Formation of Hydrochemical River Regime Under Extreme Contamination by Waste Water (the Sak-Elga River in the Chelyabinsk Region)

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Abstract. Modern technologies designed to use natural resources in different ways are applied to restructure the environment. The use of technologies results in the deformation of environment, its local, regional and global changes occur. In the course of mining the spaces disturbed by the mine opening rock heaps and processing wastes are formed and rapidly appear. These spaces are dead surfaces the negative effect of which extends to the surrounding areas. Thus, the indirect impact on the lands connected with the change of the condition and regime of the surface and groundwater, settling of dust and chemical compounds from emissions to the atmosphere as well as the products of wind and water erosion lead to deterioration in the quality of the lands, surface and groundwater resources in the area affected by mining.

1. Introduction

The technological strength of a man combined with the inability to solve ecological and social problems have resulted in a severe global environmental crisis the fact of which is proved by many observable changes in the environment. The further crisis development may result only in the global environmental catastrophe unless the coordinated actions of all the countries in the world take measures to stop it.

At present, the hydrochemical regime of most water bodies located in the industrially developed regions of our country is formed not so much by the natural factors but by the artificial ones, basically by the waste water of industrial companies. Quite often this situation is observed in low rivers flowing through the areas which are extremely contaminated by the extraction wastes and non-ferrous metal ore beneficiation. This is exactly what happens in the territory of the Karabash copper province of the Chelyabinsk region, which is one of the most polluted areas of the country [1-5].

On the basis of the research made it is revealed that in the process of extraction, beneficiation and processing of copper ores one can observe a large amount of waste on vast areas, these wastes are highly-toxic pollutants which enter the hydrosystem of this territory, primarily, in the Sak-Elga river. The situation is getting worse as the river flows into the Argazi water basin which is the source of water supply of the Chelyabinsk urban agglomeration with the population of 1.5 million people [6-10].

To calculate the parameters for water rehabilitative measures, their performance level and the selection of the methods for water purification, it is necessary to determine the conditions and principles of the formation of the hydrochemical regime of the Sak-Elga river with its tributaries.
Therefore, taking into account the current situation, the detection of changes in the chemical composition of water courses under extreme contamination is the urgent problem [11-12].

2. Specification of water bodies in the Sak-Elga river basin

The Sak-Elga river originates in the spurs of mountain Yurma, 7 km to the west of town Karabash. The Sak-Elga river is polluted by waste waters of industrial companies and domestic wastewater of Karabash. The flow of the river is partially regulated by ponds Bogorodskiy and Karabash on the Serebryanka river which is the Sak-Elga river tributary [13-15].

The river will experience a significant anthropogenic load which leads to the destruction of the river in its lower reach.

To analyze the hydrochemical regime, six hydrochemical dam sites were installed and the water samples were taken to study their chemical composition. The sites were located in such a way that one could determine the contribution of the main pollutants of the hydrosphere of the Karabash copper province [16-17].

The conducted research has shown that the main sources of pollution of water courses in the studied area are the following:

- acid pools formed on the site of abandoned mines,
- the Serebryanka river,
- Ryzhiy stream,
- tailing dump
- pyrite field in the Sak-Elga river plain.

The contribution of the pollutants to the total amount of contamination is shown in Figure 1.

![Figure 1. Contribution of the pollutants to the composition of water.](image)

According to the chemical composition of the water, the Sak-Elga river can be roughly divided into two parts: the part which is up the inflow of the Ryzhiy stream and the part which is below the inflow up to the mouth. The upper part of the river is characterized by a relatively stable chemical composition [18]. In addition, most of the constituents are within the limits of the requirements imposed on the water bodies of cultural and domestic purposes (Table 1).
Table 1. Characteristics of the chemical composition of the upper Sak-Elga river to pond Bogorodskiy.

| Parameters                  | 14.03. | 12.04. | 04.05. | 20.05. | 26.09. | 24.10. | 07.12. |
|-----------------------------|--------|--------|--------|--------|--------|--------|--------|
| pH                          | 7.4    | 7.25   | 6.1    | 6.3    | 5.52   | 7.34   | 6.3    |
| Total ferrum, mg/l          | 0.55   | 0.19   | 0.32   | 0.08   | 0.63   | 0.66   | 0.75   |
| Magnesium, mg/l             | 6.1    | 6.1    | 2.4    | 2.4    | 4.86   | 2.4    | 8.5    |
| Copper, mg/l                | 0.01   | 0.03   | 0.06   | 0.03   | 0.045  | 0.04   | 0.03   |
| Average monthly discharge rate, m$^3$/sec | 0.071  | 0.68   | 1.56   | 0.22   | 0.38   | 0.56   | 0.28   |

The water of the Sak-Elga river below the inflow of the Ryzhiy stream up to the mouth considerably differs in hydrochemical elements, their composition and quantity from the upper part (Table 2). This is due to the input of the pollutants from the surface and groundwater runoff from the catchment area of the Ryzhiy stream, the areas occupied by urban sewage treatment plants, tailing dump 4 and the river plain where a fugitive sulfide-silicate tailing dump is located [19].

Table 2. Characteristics of the chemical composition of the Sak-Elga river below the inflow of Ryzhiy stream.

| Parameters                  | 14.02. | 12.04 | 20.05 | 20.06 | 26.07 | 26.09 | 07.12 |
|-----------------------------|--------|-------|-------|-------|-------|-------|-------|
| pH                          | 7      | 5.56  | 5.15  | 4.5   | 3.8   | 4.45  | 5.15  |
| Total ferrum, mg/l          | 7.2    | 13.6  | 6.3   | 2     | 72.1  | 0.37  | 12    |
| Magnesium, mg/l             | 51.3   | 30.4  | 21.9  |       | 54    | 47.4  |       |
| Copper, mg/l                | 0.029  | 0.6   | 0.32  | 0.27  | 0.36  | 0.85  | 0.39  |
| Average monthly discharge rate, m$^3$/sec | 0.2    | 1.16  | 2.07  | 0.38  | 0.15  | 0.53  | 0.48  |

After the inflow of the Ryzhiy stream which brings an extreme amount of the polluting components into the Sak-Elga river, in the hydrological section located below one can note a significant excess of maximum allowable concentration (MAC) of all metals.

To the mouth of the Sak-Elga river the content of total ferrum in its surface water is increased (from 36 up to 68 MAC), the content of zinc increases insignificantly (by some degree of MAC) [20]. The parameters of the concentration of hydronium (pH), which are within the permissible limits (6-9) before the inflow of the Ryzhiy stream into the Sak-Elga river, were within the permissible limits only once below its mouth, apart from they didn’t exceed 5.9 (below MAC) dropping to 3.7 – 3.8.

The changes in the concentration of copper and ferric salts along the river course are shown in Figures 2,3.
3. Development of a hydrochemical model

One of the main aspects of hydrochemical calculations is the forecasting of the mode of pollution and transformation of contamination on the area of water body by the calibrated hydraulic model. The hydrochemical calculations are used to estimate the spread of pollution agents (PA) in the river and storage reservoir which is necessary to predict the changes in the water quality when there are changes in water content under the stationary mode of pollution and when the load of pollutants on a water body increases up to the detection and monitoring of possible catastrophic changes in the water quality.

To study the calibration process of a hydrochemical model and in order to obtain specific simulation results, a hydraulic and then a hydrochemical model of a section of the Sak-Elga river within the town of Karabash were developed. Hydrochemical simulation was conducted on the basis of the Sak-Elga river on the following area: the Sak-Elga river – inflow to pond Bogorodskiy taking into account two tributaries which are the Serebryanka river and the Ryzhiy stream. The inflow to the Miass river takes to the mouth of the Sak-Elga river. The morphometry of this part of the river is simple; the performance of a hydraulic model makes it possible to rapidly calculate the passage of the steady stream flow. A hydrochemical model is complicated by the fact that it has complex regimes of the stream flow highly polluted with waste.

As can be seen from the diagrams, the concentration of ferric and copper salts in the Sak-Elga river is determined by waste water as well.
Figure 4. Model of formation of water composition in the Sak-Elga river: in the columns there is concentration of metal salts, main pollutants, mg/l.

To predict the quality of water in the Sak-Elga river, a correlation regressive analysis of the dependence of the amount of the salts of metals carried by the Sak-Elga river on the distance from the confluence of the river into pond Bogorodskiy up to its mouth was made. The obtained equations of regression lines and statistics are given in the Table 3.

Table 3. Correspondence between the distance and the amount of salts of metals carried by the Sak-Elga river, kg/year.

| Type of dependence | Correlation coefficient | Student’s test | Fisher’s ratio test |
|--------------------|-------------------------|----------------|-------------------|
|                    |                         | table | forecast | table | forecast |
| Fe=50.45S-63.91    | 0.906                   | tr=3.182 | tp=3.72 | F_t=10.1 | F_p=13.81 |
| Cu=1.337S-1138     | 0.808                   | tr =3.34 | tp =4.36 | F_t=10.1 | F_p=11.18 |
| Zn=2.697S+1642     | 0.945                   | tr =3.182 | tp =4.99 | F_t=10.1 | F_p=24.87 |

For $\alpha=0.05$. Here is the distance from the confluence of the Sak-Elga river up to the mouth (m).

The analysis of the table shows that the forecast fitting criteria significantly exceed the critical ones. The dependencies between the parameters are high, given formulas can be used to predict the quality of water throughout the Sak-Elga river bed.

4. Conclusion
The conducted research has proven that the hydrochemical regime of the Sak-Elga river is primarily determined by the amount and quality of waste water from extremely polluted territories of the Karabash copper province. The results obtained show the necessity of effective ecological recovery of the Sak-Elga river to prevent the pollution of reservoir Shershni which is the source of potable water supply to the agglomeration of Chelyabinsk.

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