Diagnostics of the ecological state of aquatic and urban ecosystems using radiometric and bioindication analysis methods

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Abstract. Currently, all over the world, great attention is paid to the problem of the ecological state of urbanized territories. The issues of protection of the atmosphere, water sources, flora and fauna, soil cover are becoming increasingly acute. The issues of the methodology of environmental monitoring of ecosystem components transformed by anthropogenic activities deserve particular attention. Diagnostics of the ecological state made by physical and bioindication methods allows to obtain representative groups of indicators.

The problem of assessing environmental pollution is one of the urgent in modern society. For the territory of the Kursk region, one of the significant factors of anthropogenic impact on the components of ecosystems is the influence of the Kursk Nuclear Power Plant (KuNPP). To carry out environmental monitoring at any level, it is possible to use an extensive range of modern methods of analysis and environmental control. The use of diverse physical and bioindication methods of analysis involving the instrument base allows to obtain comprehensive reliable information about the environmental situation. The radiometric method quantifies the level of radiation contamination. However, it is impossible to assess the quality of the aquatic environment and the potential dangers for biosystems by only one method, since the main criterion (biota response) remains unappreciated. Modern anthropogenic impacts on aquatic and urban ecosystems, as a rule, are so multifaceted that even when studying a significant number of abiotic parameters, it is always doubtful that any other factors have remained unaddressed. Thus, the aim of the work is to verify the combination of bioindication and radiometric methods to assess the ecological state of water bodies. The research objectives included:

1. To study the specifics of the impact of the nuclear power plant on water bodies and urban ecosystems.
2. To study the ecological and population characteristics of the fauna in biotopes with different levels of pollution.
3. To evaluate the information content and correlation of the results of radiometric and bioindication methods.

The city of Kurchatov is located in the south-east of the Kursk NPP and can be strongly affected by the nuclear power plant, since during the observation period the prevailing wind direction in this territory is western. The maximum wind speed was observed in April-May 2018 and amounted to 18 m/s.
To measure the radiation background in the territory of Kurchatov, we took points located on the path of circulation of air masses, energy and material flows, which are the main highways in the landscape structure of the city. To exclude the impact of inner-city objects of increased radiation hazard, samples were taken in the immediate vicinity of such facilities as thermal power plants (TPP). Until recently coal has been used in their production cycle, during the burning of which radionuclides hazardous to humans are emitted: K-40, U-238, Th-232, etc. Ash dumps are used for the storage of spent carbon. The specific activity of radionuclides in the ash is an order of magnitude higher than in the original product. Now all TPPs have been converted to natural gas, but ash dumps remain, the gas-powered power plant, according to the estimates of NKADR in 2000 emits 230 GBq/year\(^{-1}\) of radionuclides into the atmosphere per year [1].

Other potentially dangerous objects are medical facilities, since the use of ionizing radiation is simply necessary in the diagnosis and treatment of many diseases, but we wanted to find out if the influence of the radiation factor also affected the health of the population living a few meters from the medical facility.

Large-panel multi-storey buildings, as well as other buildings made of slag concrete, can also be a danger due to the potentially increased radioactive background of building materials components.

As a part of the research work in Kurchatov, the values of the exposure dose rate were investigated, the study was carried out according to the method “Measurement of dose equivalent rate (DER) in an open area” using the SOEKS 01M dosimeter, we performed 5 measurements at 45 points. Then, the results were checked by professional dosimeter DKG-02U "Arbiter". Sampling points within urban areas were located as evenly as possible to obtain a clearer picture of the spread of the radiation background.

According to the results of our measurements, we can note that in general the radiation background in the city is within normal limits (average value is 0.12 μSv/h, while the norm is 0.20 μSv/h). Potentially dangerous in the territory are sampling points located near residential buildings and on the city embankment, here we can see a slight excess of up to 0.16-0.18 μSv/h. (figure 1).

These values slightly differ from the average background values in the city (0.15 ± 0.03 μSv/h) and, therefore, we can conclude that they are not dangerous objects from the point of view of radiation pollution. The excess can be explained by the fact that during the construction of the city, granite chips, which have a natural background above average values, were used to strengthen the walls of the houses.

Sanitary Rules and Norms (SanPiN) 2.6.1.2523-09 indicate the dose limit for the population - 1 μSv/year on average for any consecutive 5 years, but no more than 5 μSv/year. On the territory of Kurchatov, on average, the exposure dose rate is 0.15 μSv/h, thus, for a year, residents receive a radiation dose of 1.3 mSv/year. This value exceeds the minimum norm limit, which is specified in Radiation Safety Standards (RSS)-99/2009 by 1.3 times, but does not go beyond the upper zone, therefore, the
situation is not critical, and the state of the radiation background in the territory of Kurchatov can be considered satisfactory.

Observations of radioactive contamination of the surface atmosphere are carried out by sampling atmospheric aerosols using an air filter unit (AFU) Typhoon-3a. Samples of a five-day exposure (6 samples per month) were taken in Kurchatov.

The measurements of the total beta activity of the samples were carried out on alpha-beta radiometers UMF-2000, radiometers RUB-01P5.

In non-ash samples from short-lived radionuclides, I-131 was identified. Long-lived radionuclides Cs-136, Mo-99, Te-129, Te-132 and other technogenic radionuclides were periodically determined.

In monthly samples technogenic radionuclides - Cs-137, Co-60, Mn-54; natural - Be-7, K-40, Na-22, Pb-210, Th-232; occasionally technogenic - Fe-59, Zr-95, Nb-95, Co-58, Cs-134, Cr-51 were regularly recorded [2].

In order to assess the degree of danger of recorded radionuclides in Kurchatov, according to the gamma-spectrometrical analysis of five-day and monthly samples, the volumetric activity of technogenic radionuclides in atmospheric aerosols was calculated. The calculation was carried out in fractions of the permissible volumetric activity for the population (DOAnas, RSS-99/2009) for the average annual and maximum per year values. So, for example, the maximum activity value of $^{131}$I - 2.17 Bq/m$^3$ x 10$^{5}$, with the norm specified in RSS-99/2009 at 4Bq/m$^3$, then the activity of this radionuclide is almost 185 thousand times lower than the permissible value, $^{137}$Cs - 0.4 x 10$^{5}$ Bq/m$^3$, DOAnas $^{137}$Cs - 1.7 Bq/m$^3$ activity. $^{137}$Cs is 425 thousand times lower; activity $^{60}$Co, $^{54}$Mn, $^{54}$Fe and $^{95}$Nb is several million times lower than normal. Thus, the radionuclides contained in the atmospheric air of Kurchatov: I-131, Na-24, Cs-137, Co-60, Mn-54, Fe-59 and Nb-95 have very low activity (hundreds of thousands and millions of times lower than normal), and therefore are not dangerous to public health.

For a comprehensive assessment of the ecological state of the rivers under the influence of the whole complex of pollutants from urban and industrial effluents, it is necessary to use not only chemical methods of analysis, as generally accepted but biological methods, as the most fully reflecting the quality of river waters.

Biological methods are based on the fact that an environment of a certain chemical composition is necessary for the life of living creatures. When it changes, the living creature gives a response signal. Establishing a connection between the nature or intensity of the response signal of the body (called the indicator) with the amount of the component changed in the medium serves to detect or determine it [3].

At present, bioindication methods using zooplankton communities and clams have already completely proved themselves. These methods are used in works by A. Makrushin [4], G. N. Skoptsova [5]. Rudnev V. V uses biological methods to assess the pollution of water bodies in the Kursk region [6].

Changes in hydrochemical and hydrobiological, radiation indicators of watercourses under anthropogenic influence can be assessed on the example of the Seymi, Reut rivers. The criterion for assessing the degree of impact on the watercourse will be the chemical composition, zooplankton communities, clams, indicators of total beta activity. The total beta activity of radionuclides in the aquatic environment is considered one of the most informative integral indicators characterizing radiation safety.

The basis is data collected in the summer field season of 2019, as well as data from analyzes carried out in the Central Chernozem radiometric and chemical laboratory [7].

The river water quality was determined according to the Pantle and Buka method in the modification of Sladeček [8], which is based on the sensitivity of many species of zooplankton communities to the presence of pollutants in the water. The system for determining saprobity (the ability of organisms to withstand varying degrees of organic pollution of water) is used in this method. To determine which saprobological class this or that monitoring point of the reservoir examined by us falls into, the designation of saprobity classes is used (table 1) [9].
Another biological (bioindication) indicator of the state of the river ecosystem used by us is clams: painter’s mussel (Uniopiktorum) and swan mussel (Anodonta cygnea). They are also sensitive to changes in the chemical composition of river waters.

The study has shown:

According to hydrochemical indicators on the Seym river (observation point of Anakhino village), violations of the standards were recorded within 4 MACs for NH4 and NO2, 1.5 MACs — oxidation of dichromate, 1.6 MACs — BOD5, average annual excess for MACs for copper is 1, 2 MPC. The saprobity index is already 2.32, i.e. water quality is moderately polluted. This item refers to the alphabetamezosaprobic class of water. 100 painter’s mussels with a predominant length of 9-10 cm and 80 swan mussels with a length of more than 12 cm were found here. The average total beta activity for 2019 is 0.18 Bq / l.

The next point of water sampling on the Seym river is the village of Sugrovo. Here, an exceance of MAC by 1.2 times was recorded only for the oxidation of dichromate. The saprobity index is 1.64, i.e. water in this place belongs to the betamezosaprobny class - lightly polluted. The number of mollusks: 28 painter’s mussels with a length of 6-7 cm and 19 swan mussels with a length of 8-9 cm. Average total beta activity for 2019 is 0.33 Bq/l.

On the Reut river, a water sampling point is located 0.5 km above the KuNPP. Here, an exceedance of MAC by 1.2 times was recorded only for the oxidation of dichromate. The saprobity index is 1.64, i.e. water in this place belongs to the betamezosaprobny class of water - lightly polluted. The number of mollusks: 21 painter’s mussel with a length of 6-7 cm and 15 swan mussels with a length of 8-9 cm. Average indicator of total beta activity for 2019 is 0.27 Bq/l.

One more point of water sampling on the Reut river is located 1 km far from entering the Seym river. Here the MAC is exceeded for the following chemical elements: bichromate oxidation - 1.5 MAC, BOD5 - 1 MAC, NO2 - 1.5 MAC, phosphates - 1.6 MAC, copper - 1.1 MAC. The saprobity index is 2.20, i.e. water in this place belongs to the alpha-betamezosaprobic class of water - moderately polluted. The number of mollusks is 9 painter’s mussels with a length of 8-9 cm. and 5 swan mussels with a length - 10-11 cm. The average indicator of total beta activity for 2019 is 0.26 Bq / l. The indicators of the background cross on the Reut river show that the watercourse in this place is not contaminated with chemical pollutants, which biota adequately responds to. Zooplankton species found here are adapted to inhabit mainly in unpolluted water bodies. These are scud (Amohipoda), sidacrystallin (Sidacrustallina), alona (Alona sp.). Indications of total beta activity are within the natural background.

It cannot be said about the mouth of the Reut river. Household faecal sewage from the city of Kurchatovis discharged into the Reut river. And here, according to hydrochemical indicators, the
The biogenic pollution is traced on the river Seympast the city of Kursk. And therefore, there is an increase in the saprobity index and a significant increase in the number and biomass of clams. Zooplankton organisms with low saprobity indices were found here, i.e., living in polluted water bodies: larvae of chironomids, water louse (aselussaquaticus), tick (nidrocarina). Indications of total beta activity in water compared with background indications increased slightly and amounted to 0.30 Bq/l.

For about 50 km to the next monitoring point on the Seym, river the water content increases, the channel becomes broad and water abundant. Diluted pollutants are brought into the Seympada and Reut rivers. In addition, off-balance water from the KNPP is discharged into the Seym river. At this point, the nutrient pollution is also observed. However, according to the saprobological classification, the water here is lightly polluted. Organisms with both a low saprobity index and a high one were found in water. For example: alona sp., chydoridae sp., water louse (aselussaquaticus). Species of zooplankton adapted to inhabit in clean waters dominated here.

An interesting fact is being observed: at a considerable distance from the KNPP at this monitoring point the Seym river (Sugrovo village) indicators of total beta activity increased from all monitoring points and the average for the year is 0.33 Bq/l. There can be several reasons for this fact: the discharge, albeit treated and tested, of off-balance water from the KNPP; added radionuclides in water from the Reut river.

In 2019, H-3 (tritium) was recorded in the off-balance waters of the KNPP. Tritium made the main contribution to the activity of discharges, but its annual discharge did not exceed 0.13% of the allowable. According to gamma-spectrometric analysis, the volumetric activity of technogenic radionuclides in water samples, united by points over the year, did not exceed the lower limit of measurements of the range of measured activity (0.5–1.0 mBq/l).

According to hydrochemical analysis, the copper content is detected in almost all monitoring points. The increase of iron and copper concentrations in the Kursk region is associated with more intensive recharge of aquifer with this geochemical feature [10].

In both cases, there is a change in the hydrochemical and hydrobiological indicators of the state of the rivers. There is an increase in maximum allowable concentrations of chemical elements. It affects zooplankton and there is an increase in the saprobity class of the reservoir. The number and size of clams also change. Total beta activity at all sampling points is significantly lower than the high pollution indications according to RSS 99 / 2009 for drinking water.

The analysis of the hydrochemical, hydrobiological, and radiometric parameters of the studied watercourses has shown that the objects under consideration are heterogeneous in the degree of anthropogenic load.

Correlations between the results of radiometric and bioindication methods according to the data obtained is not observed. Since there is no high radioactive pollution of water bodies that affect the livelihoods of zooplankton. It is once again shown that hydrobiological indicators for zooplankton communities and clams are reliable indicators in the conditions of the Kursk region. They respond to changes in the chemical composition of watercourses.

In general, the results of the study are informative and show that the radiation situation in the territory of Kurchatov and the water bodies around it is stable. The exceedance of safety standards is not observed.

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