The current state of the water and bottom sediments in the Irkutsk Reservoir

G A Karnaukhova and S I Shtel’makh
Institute of the Earth’s Crust SB RAS, Irkutsk, Russia

E-mail: karnauh@crust.irk.ru

Abstract. We present the results of the study on the state of the water and bottom sediments in the Irkutsk Reservoir for the period from 1976 to 2018. This reservoir is the main in the cascade of the Angara River reservoirs. It belongs to shallow artificial reservoirs with high flow. The Irkutsk Reservoir receives the basic water supply from Lake Baikal, which serves as its summit pound. We have determined that the composition of the water and bottom sediments in the reservoir depends on the elemental composition of the rock composing its eroded banks as well as on the water flowing from Lake Baikal. Based on the concentrations of the main elements, the water in the reservoir after 60 years of its operation corresponds to potable water standards. The water pollution coefficient for all elements, especially for Pb and Mn, slightly exceeded the MPC values at the sites of Nikola (Baikal water) and Solnechny (near the dam of the Irkutsk Hydroelectric Power Station). Based on the pollution coefficients, the bottom sediments are at the level of the geochemical background of the rocks composing the south of the Siberian platform. The geochemical parameters of the water and bottom sediments indicate that the Irkutsk Reservoir belongs to water bodies with the low anthropogenic pressure.

1. Introduction
The state of the environment and sustainable development in the Baikal region under the conditions of active anthropogenic impact on the natural processes is one of the modern problems. The study of the natural migration of chemical elements in the lithosphere of the south of the Siberian platform and their transformation after regulating the flow of the Angara River and creating the cascade of artificial Irkutsk, Bratsk, Ust-Ilim, and Boguchany reservoirs is becoming the most relevant.

The Irkutsk Reservoir is the main in the cascade. Its length is 55 km; the area is 154 km², and the volume of water mass is 2.1 km³. The reservoir belongs to shallow artificial reservoirs with high flow. The Irkutsk Reservoir receives the basic water supply from Lake Baikal that serves as its summit pound. The average annual runoff from the reservoir through the Irkutsk Hydroelectric Power Station is 99.9% of the total discharge [1]. The influx of substances with the material from its coastal erosion and the composition of the Baikal water determine the elemental composition of the water and the bottom sediments in the reservoir. The water composition of Lake Baikal and the Irkutsk Reservoir at its source indicate their significant elemental identity [2-4]. The Irkutsk Reservoir serves as the main source of water supply for the Irkutsk city and the Shelekhov town. Therefore, this study aims to analyze the elemental composition of the material of the supply sources, the water, and the bottom sediments from the reservoir to identify the direction of migration and deposition of the elements that determine the state of the water and bottom sediments in the reservoir after 60 years of its operation.
2. Objects, data and methods
The compositions of rocks in the supplying provinces, the bottom sediments, and the water of the Irkutsk Reservoir were studied from 1976 to 2018 through fieldworks, analytical laboratory methods, and calculation methods. Fieldworks were carried out along 12 profiles, 4 of which were control profiles (the Istok, the Kurma, the Patrony, and the Solnechny) (figure 1).

The sampling of the rocks composing eroded banks as well as of water and bottom sediments along 12 profiles was carried out from the board of the research vessel (RV). The surface water samples were taken using a plastic bucket. Molchanov bathometer was used to take water samples at various depths. The sampling of bottom sediments was carried out with the PI-27–II core sampler. For shallow depths, core sampling devices of different modification groups and bottom grab were used from the board of the RV. The granulometric composition of the samples was determined by mechanical analysis, the Sabanin method, pipette analysis and combined method under laboratory conditions using the equipment located at the Center for Geodynamics and Geochronology (IEC, SB RAS). The chemical compositions of the rocks of coastal scarps and the bottom sediments were determined using the methods of the conventional complete chemical analysis and the instrumental methods, including quantitative X-ray fluorescence spectrometry (XRF), the main advantage of which is the determination of concentrations of macro and trace elements in the samples without their destruction [5]. The hydrochemical studies of the chemical parameters of the reservoir water, as well as the study of the movement of sedimentary material and concentration fields of suspended solids in time and space, were carried out by the method of polygon surveys, during which direct water sampling was carried out along the same profiles and at the same sites as the sampling of the bottom sediments. Four sites (Nikola, Kurma, Patrony, and Solnechny) were selected as control (figure 1). The macro element composition of the water samples was determined by classical methods of analytical chemistry under laboratory conditions [6]. The content of trace elements was determined by emission spectroscopy according to the technique recommended for the waters of the Baikal region [7]. The calculation of the coefficients and the assessment of the water pollution in the reservoir were carried out according to the recommendations of the Russian State Standards for Surface Water Protection (SanPiN 2.1.5.980-00, 2004) [8] and the Methodological Guidelines for the Implementation of State Monitoring of Water Bodies [9].

3. Results and discussion
The main factors determining the formation of the elemental composition in the water and the bottom sediments of the Irkutsk Reservoir are the features of the geological structure as well as the
Environmental transformation and sustainable development in Asian region

IOP Conf. Series: Earth and Environmental Science 629 (2021) 012009
IOP Publishing
doi:10.1088/1755-1315/629/1/012009

3.1. Water

The hydrological features of the Irkutsk Reservoir do not contribute to deposition and retention of elements. The concentration of elements in the reservoir water does not remain constant along the length of the reservoir. The main causes of the changes are fluctuations in the concentrations of the water coming from Lake Baikal, the intensity of the flow as well as the water level in the reservoir, to which the erosion processes in the coastal zone are closely related. The unidirectional runoff dominates from the source of the reservoir (the Nikola site) to the conventional border of the reservoir’s river part with its lake-reservoir part (the Kurma site). The elemental composition of the water does not change here. The concentrations of Mn and Zn dominate the elements in the water flowing into the reservoir. The elements of lithophilic group (V and Cr) have the lowest concentrations (table 1).

| Element | Sites          |
|---------|---------------|
|         | Nikola | Kurma | Patrony | Solnechny |
| Mn      | 9.20    | 7.00  | 7.30    | 24.70     |
| V       | 0.47    | 0.40  | 0.40    | 1.20      |
| Cr      | 0.65    | 0.07  | 0.42    | 1.84      |
| Pb      | 4.70    | 0.62  | 4.50    | 4.10      |
| Cu      | 5.40    | 1.35  | 4.80    | 6.30      |
| Zn      | 9.00    | 0.40  | 6.00    | 17.00     |
| Ni      | 2.64    | 0.08  | 2.48    | 3.02      |

At the Kurma site, decline of runoffs lead to a significant decrease in the concentration of elements in water. The largest decrease in the concentrations of Ni, Zn, Cr, and Pb is observed at the Nikola site. Pb, Mn, and V are less intensively removed from the water. Further, at the Patrony site, in the water moving along the reservoir towards the dam, the concentrations of Zn, Ni, Cr, Cu, and Pb sharply increase due to the addition of the erosion material from the banks of the reservoir. The V concentration does not change in the water (table 1). The concentrations of Mn and Zn dominating among other elements in the influx from Lake Baikal increase at the Solnechny site near the dam of the Irkutsk Reservoir. However, the concentrations of these elements are much lower in the water from Lake Baikal than in the influx from Lake Baikal.

3.2. Bottom sediments

Sands, large siltstones and fine aleuritic oozes are the main types of bottom sediments in the Irkutsk Reservoir, occupying 13%, 16% and 2%, respectively, of the overall bottom area. The average accumulation rate of sands and large siltstones is 2-3 mm/year, and that of fine aleuritic oozes is less than 2 mm/year. Eroded banks are the main source of the formation of bottom sediments in the reservoir. The banks of the reservoir composed of the Jurassic sandstones and the Quaternary diluvial loess loams are exposed to erosion. According to [11], the length of the eroded banks composed of the Jurassic sandstones is approximately 60 km, and those composed of and the Quaternary diluvial loams and the sandy loams with the absolute dominance of the loams are more than 90 km in length. The dominance of the elements of the lithophilic group in the composition of sandstones and loams is typical, determining their prevailing concentrations in the bottom sediments.
From the source to the Kurma site, the reservoir bottom is composed mainly of the submerged channel sand of the Angara River. Modern sedimentation is recorded only from this site. At this site, there is an intensive accumulation of elements in sediments, which is associated with a decrease in the transporting capacity of the water flow and the deposition of these elements from the Baikal water and water coming from Kurma Bay, as well as with the addition of elements from the erosion material. The bottom sediments of the reservoir consist of fine-grained sands and large siltstones. There is an active deposition of Mn, Cr, and V at this site. The poor accumulation of Pb and Cu is typical of the bottom sediments (table 2). Moreover, Mn, Cr, and V are the dominant elements in the bottom sediments at the Patrony site. However, there is a decrease in the amount of Mn and an increase in the concentrations of V, Zn, Ni, and Cu, with a constant concentration of Cr and Pb. The bottom sediments at the Solnechny site have higher concentrations of Mn, Cr, and Ni and lower concentrations of V, Pb, Cu, and Zn compared to the sediments at the Patrony site.

**Table 2.** The concentrations of elements in the bottom sediments of the Irkutsk Reservoir, mg/kg.

| Element | Eroded banks (background) | Sites |
|---------|--------------------------|-------|
| Mn      | 1055                     | 1047  |
| V       | 88                       | 112   |
| Cr      | 100                      | 140   |
| Pb      | 23                       | 22    |
| Cu      | 29                       | 24    |
| Zn      | 69                       | 43    |
| Ni      | 62                       | 34    |

3.3. *The current state of the water and bottom sediments in the Irkutsk Reservoir*

The state of the water and bottom sediments in the reservoir determine its ecological status. The current state of the reservoir water was assessed according to the pollution coefficient by the method [8] based on the comparison of the concentration of each element with its maximum permissible concentration (MPC) for drinking water (table 3).

**Table 3.** The pollution coefficient of the water from the Irkutsk Reservoir.

| Element | MPC, μg/l | Sites |
|---------|-----------|-------|
| Mn      | 100       | 0.0920 | 0.0700 | 0.0730 | 0.2470 |
| V       | 100       | 0.0047 | 0.0040 | 0.0040 | 0.0102 |
| Cr      | 100       | 0.0065 | 0.0007 | 0.0042 | 0.0184 |
| Pb      | 30        | 0.1567 | 0.0207 | 0.1500 | 0.1367 |
| Cu      | 1000      | 0.0054 | 0.00135| 0.0048 | 0.0063 |
| Zn      | 1000      | 0.0090 | 0.0004 | 0.0060 | 0.0170 |
| Ni      | 100       | 0.0264 | 0.0008 | 0.0248 | 0.0302 |
| The total amount | 0.3007 | 0.09795| 0.2668 | 0.4658 |

The obtained results indicate that a low pollution coefficient is typical of the water in the Irkutsk Reservoir. The Nikola site (entrance section) and the Solnechny site (downstream section) show a slight increase in the pollution coefficient for all elements. Mn and Pb have the maximum values of the pollution coefficient. V, Cu, and Cr have the minimum values of the pollution coefficient at the Nikola site. Zn, Cr, and Ni have the minimum values of the pollution coefficient at the Kurma site. The minimum values of the pollution coefficient for V and Cr are typical of the Patrony site as well as for Cu and V at the Solnechny site.
With existing fluctuations in the pollution coefficient along the length of the reservoir, the total amount of the ratios of the elements to their MPCs does not exceed one at each site. Therefore, according to SanPiN 2.15.980-00 [8], the water in the Irkutsk Reservoir belongs to unpolluted ecologically clean potable waters.

The quantitative presence of elements in the water of the reservoir, as well as the water quality, largely depend on the intensity of transition of elements into the bottom sediments based on the pollution coefficient of the bottom sediments [9] calculated as the quotient from the arithmetical division of the concentration of an element in the bottom sediments by its background concentration (table 4). The average concentration of each element in the rocks composing eroded banks of the reservoir served as the background concentration.

Table 4. The pollution coefficient of the bottom sediments from the Irkutsk Reservoir.

| Element | Kurma | Patrony | Solnechny |
|---------|-------|---------|------------|
| Mn      | 0.992 | 0.881   | 0.957      |
| V       | 1.273 | 1.500   | 0.958      |
| Cr      | 0.933 | 0.933   | 0.967      |
| Pb      | 0.917 | 0.956   | 0.833      |
| Cu      | 1.043 | 1.174   | 0.956      |
| Zn      | 1.869 | 2.695   | 2.348      |
| Ni      | 0.641 | 1.019   | 1.075      |

In terms of the pollution coefficients, there are three groups of the bottom sediments in the Irkutsk Reservoir. In the first group, the concentrations of the elements are below their geochemical background of the area (Mn, Cr, and Pb). In the second group, the concentrations of the elements are at the level of the geochemical background (V, Cu, and Ni). In the third group, the concentrations of the elements are above the geochemical background (Zn). Therefore, the concentrations of the elements in the bottom sediments of the reservoir do not differ significantly from their concentrations in the source material (water from Lake Baikal and the rocks of eroded banks). Hence, the bottom sediments inherit their geochemical specialization.

The relatively low concentrations of the elements in the water flowing from Lake Baikal, the relatively small volumes of the influx of erosion material, and the high flow rate of the Irkutsk Reservoir do not contribute to the active accumulation of the elements in the bottom sediments. The concentrations of the elements in the water and bottom sediments of the reservoir did not remain constant over the period of its operation. The main causes of the changes were the fluctuations in the concentrations of the elements in the water flowing from Lake Baikal as well as the water level in the reservoir, to which the erosion processes in the coastal zone, the intensity of the influx of the eroded material to the reservoir, and a decrease in the velocity field of the water mass are closely related.

4. Conclusions
The conditions of both natural and anthropogenic origin determine the current state of the water and bottom sediments in the Irkutsk Reservoir:

- based on the concentrations of the studied elements, the water in the Irkutsk Reservoir corresponds to the water quality standards for drinking water;
- the Nikola site (water from Lake Baikal) and the Solnechnyi site (near the dam of the Irkutsk Hydroelectric Power Station) show a slight increase in the pollution coefficient of the water relative to MPC for all elements, especially for Pb and Mn;
- based on the pollution coefficients, the bottom sediments are at the level of the geochemical background of the rocks composing the south of the Siberian platform;
the concentrations of the studied elements in the water and bottom sediments allow us to attribute the Irkutsk Reservoir to artificial reservoirs with the low geoecological hazard;

- based on the geochemical parameters of the water and bottom sediments, the reservoir belongs to the water bodies with low anthropogenic pressure.

Acknowledgments
This study was supported by the Russian Foundation for Basic Research within the framework of the scientific project No. 18-05-00101-a.

References
[1] Hydrometeorological Regime of Lakes and Reservoirs in the USSR. Irkutsk Reservoir 1980 (Leningrad: Hydrometeoizdat) p 140
[2] Koval’ P V, Udodov Y N, Andrulaitis L D, Gapon A E, Sklyarova O A and Chernigova S E 2005 Hydrochemical characteristics of the surface runoff of Lake Baikal (1997-2003) Reports of the Academy of Sciences 401(5) 663-7
[3] Karnaukhova G A 2008 Hydrochemistry of the Angara and reservoirs of the Angara cascade Water Resources 35(1) 72-80
[4] Grebenshchikova V I, Zagorul’ko N A and Pastukhov M V 2012 Monitoring studies of the microelement composition of the source water of the Angara River Water: Chemistry and Ecology 12 3-8
[5] Revenko A G 2002 X-ray fluorescence analysis of rocks, soils and sediments X-ray Spectrometry 31(3) 264-73
[6] Novikov Yu V, Lastochkina K O and Boldina Z N 1990 Methods for Studying the Quality of the Water in Reservoirs (Moscow: Medicine) p 400
[7] Vetrov V A and Kuznetsova A I 1997 Microelements in the Natural Environments of the Lake Baikal Region (Novosibirsk: Scientific Research Center of the JIGGM, SB RAS) p 236
[8] Water Sanitary Rule Guidelines and Methods of Safe Water Use of the Population Regulatory Collection 2004 2nd edition, revised and enlarged (Moscow: InterSEN) p 768
[9] Bulletin of Normative Acts of Federal Executive Bodies 2014 39 20
[10] Karnaukhova G A 2018 Changes in the hydrochemical composition of the water during the operation of the Irkutsk reservoir Meteorology and Hydrology 7 87-96
[11] Ovchinnikov G I, Trzhtsinskii Yu B, Zhentala M and Zhentala M A 2002 Abrasion-Accumulative Processes in the Coastal Zone of Reservoirs (on the Example of the South Angara Region and the Silesian Upland) (Sosnowiec-Irkutsk: IEC – University of Silesia) p 123