginning of each ES. This approach to the decomposition does not contradict to the above- mentioned, as these sites are located in places where the tributary falls into the river or there is a discharge of sewage water, or water quality significantly changes (there are rapids or slow fluvial reservoir flow, etc.)..

So, there is a problem of such ES coding. There are many known approaches to coding.

For example, in 2-TP system (water handling facilities), used for state accounting of water use in Ukraine (and contains approaches to coding inherent in Soviet times) rivers of each region have multilevel structure [6]. There are rivers of zero level, which do not fall into any other river and flow directly into the sea. Rivers of the first level fall into the rivers of zero level, etc.. Coding of the river of zero level begins with its title abbreviation such as "Y. Bug" or "Dnipro". Coding of the tributaries of this river is formed from the distances in kilometers from the mouth of zero level river to the confluence of its tributaries. Due to this multi-tree structure is the possibility to accurately identify the river on the map (the drawback is that this coding accuracy is 0.5 miles and does not take into account if the river is right or left tributary, that is why sometimes there appears the discrepancy when comparing this coding with the map). This coding takes into account 7 levels of river tributaries and has 8 sections: the name of the main river and 4-digit mileage of confluence. If the river is a tributary, for instance, of the 2^{nd} -order, i.e., tributary of the main river, then it will contain the name of the main river, mileage of confluence in it of tributary of the 1^{st} order, mileage of confluence in this tributary , but in all other sections there will be zero. Example of the fragment (initial section of the coding) of the corresponding table of form 2-TP "Water holding facilities " is shown in Fig. 2.

П.БУГ	0395	0044	0000

Fig. 2. Coding of the tributary of the 2nd order, the Southern Bug

That means that the river at 44^{th} -kilometer falls into the river, which at 395^{th}-kilometer falls in the Southern Bug.

Such coding is convenient for calculations (there are lengths of all ES between falling of tributaries into the same river and distance, covered by pollutants from the confluence to the mouth of the main river), but it is not convenient for designation of corresponding characteristics of ES in formulas and ratios. For such designations more convenient is coding by fixed number of digits.

We suggest to code each i-th ES of –rivers in the following way :

$$i = k_{1i}\, k_{2i}\, k_{3i}, \tag{7}$$

where: k_{1i} – is the order (level) of the river where the i^{th} ES is located: 0 – primary (or main) river, 1

– a tributary of the main river, 2 – a tributary of that tributary etc.
k_{2i} –is consecutive number of the k^{th} level tributary , where the i^{th} ES is located, on the river of $(k_1-1)^{th}$ level (for the main river: $k_2 = 0$), starting from the mouth of the latter;
k_{3i} – is consecutive number of ES on the river of k_2^{th} level, counting from its mouth.

The number k_1 – this is usually one digit – it is clear that such coding allows maximum 9 levels, which is sufficient for coding of hydrologic network.

The numbers k_2 and k_3 can be coded by 1 -, 2 - and even 3-digit combinations of numbers, depending on their maximum values. Although, if you remember that this coding is used to code the ES and calculation of environmental risks, hence, each ES should have one site of observations of water quality, it means that for their coding 1-2 digits will be sufficient .

It should be noted that the primary (or main) river, that is, the river of 0-level - it is not necessarily the river that flows into the sea, as in the system 2-TP (water handling facilities) (see Fig. 4.2). Typically, this is – the river on which the closing ES is located, environmental risk of which must be calculated. Under these conditions, in most cases, it will be sufficient to apply coding (7) of three digits - one digit per each type of code.

Let us illustrate this coding on the example of the river with tributaries of the 1-st and 2-nd order:

– For the main rivers

$$0\ 0\ p_3, \tag{8}$$

where: p_3 – is consecutive number of ES on the main river;

– for the main tributaries of the river:

$$1\ p_2\ p_3, \tag{9}$$

where: p_2 – is consecutive number of the tributary of the main river; p_3 – is consecutive number of ES on a tributary;

– for tributaries on the tributary of the main river:

$$2\ p_2\ p_3, \tag{10}$$

where: p_2 – is consecutive number of a tributary on the tributary of the main river; p_3 –is consecutive number of ES on this tributary.

Example of the scheme of geometric networks of such river system is shown in Fig. 3.

So, first, it is necessary to define environmental risk for each ES, and after that to determine its expected value for closing section of the main river , including environmental risks for ES and tributaries, located upstream. In this case, you should consider the time of water passage from one ES to another. Average time t_i of water passage from the beginning to the end of the i^{th} ES is easily calculated by the formula:

$$t_i = \frac{L_i}{v_i}, \tag{11}$$

where L_i – is the length of i^{th} ES, calculated along the line of average flow of the river (usually in the middle of fairway), m; v_i –is the average (or maximum) flow rate of the river, calculated along the line of averaged flow of the river (usually in the middle of the fairway), m / sec.

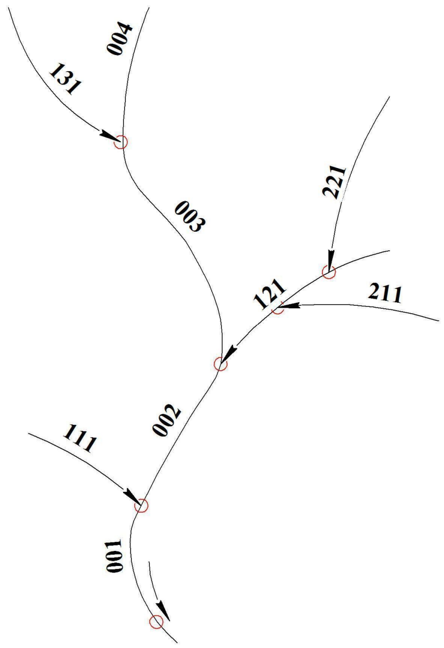

Fig. 3. The example of the scheme of decomposition of river system geometric network with codes of elementary sections formed at the confluence of the tributaries into the rivers

Thus, the total time T_i of water passage from the beginning of the i^{th} ES to the mouth of the river will be the sum of the following parameters for each of the ES from the i^{th} to the last (N^{th}):

$$T_i = \sum_{j=i}^{N} t_j. \qquad (12)$$

Mathematical apparatus is suggested for calculating the expected environmental risk of closing elementary section (code 001) as a result of pollution arrival at ES, located upstream, using the suggested ES coding and notation system.

Deducing the relation for the evaluation of the expected environmental risk of the closing section of the river

As it was mentioned above, the expected environmental risk is ecological risk, due to the negative impact of river water state (or discharges) located upstream. Taking into account the decomposition of the river system, suggested above it can be stated that the expected environmental risk must be computed iteratively , moving from river to river, from ES to ES. First, you must calculate environmental risk in the closing range of each tributary, which has more than one ES, or in its turn, has its tributaries must be calculated. Then, calculate the impact of closing range of ES, located downstream, etc. For example, for the scheme in Fig. 3 such algorithm of calculation can be offered:

ES 221 i ES 211 $\rightarrow$ ES 121

ES 004 i ES 131 $\rightarrow$ ES 003

ES 003 i ES 121 $\rightarrow$ ES 002

ES 002 i ES 111 $\rightarrow$ ES 001.

Remember that, in general, the distance between the confluence of several tributaries may be divided into several ES.

Let us consider the general case of the calculation when river system has N ES. Accordingly, ecological risk in closing N^{th}- of ES on the main river is influenced by the ecological risk (N-1) of ES located above. Let for all these ES of the river system ecological risk r_i (i = 1, ..., N) be calculated by one of the formulas or techniques described above. The task is to calculate the expected environmental risk of R in closing ES of the main river, taking into account ecological risks on ES located upstream and distances from the initial ranges of these ES to the initial range of closing ES.

Mathematical apparatus is built on the following assumptions and constraints:

1. Effect of environmental risk of the i^{th} ES on N^{th} ES is inversely proportional to duration of water run Ti from i^{th} ES to mouth (final range of N^{th} ES), that is, further ES located from closing, the less is its influence, but this influence is still present;
2. Expected environmental risk of N^{th} ES R is calculated as the weighted average value of environmental risks of all ES r_i ($i = 1, ..., N$), referred to corresponding time values of *Ti reaching;*
3. Even if environmental risk on all ES equals 1, then R can not exceed 1 (by definition);
4. If environmental risk on all ES will be 0, then R must also be 0.

Taking into account these constraints and assumptions the following expression is suggested for calculation of ES environmental risks of extensive system of river, taking into account the influence of water state on the ES, located upstream:

$$R=\frac{\sum_{i=1}^{N}\frac{\alpha\cdot r_i}{T_i}}{N}, \qquad (13)$$

where: a is a special coefficient to satisfy condition 3, which is calculated from the equation:

$$\frac{\sum_{i=1}^{N}\frac{\alpha\cdot 1}{T_i}}{N}=1.$$

It is easy to show that:

$$\alpha=\frac{N\prod_{i=1}^{N}T_i}{\sum_{i=1}^{N}\prod_{\substack{j=1\\ j\neq i}}^{N}T_j}. \qquad (14)$$

For example, if $N = 3$:

$$\alpha=\frac{3T_1T_2T_3}{T_2T_3+T_1T_3+T_1T_2}. \qquad (15)$$

We will demonstrate the correctness and effectiveness of the proposed mathematical apparatus on the example.

Example of automatic processing of the results of water parameters measurement

We will perform the calculation the expected environmental risk for the river system, that has N = 6 ES with lengths *Li,* that equal respectively

L_1 = 10 m, L_2 = 20 m, L_3 = 30 m, L_4 = 50 m, L_5 = 60 m, L_6 = 70 m. Current velocity v_i = 0,5.

Let us consider several options for different values of risk of each ES.

For the calculation we use the environment MathCad.

In the first version we will perform calculation for the following values: r_1 = 1; r_2 = 0.9; r_3 = 0; r_4 = 0; r_5 = 0.8; r_6 = 0.9.

Similarly, we execute calculations for other values of r_i, their values and the results are shown in Table 1:

Table 1

Results of expected environmental risk calculation

№	1	2	3	4	5	6	7	8
r_1	1	0	1	0.5	0.1	0.9	1	0
r_2	0.9	0	1	0.5	0.2	0.8	1	0.2
r_3	0	0	1	0.5	0.3	0.7	0	0.4
r_4	0	0	1	0.5	0.4	0.6	0	0.6
r_5	0.8	0	1	0.5	0.5	0.5	1	0.8
r_6	0.9	0	1	0.5	0.6	0.4	1	1
R	0.731	0	1	0.5	0.234	0.766	0.772	0.269

So after obtaining the results we see that all restrictions for R, described above, are met.

Also, we can make a conclusion that R has significantly higher value ,when *ri* is greater at initial sections, than on final, that is why, it is particularly important to monitor the value of risk at ES at the beginning of the river system.

Conclusions

New approach for the evaluation of the expected environmental risk at closing section of ramified river, which, unlike existing ones takes into account the impact of discharges and water quality in the tributaries of the river in sites, located upstream in the basin of the river. The proposed approach can be applied not only for the river, but also for other natural systems that can be represented in the form of information models with geometric networks. Also, it is possible to apply this approach for ecological networks or for modeling ecological risks as a result of air pollution, that will give the possibility of more accurate assessment of the expected environmental risks.

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