Investigation of a small river ecosystem to calculate the risk of quantitative and qualitative depletion of watercourse

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Abstract. Economic development of catchment areas, where the flow of large and small rivers forms, leads to irreversible environmental changes and the disappearance of small rivers. Flowing through the areas of residential and industrial development of cities, towns and other settlements, they are exposed to the most intense anthropogenic pollution, resulting in a sharp deterioration of water quality and depletion of water resources. The aim of this study is to test the methodology of integrated assessment of watercourse pollution according to hydrochemical indicators. When calculating the risk of quantitative depletion of water resources it is necessary to take into account the peculiarities of territory use: arable land, woodiness, artificially created areas, etc. The method has been tested in alignments of small rivers of the Republic of Bashkortostan (Russia). At a complex estimation quantitative and qualitative risks of the small river depletion for the long-term period have been defined. The hydrological scheme of zoning on size of geoeconomic risk of qualitative and quantitative depletion of water resources of studied alignments of small rivers, in a zone of influence of the mining and processing enterprise is drawn up.

1. Introduction
Small rivers are among the largest types of water bodies and play an important role in shaping the quality of medium and large rivers. Today, however, small rivers are increasingly subject to anthropogenic impacts. A small but highly polluted small river has on average 10 times more impact on the water quality of its receiving river than on its quantity. The main causes of pollution of small rivers are agricultural development, deforestation and plowing of the steppe within the catchment area, as well as chemical, bacteriological, thermal and other water pollution. Contamination of the water body is stated when changing physical and organoleptic properties (turbidity, color, smell, etc.), chemical composition, including the appearance of toxic contaminants, formation of bottom deposits, foam, surface films, reduction of dissolved oxygen in water, appearance of various types of new organisms, including pathogenic microbes, the contamination of the water body is stated. Pollutants are those that cause irreversible changes in biotic communities in a water facility, and the quantitative characteristics of such changes go beyond natural possible fluctuations.

Pollution processes are opposed by self-cleaning – a combination of natural biochemical and physical (inflow of ultraviolet radiation from the atmosphere, dissolved oxygen content, sorption and desorption processes, cationic exchange, presence of microorganisms, etc.), hydrodynamic (flow rate, roughness of the channel, shoreline roughness, turbulence of the flow, etc.) processes leading to reduction of the concentration of pollutants, and in case of complete self-cleaning to restoration of the original of the
water object. Each water object has a certain limit of self-recovery capacity, at the excess of which it turns into a drain ditch.

There are known works that consider only qualitative indicators of the depletion of small rivers [1-5], assessing the risk of insufficient water supply from small rivers [6-8], the risk of drying of small rivers. In this paper, the authors propose an integrated approach to the assessment of the depletion of small rivers by water quality indicators and quantitative characteristics of water flow (water consumption and water availability).

The objects of the study are small rivers flowing in the zone of influence of mining industry of the Republic of Bashkortostan and Chelyabinsk region (Russia): Kydish, Aikreelga, Tanychau, Erekly, Buydy, Yamelga, Suyaska, Uy. The hydrochemical and hydrological indicators of these rivers for the period 2000-2017 have been studied. In river water, the maximum permissible concentrations of heavy metals – copper, zinc, nickel, iron, as well as oil products, biogenic components, organic compounds, suspended substances, mineral salts – are periodically exceeded. The presence of these pollutants is due to the influence of the chemical and mining industry, which discharges industrial and domestic untreated or insufficiently treated wastewater. Watercourses crossing the borders of the adjacent territories carry out transboundary transfer of pollutants, causing damage to the ecological condition of water resources. It is therefore necessary to conduct an integrated assessment of the degree of pollution.

2. Methodology for integrated assessment of watercourse pollution by hydrochemical indicators

Calculation of the value of the complex pollution index and relative assessment of water quality in the studied areas of the small rivers carried out in 2 stages: first, for each studied ingredient and water pollution index, then considered simultaneously the whole complex of pollutants and the resulting assessment.

In this work, the calculation of geoecological risk characterizing water pollution, water depletion, degradation of the river network is based on an approach to determining the risk of long-term (chronic) exposure. This approach to risk calculation is adapted to domestic regulations and can be applied to various components of the environment (air, drinking water, etc.). The system is based on mathematical models.

Geocological risk of quantitative and qualitative depletion of the catchment of the studied small rivers, using the methods described above for calculating the risk of long-term (chronic) exposure, are calculated according to the equations:

\[ Risk_{\text{poll}} = 1 - e^{\ln(0.84) \cdot SCWPI \cdot K_1 \cdot K_2}, \]  
(1)

where SCWPI – specific combinatorial water pollution index;

\[ K_1 \] – safety factor taken equal to 10;

\[ K_2 \] – pollution factor.

In the equation (1), \( K_2 \) is a correction factor that takes into account the water quality class of water bodies and depends on the variation of the value of the hydrochemical index of water pollution.

The amount of water depletion is calculated by the equation:

\[ Risk_{\text{depl}} = 1 - e^{\ln(0.84) \cdot K_{\text{depl}} \cdot K_{\text{corr}}}, \]  
(2)

where \( K_{\text{corr}} \) – the correction factor depending on the depletion factor \( K_{\text{depl}} \);

The water resource depletion factor is calculated:

\[ K_{\text{depl}} = \frac{V_{\text{surf}} + V_{\text{gr}}}{Q}, \]  
(3)

where \( V_{\text{surf}} \) and \( V_{\text{gr}} \) – surface and groundwater drainage, thousand m\(^3\)/km\(^2\);

\( Q \) – average summer flow rate of annual drain, m\(^3\)/s.

The equation for calculating weighted average risk is:
$$Risk_{wa} = 1 - e^{-\frac{1}{2}\left[\ln(1 - Risk_{poll}) + \ln(1 - Risk_{depl})\right]}$$, \hspace{1cm} (4)$$

where $Risk_{poll}$, $Risk_{depl}$ are indicators of two types of risk.

The severity of the risk was identified by ranking the weighted average risk according to table 1.

Table 1. Ranging of value of risk.

| Weighted Average Risk Values, $Risk_{wa}$ | Sharpness of risk |
|-----------------------------------------|-------------------|
| 0.00-0.25                               | Weak              |
| 0.25-0.50                               | Average           |
| 0.50-0.75                               | Strong            |
| 0.75-1.00                               | Very strong       |

The assessment of the ecological state of water bodies is a necessary element for the rational use of water resources.

In solving ecological and hydrological problems of rational water use, a number of methodical and methodological problems arise: uncertainty of criteria for assessing the ecological state of water bodies; polyvariety of relationships between quantitative and qualitative characteristics of a water body due to regional natural, anthropogenic, climatic features of the territory.

Assessment of the geoecological state in the studied alignments of small rivers in the zone of influence of the mining and processing plant under geoecological hazards, for example: periods of low, high water content, pollution spills, were carried out on the basis of geoecological risk.

The authors of this work have improved the method of determining the risk of depletion of water bodies by integrating the available initial spatial information of the characteristics of the watercourse, as well as the water pollution index is replaced by the specific combinatorial water pollution index.

The scheme visualizing the sequence of computational operations carried out in carrying out the assessment of the geoecological risk of quantitative and qualitative depletion of the watercourse is interpreted in figure 1.

![Figure 1. Scheme for carrying out risk assessment of quantitative and qualitative depletion of water resources.](image-url)
Integrated assessment of water quality of the studied small rivers in the zone of influence of the mining and processing plant was carried out on the following indicators: dissolved oxygen, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, biological oxygen consumption in 5 days, chemical oxygen consumption, sulphates, chlorides, general iron, copper, nickel, manganese, mercury and cadmium.

Results of calculation the coefficient of pollution $K_{\text{poll}}$, the value of risk of pollution studied alignments of small rivers for the period 2000-2017 Risk$_{\text{poll}}$ are given in table 2.

Table 2. Estimated values of SCWPI, pollution factor and risk value of pollution in the studied alignments of small rivers in the zone of influence of mining and processing plant.

| Alignments                        | SCWPI | $K_{\text{poll}}$ | Risk$_{\text{poll}}$ |
|-----------------------------------|-------|-------------------|-----------------------|
| 1 alignment – 5 km below tech. pond | 8.88  | 2                 | 0.99                  |
| 2 alignment – the inflow mouth of a small river | 9.25  | 2                 | 0.99                  |
| 3 alignment – above the mouth of the inflow | 5.59  | 1.5               | 0.99                  |
| 4 alignment – below the mouth of the inflow | 8.00  | 2                 | 0.99                  |

Values of risk of pollution studied alignments of small rivers are equal to 0.99 – maximum value of water flow contamination risk.

In calculating the risk of depletion of water resources, the areas of catchment basins, data on the catchment of underground and surface waters, data on the use of the territory, average summer expenses of annual drainage were taken into account.

Long-term average annual values of water depletion factor $K_{\text{depl}}$, risk values of water depletion Risk$_{\text{depl}}$ and volumes of annual water drain calculated for the studied river alignments are summarized in table 3.

Table 3. Calculated volumes of annual runoff, factors and values of risk of depletion of water resources of the studied river alignments in the zone of influence of mining and processing plant.

| Alignment                             | $K_{\text{depl}}$ | Risk$_{\text{depl}}$ | $Q, m^{3}/s$ |
|---------------------------------------|-------------------|-----------------------|--------------|
| 1 alignment – 5 km below tech. pond   | 1.4               | 0.3013                | 0.046        |
| 2 alignment – the inflow mouth of a small river | 0.5       | 0.0448                | 0.12         |
| 3 alignment – above the mouth of the inflow | 0.06             | 0.0104                | 0.45         |
| 4 alignment – below the mouth of the inflow | 0.05             | 0.0039                | 0.6          |

It can be seen from table 3 the average long-term risk of quantitative depletion of water resources in the studied river alignments during the period 2000-2017 from the river alignment below the technical pond to the alignment of the main small river decreases downstream, therefore, when developing conservation measures and territorial planning it is necessary to take into account the water content of the river in each alignment. Average annual risk values of water resources depletion in the studied river reaches varies from 0.0039 to 0.3.

3. Calculation of risk of quantitative and qualitative depletion of small rivers over a long period
The risk of quantitative and qualitative depletion of a watercourse is a generalized indicator of the risk of watercourse pollution and the risk of quantitative depletion of water resources.
For an estimation of a geoecological condition of studied alignments of the small rivers of Republic Bashkortostan and Chelyabinsk region in an influence zone of mining and processing plant the average annual risk of quantitative and qualitative depletion of water resources (in table 4) was calculated.

As can be seen from table 4 the risk values of quantitative and qualitative depletion of water resources have a maximum value of 0.99.

Table 4. The results of the calculation of the risk of quantitative and qualitative depletion of water resources of the studied river alignments in the zone of influence of mining and processing plant.

| Alignment | Risk<sub>poll</sub> | Risk<sub>depl</sub> | Risk<sub>wa</sub> | Geoecological risk class |
|-----------|-----------------|-----------------|-----------------|-------------------------|
| 1 alignment – 5 km below tech. pond | 0.99 | 0.3013 | 0.99 | Very strong |
| 2 alignment – the inflow mouth of a small river | 0.99 | 0.0448 | 0.99 | Very strong |
| 3 alignment – above the mouth of the inflow | 0.99 | 0.0104 | 0.99 | Very strong |
| 4 alignment – below the mouth of the inflow | 0.99 | 0.0039 | 0.99 | Very strong |

Hydrological scheme of zoning by the value of the risk of qualitative and geoecological risk of depletion of water resources of studied alignments of the small rivers in a zone of influence of influence of mining and processing plant is presented in figure 2.

As can be seen from figure 2 on all studied alignments of small rivers of Republic Bashkortostan and Chelyabinsk region in a zone of influence of mining and processing plant for the period 2000-2017 the value of geoecological risk of qualitative and quantitative depletion of water resources is characterized as "very strong" (values range from 0.99). The offered technique of risk assessment of quantitative and qualitative depletion of water resources allows to reveal water flow areas (the value of geoecological risk of pollution ≥ 0.5) demanding immediate realization of nature protection actions and adoption of management decisions on rational use of water resources.

4. Conclusion
Integrated assessment of the quality of small rivers over a long-term period showed that in all the seasons of the year under consideration, the average of the summer concentrations of nitrites, ammonium ion,
sulfates, iron, mercury, copper, zinc, manganese and cadmium exceed limit values of fishery concentrations in all control points.

If manganese pollution is related to the geological features of the territory under consideration, heavy metal pollution occurs in a chronic mode, due to a large complex of mining operations built without taking into account the environmental burden, which leads to serious environmental problems related to pollution of natural waters.

To study changes in concentrations of priority pollutants throughout the small river basin in the zone of influence of the mining and processing plant it is necessary to draw up a map-scheme of zoning of the watercourse basin (for all observation points) on the content of priority pollutants along the river stream.

Emergency inputs of pollutants into river waters, construction of various hydraulic structures can have an adverse impact on the river ecosystem. Water quality assessment is necessary for the operational management of water resources and the development of engineering solutions for the rehabilitation of watercourses.

Thus, analysis of the relationship between hydrochemical indicators and water consumption showed the need to consider water quality and quantity indicators in an integrated form.

When calculating the risk of quantitative depletion of water resources of small rivers it is necessary to take into account the peculiarities of territory use: arable land, forestry, artificially created areas, etc. For this purpose, it is necessary to draw up an information map of the use of the territory, which allows to zoning the territory of the catchment area of the study basin by the used areas.

Values of long-term risk of quantitative and qualitative depletion of water resources of studied alignments of the small rivers of Bashkortostan Republic and Chelyabinsk region in a zone of influence of mining and processing plant have a risk class of “very strong” (0.75-1.0).

Results of assessment of risk of quantitative and qualitative depletion of water resources allows to identify the alignments of a waterway demanding immediate realization of nature protection actions and adoption of management decisions on rational use of water resources.

References
[1] Krasnogorskaya N N and Nafikova E V 2015 Geoecological assessment and forecasting of dangerous natural and man-caused processes on the watershed of the river (Ufa: Ufa State Aviation Technical University) p 242
[2] Safarova V I, Abdrahmanov I A, Shydulina G F, Vdovina I V, Smirnova T P and Kostitsyn V G 2009 The impact of a large mining and processing enterprise on the hydrochemical and ecological condition of small rivers Environmental systems and devices 9 p 36-41
[3] Beyene A, Awoke A and Triesta L 2014 Ecological Indicators 37 p 58-66
[4] Dolgonosov B M and Korchagin K A 2013 Journal of Hydrology 504 p 104-14
[5] Li R, Zou Z and An Y 2016 JES 50 p 87-92
[6] Ishikawa Y, Murata M and Kawaguchi T 2019 Journal of Cleaner Production 239 118027
[7] Reynolds L V, Shafroth P B and Poff N L 2015 Journal of Hydrology 523 p 768-80
[8] Huang J, Wang W, Cui X, Wang D, Liu W, Liu X and Wang S 2020 Science of the Total Environment 711 134655