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Information and analytical providing for research of reservoirs' state in conditions of anthropogenic pollution

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Abstract. In this paper the authors have analyzed the heavy metals influence on the ichthyo-fauna state and systematized it, classified the aquatic ecosystem states, developed the model for their identification based on a modified Perceptron. A cognitive analysis of the factors of the influence of heavy metals on the aquatic ecosystem is performed. A special software has been developed. The model and software using solves a number of problems of studies of the heavy metals influence on the living organisms in biogeochemical conditions in the Lower Volga region and improving environmental conditions and also considerably lowering the costs associated with the research conduct due to the reduction of the number of natural experiments.

1. Introduction

Volga is the largest river in Europe. More than a third of dumping of sewage in Russia is the share of the Volga basin. Despite a large number of water and wastewater treatment facilities in the region, the efficiency of their work is extremely low. Therefore, a large amount of pollutants comes to water objects. The main reason of reduction of number and disappearance of a number of valuable species of fish through passage is the amplifying anthropogenic influence. One of the strongest and the most widespread chemical pollution is environmental pollution by heavy metals. [1]. There is also a problem of uncontrolled application of minerals in fishery without regard to contents them in the habitat of fishes and in their organisms. Now scientists of the Astrakhan state university do research in the directions of studying of biogeochemical composition of waters of the basin of the Lower Volga [2-3]. Researchers have received large volumes of experimental data. However, complexity of taking note of all variety of factors on a fish fauna, need of carrying out expensive natural experiments do relevant a problem of mathematical and computer modeling of influence of heavy metals on a condition of an ecosystem of the Lower Volga.

2. Analysis of the influence of heavy metals on aquatic ecosystem

The influence of heavy metals on living organisms of aquatic ecosystem is not uniquely defined and determined by their concentration. On the one hand, they are the significant toxicants. On the other hand, many of them are trace elements necessary for the metabolism of fish. In addition, not every excess of maximum permissible concentration of the metal causes the problems of ecosystem. In assessing of the ability of ecosystems of the reaction to external toxic exposure they speak about the buffer capacity of the ecosystem. The buffer capacity of freshwater ecosystems to heavy metals - is the amount of metal-toxicant, which does not significantly impair the functioning of the entire natural ecosystem.

Thus, the state of the aquatic ecosystem is determined by the concentration of heavy metals and adaptive capacity of the medium.

Occurring in the biosphere geochemical and biogeochemical processes and human activities are responsible for the migration, dispersal and concentration of chemical elements (including trace elements) in rocks, soils, soil, water, air, plants and animals, impacting the geochemical environment in some areas of the planet and hence on its inhabit plant and animal organisms (Kowalski, 1974). Aquatic ecosystems are characterized by considerable diversity of the distribution and migration of elements. V.I. Vorobiev developed the fundamental principles of the biogeochemical and ecological-physiological paradigm of studying of the role of mineral substances (macro- and micronutrients) in aquatic ecosystems and their use in the aquaculture [3].

Adaptive capacity of the aquatic ecosystem depends on heavy metals state in an aqueous medium:

- Metal is in dissolved state;
- Adsorbed and accumulated by phytoplankton, i.e. plant organisms;
- Connected with bottom sediments as a result of sedimentation of suspended organic and mineral particles from the aqueous medium;
- Adsorbed on the surface of the bottom sediments directly from the water medium in a soluble state;
- In the adsorbed state on suspended particles.

Aquatic organisms (eg, shellfish), complexing agents influence the state of heavy metals in the water. They alter a heavy metal in a non-toxic or low toxic form. The intensity of the formation of insoluble complexes that extend the buffer zone depends on the amount of biomass. The amount of biomass is determined by natural and climatic conditions (water temperature, season). Other components of the aqueous medium form soluble organic compounds by interacting with heavy metals, greatly increasing the toxicity of heavy metals. The acidity and the presence of fungus in water affect the formation of highly soluble organic compounds of heavy metals. There are many other factors difficult to calculate that alter the boundaries of the buffer zone. All this shows the complexity of the processes occurring in the surface water when it is hit by metal-pollutants and the appropriateness of modeling techniques applying for the study of these processes. To create the model, the authors systematized and formalized factors of the heavy metals influences on aquatic ecosystem.

By the degree of heavy metals influence on aquatic ecosystem authors of the proposed work it was identified four of its state (zone), the boundaries of which are determined by the heavy metals concentration: micronutrient deficiencies, an enabling environment for adaptation (buffering capacity) and toxicity (acute and chronic influence). The lower boundary of the favorable conditions zone is determined by the concentration of trace elements necessary for the metabolism of the fish. The maximum permissible concentration (MPC) of heavy metal in the first approximation, is the upper limit of the zone. However, for more accurate modeling, we must take into account the adaptation of different species of fish to environmental conditions. In this case, it will depend on the species composition of fish. The upper boundary of the buffer zone (zone adaptation) depends on many factors and it can vary greatly depending on the water composition, climatic conditions and the kind of fish.

3. Modified perceptron model

A large number of researches is devoted to ecosystems modeling [3-9]. However, for accounting of specifics of the region and influence of heavy metals on a water ecosystem authors used the approach.

To identify the aquatic ecosystem's state, the authors have developed a model in the form of a modified Perceptron (figure 1) [11,12].

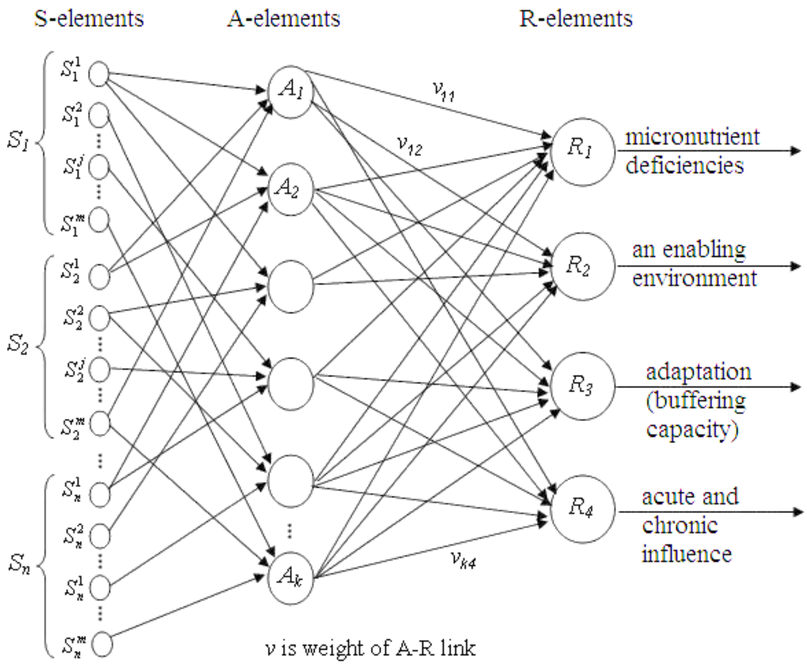

Figure 1. Modified perceptron model for identification of the status of the aquatic ecosystem.

All input parameters are divided into quantitative and qualitative criteria. Quantitative criteria include temperature and acidity of the water, concentrations of heavy metals and etc, qualitative criteria include the structure and composition of the aqueous medium. Qualitative criteria are determined by experts. For each value of the quality criterion an integer is assigned. For commensurability of input parameters, the authors proposed to represent sensory S-elements in the form of triggers possessing a boolean value as 0 or 1. For this purpose, during presetting of the Perceptron, a continuous scale of numerical criteria is divided into intervals. S-elements are divided into groups: S1, S2, ..., Sn. Each group of S-elements corresponds to one criterion. Each interval of the input variable values is associated with the sensor element, which in the working process possesses the value of 1 in the case the input value falls in its interval and 0 - otherwise. Thus, a continuous quantity is converted into a discrete one. In the same manner the sensing element is determined for each value of qualitative criteria transformed into quantitative indicator.

In contrast to the conventional model of the perceptron S-elements are connected to the A-elements not in an arbitrary way. One arbitrary sensor element of each elements group is connected to each A-element, ie, an arbitrary set of all criteria values is connected to A-element. Sets of criteria values are not repeated.

To reduce some redundant (not really existing) connections between S- elements and A-elements in the process of learning and working, the system analyzes the excitation of A-elements and eliminates broken links.

One of the four states of the aquatic ecosystem corresponds to each R-element. After processing each experiment, the system calculates the coefficients v of the strengthening links between A-elements and R-elements as the number of cases, the correct response of the links for the entire period of the system work. The value of the variable v of the relationships connected to each R-element are summarized in it. R-element that is received through the relationships with A-elements the maximum value of v is the identifier of the aquatic ecosystem state.

4. Cognitive map of the aquatic ecosystem parameters

However, the diversity of the influencing factors and complexity of their accounting significantly impede the use of the model, which reduces the efficiency of its use. In this regard, there is a need to reduce the considered factors amount based on their ordering and analysis. In order to determine what factors we will consider it is necessary to determine their significance.

To create the model, the authors systematized and formalized the heavy metals influences on the aquatic ecosystems [11]. The factors influencing the heavy metals form state in water and, consequently, the degree of the aquatic ecosystem adaptation to heavy metals, were systematized and presented in a four-level system (Figure 2).

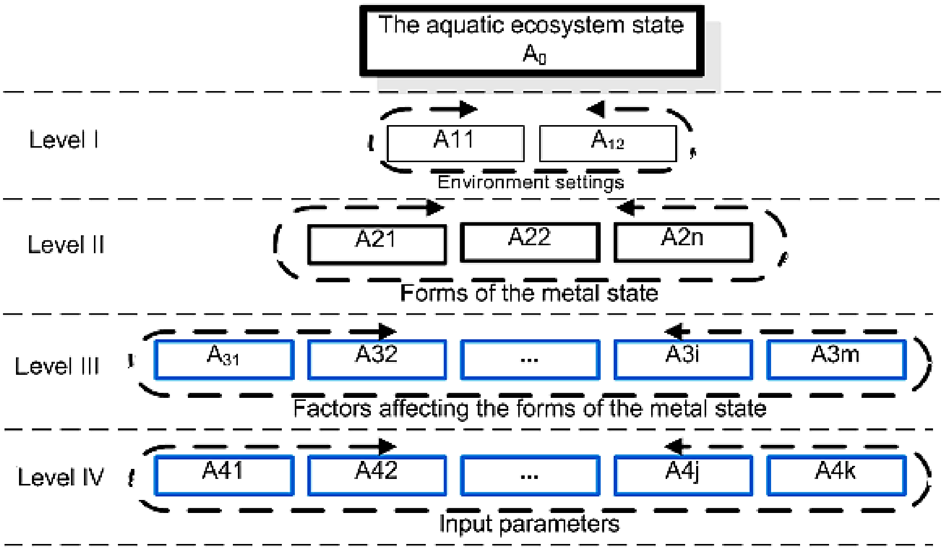

Figure 2. Modified perceptron model for identification of the status of the aquatic ecosystem.

The aquatic ecosystem can take three states: micronutrients deficiencies, an enabling environment for adaptation (buffering capacity) and toxicity (acute and chronic influence).

On the basis of the system of factors influence on the aquatic ecosystem state (Figure 3) and data from the tables I-VI the cognitive map were developed (figure 3).

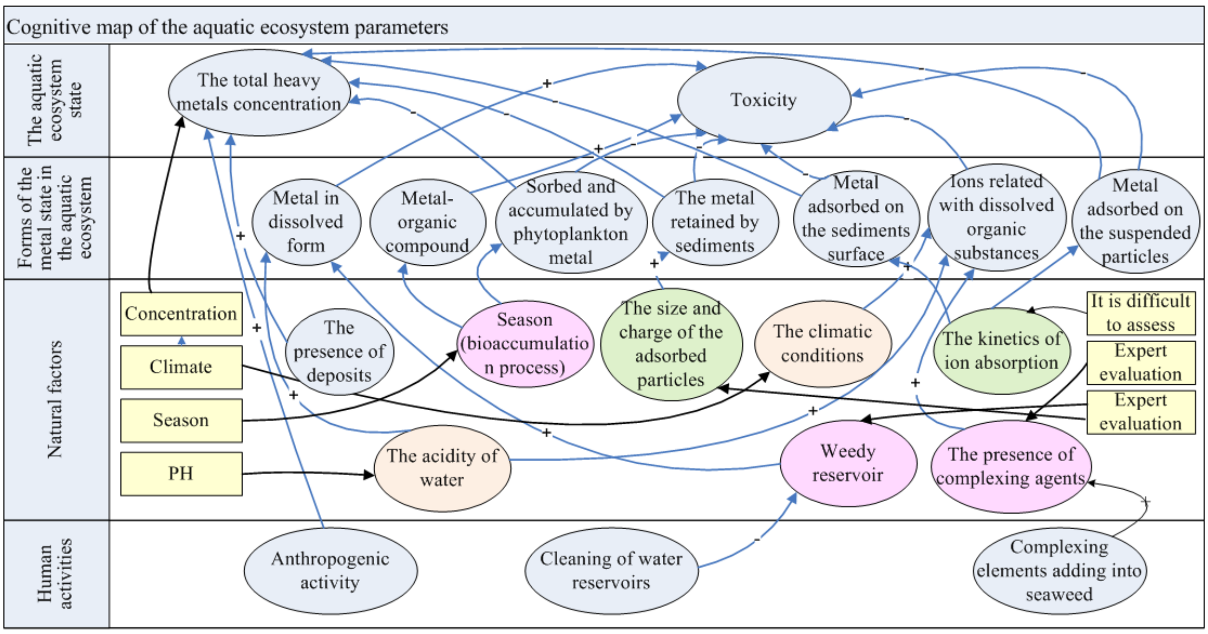

Figure 3. Cognitive map of the aquatic ecosystem parameters.

Analysis of the cognitive map reduced the number of factors taken into account when modeling of the heavy metals influence on the aquatic ecosystem. Acidity, the seasonal change in temperature (climate), eutrophication, a complex-forming reagents presence are the most influencing factors. We also need to take into account the kind of fish.

On the base of the theoretical studies the software was developed [12]. One of the system's interfaces of arise provided in figure 4.

A-element list

A-element number	Combination of S-elements	Acidity of water (pH)	Overgrowing of a reservoir	Water temperature (Celsius degree)	Climatic conditions	Type of heavy metal	Concentration of heavy metal / maximum allowable concentration	Species of fishes
97	$S_1^1 S_1^2 S_1^3 S_1^4 S_{10}^5 S_4^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	nickel	1.5 - 2	sturgeon
98	$S_1^1 S_1^2 S_1^3 S_1^4 S_{10}^5 S_4^6 S_2^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	nickel	1.5 - 2	salmon
99	$S_1^1 S_1^2 S_1^3 S_1^4 S_{10}^5 S_5^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	nickel	2 - 5	sturgeon
100	$S_1^1 S_1^2 S_1^3 S_1^4 S_{10}^5 S_5^6 S_2^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	nickel	2 - 5	salmon
101	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_1^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	0 - .7	sturgeon
102	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_1^6 S_2^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	0 - .7	salmon
103	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_2^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	.7 - 1	sturgeon
104	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_2^6 S_2^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	.7 - 1	salmon
105	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_3^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	1 - 1.5	sturgeon
106	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_3^6 S_2^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	1 - 1.5	salmon
107	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_4^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	1.5 - 2	sturgeon
108	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_4^6 S_2^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	1.5 - 2	salmon
109	$S_1^1 S_1^2 S_1^3 S_1^4 S_{11}^5 S_5^6 S_1^7$	4.5 - 5.5	poor	0 - 5	cold reservoirs	tin	2 - 5	sturgeon

Figure 4. A-element list.

5. Conclusion

Based on domain analysis the authors systematized the factors affecting the fish fauna state, classified the aquatic ecosystem states. For elaboration of the model of identification of the influence of heavy metals at the water ecosystem the authors have chosen the neural network using the study with a teacher; with dynamic connections (there is a setting of the synaptic balance for them); with a binary type of the input information (all input information in such type of the networks is presented in the form of 0 and 1); direct distribution (all connections are strongly directed from the input neurals to the output ones) Developed a mathematical model is based on a modified Perceptron. The authors defined qualitative and quantitative input parameters of the system, designed functional model and information and logical model of information system for the study of the heavy metals influence on living organisms in order to create a problem-oriented software.

The practical using of the developed software on the basis of the proposed model will solve the following problems:

- A significant reduction in the number of field experiments to identify the state of aquatic ecosystems;
- Forecast of the aquatic ecosystems;

- Analysis of the boundaries of the buffer zone based on the known state of the ecosystem (inverse problem);
- Selection of the most effective tools and techniques to improve the ecological state of the environment;
- Determination of the type of fish for breeding in a particular body of water;
- Determination of the optimal reservoir for breeding certain species of fish;
- Creating conditions in artificial ponds close to the natural habitats of fish;
- Determination of the optimal number of trace elements used in fish farming based on their content in fish habitat and in their bodies.

Analysis of cognitive map reduced the number of factors taken into account when modeling of the heavy metals influence on the aquatic ecosystem.

On the base of the theoretical studies the software was developed.

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