Hydroecological characteristic of coal-mining regions with crucial anthropogenic load (in the case study of the Yaiva river basin)

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Hydroecological characteristic of coal-mining regions with crucial anthropogenic load (in the case study of the Yaiva river basin)

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Abstract. Coal mines closure is usually associated with a list of environmental problems and one of them is their negative impact on a region's river system. Hydroecological features of the Yaiva river basin located on the Kizel coal basin territory have been assessed. This river basin is typical for the Kizel coal basin territory that is why it has been taken as a model to verify the research algorithms. Further these algorithms will be applied for the investigation of other rivers running in the Kizel coal basin territory. The main negative consequences of anthropogenic impact on the Yaiva river basin watercourse have been revealed.

1. Introduction

The Kizel coal basin (the Western Urals, Russia) occupies area of 200 km^2 and is located within West Urals folding zone adjacent to the pre-Ural boundary deflection. Folds have meridional and close to meridional orientation, they are elongated for tens of kilometers and complicated by numerous disjunctive dislocations [1]. Mining in the Kizel coal basin (KCB) had been carried out since 1796. The Kizel coal basin territory is within the drain area of the West Ural rivers that belongs to the Kama river basin (the Kama reservoir). All rivers are greatly influenced by the KCB. Coal mining makes ecological situation worse that is determined by lithologic-and-geochemical characteristics of coal-bearing formations. More than 50 elements have been found in coal, 12 of which have 10–1,000 times higher concentration in coal than in background strata [2].

The KCB is intensively karsted. The karst of the region is considered to be bare and covered that determines the dependence of the karst water regime of active circulation zone on atmospheric precipitation circulation regime [3, 4]. As a result of thickness diversity, great mining depth (up to 1,000 m) and overlying limestone being karsted the coal mining conditions are characterized as difficult. The increment of water in to the mines was 2,500 m^3/h in karst zones.

These two factors caused intensive environment pollution during coal mining. Water containing 4% of pyrite becomes acid (pH of 2–3) and is enriched with sulphate because of the pyrite oxidation. During the basin operation up to 100 million m^3 of mine waters were discharged into the local hydrological system without being purified [5].

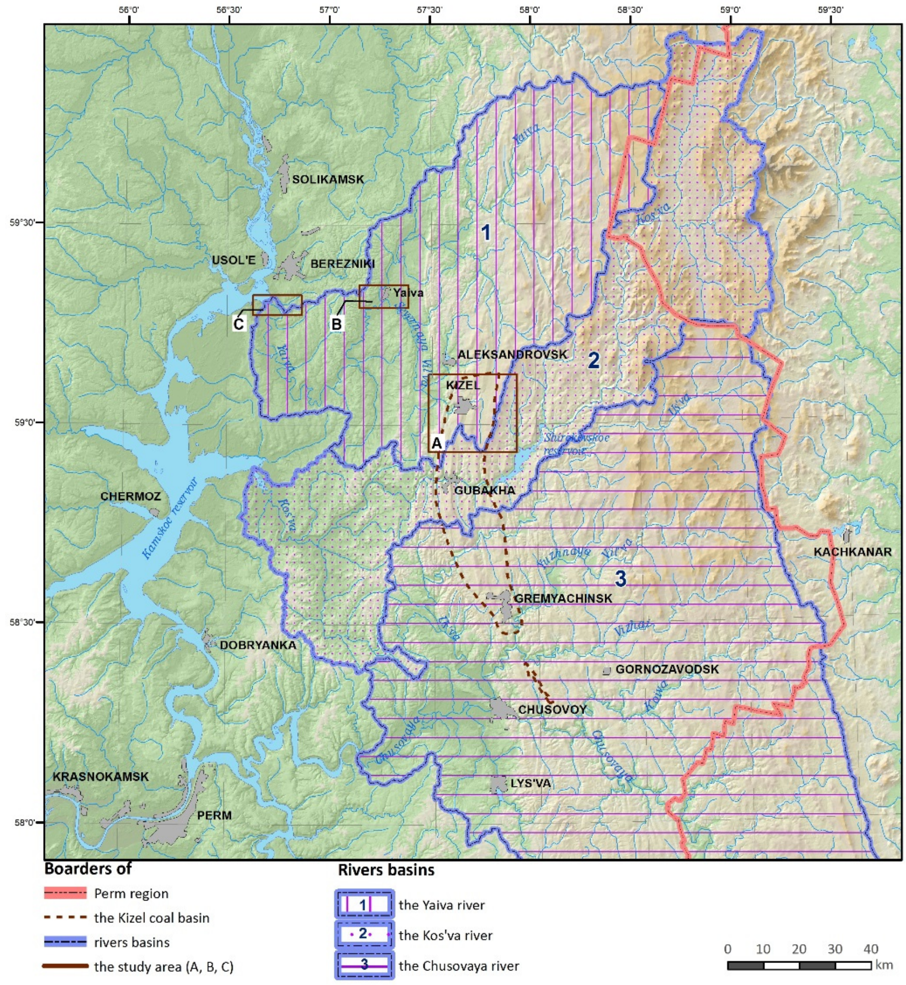

Figure 1. The Kizel coal basin surface waters.

The mines closure in the 1990s did not resolve the environmental problems [6]. After a gradual restoration of underground water level the mine water discharged during several years and according to several scientists the quality of the mine water discharge may worsen or become stable during 20-40 years [7]. When acid mine and drainage waters enter natural waterways, changes in pH and the formation of ochreous precipitates can have devastating effects on aquatic ecosystems [8, 9, 10, 11, 12].

The basins of three large rivers – the Yaiva, the Kos'va and the Chusovaya rivers were significantly effected by the anthropogenic load after the coal mines closure (figure 1). The Yaiva river basin is typical for the Kizel coal basin territory that is why it has been taken as a model to verify the research algorithms. Further these algorithms will be applied for the investigation of other rivers running the Kizel coal basin territory.

2. The problem statement

The Yaiva river starts in the North Ural mountains (the Kvarkush mountain range), 879 km from its mouth the river flows into the Kama reservoir making the Yaivinskii bay. The Yaiva basin is mostly located outside the boarders of the Kizel coal basin territory only the south-eastern part of the Yaiva catchment area is within its territory. The Severnaya Vil'va, being the first-order tributary of the Yaiva, is in the immediate region of the early developed coal field. Almost all pollution sources connected to coal production are located on the catchment area of the right tributary of the Severnaya Vil'va- the Bol'shoi Kizel river. The Bol'shoi Kizel and its tributaries are polluted as a result of the long-term influence of mine waters (figure 2A). There are no pollution sources among the Bol'shoi Kizel's tributaries except the Severnyi Kizel catchment – the reason why the hydrochemical composition of the Severnyi Kizel's waters were not observed. The Bol'shoi Kizel when flowing into the Severnaya Vil'va has a negative impact on it.

There are three main pollution sources of surface water at the Yaiva catchment area: mine water discharge, polluted springs and tailingspiles' drainage water. There 7 discharges of mine water, 13 springs (7 of them are polluted) and 24 tailingspiles were discovered on the Yaiva river basin.

The monitoring of the surface water of the Kizel coal basin that is conducted by the Ural Centre for social-ecological monitoring of coal-mining territories [13], suggests regular water composition observations of the Yaiva river throughout its length. The observation results indicate a negative impact of the Kizel coal basin on the Yaiva river and its tributaries till it flows into the Kama reservoir. To analyse ecological condition of surface water objects standards for fishery water objects- the maximum permissible concentration (MPC_{fwo}) were used. The specific combinatorial index of water pollution (SCI WP) was also calculated according to the operating management directive RD 52.24.643-2002 [13] that also confirms a high anthropogenic load on the basin hydrological network. Based on the SCI WP values the surface water is divided into 5 classes according to its pollution (table 1). The management directive regulating the quality of surface and underground water for other purposes GN 2.1.5.1315-03 (MPC_{OP}) was used to assess the pollution of underground water (springs) [14], the composition of mine water discharge and of tailingspiles' drainage water.

Table 1. Classes of pollution and hydroecological assessment.

Class	Rank	Description	Hydroecological assessment [15]
1		Conditionally pure	normal
2		Slightly polluted	risk
3	a	Polluted	
	b	Significantly polluted	crisis
4	a	Polluted	
	b	Polluted	
	c	Significantly polluted	disaster
	d	Significantly polluted	
5		Extremely polluted	

3. Results and discussion

Water pollution in the monitoring section ranged from "polluted" (3 class "a") to "polluted" (4 class "b") based on the SC IWP calculation results by 14 components over 2013. According to the SCI WP the total hydroecolocical condition of watercourses was ranged as being normal, in risk, in crisis and in disaster (figure 2) [15]. Compounds of iron, aluminium, beryllium, lithium, manganese mostly contribute to water quality and this fact makes them critical indices of water pollution of these water objects. The schema (figure 3) provides the highest possible excesses of maximum permissible concentration (MPC) in the monitoring sections. The highest possible exceedance of MPC was observed at the Poludennyi Kizel river (below spring No 030): Fe – 9450, Mn – 1118, Al – 127, Be – 56.

Considering the above mentioned data we may conclude that surface water is contaminated along the rivers chain: the Poludennyi Kizel, the Bol'shoi Kizel (figure 3A), the Severnaya Vil'va (figure 3B), the Yaiva (figure 3C) rivers right up to the Kama reservoir. Special attention should be paid to the Bol'shoi Kizel river basin as most polluters are located there.

The Bol'shoi Kizel river (or the Kizel river) starts from the confluence of two rivers: the Poludennyi Kizel and Vostochnyi Kizel (figure 3A). The Bol'shoi Kizel stresses about 20 km from the Poludennyi Kizel's confluence to its mouth. Seven small rivers flow into the Bol'shoi Kizel and only one of them (the Severnyi Kizel) is not polluted by the Kizel coal basin mining. The tributaries bring a lot of pollutants into the Bol'shoi Kizel. Moreover the Bol'shoi Kizel is impacted by acid tailingspiles' drainage water and mine water discharge (figure 4). The Bol'shoi Kizel riverbed is stony and silted with hydrate Fe sediments.

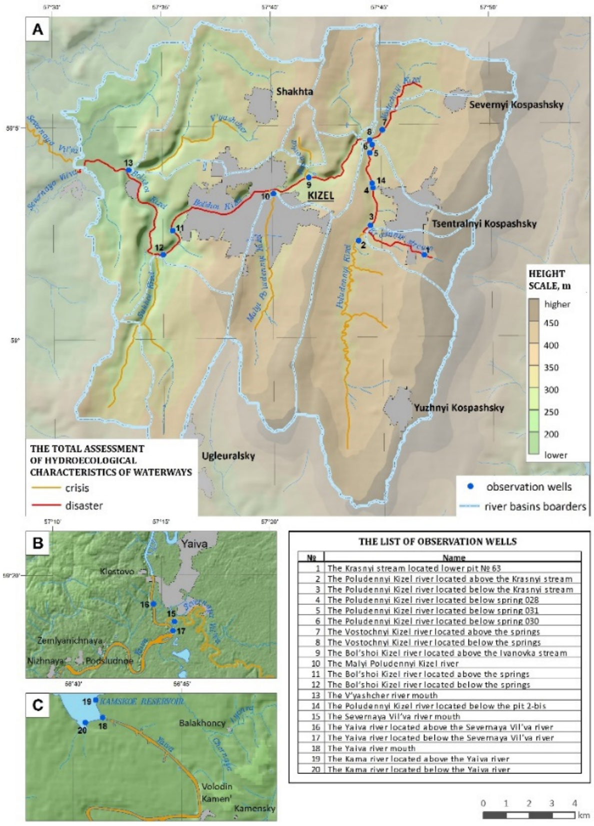

Figure 2. Total hydroecological assessment of watercourses and the measuring sections.

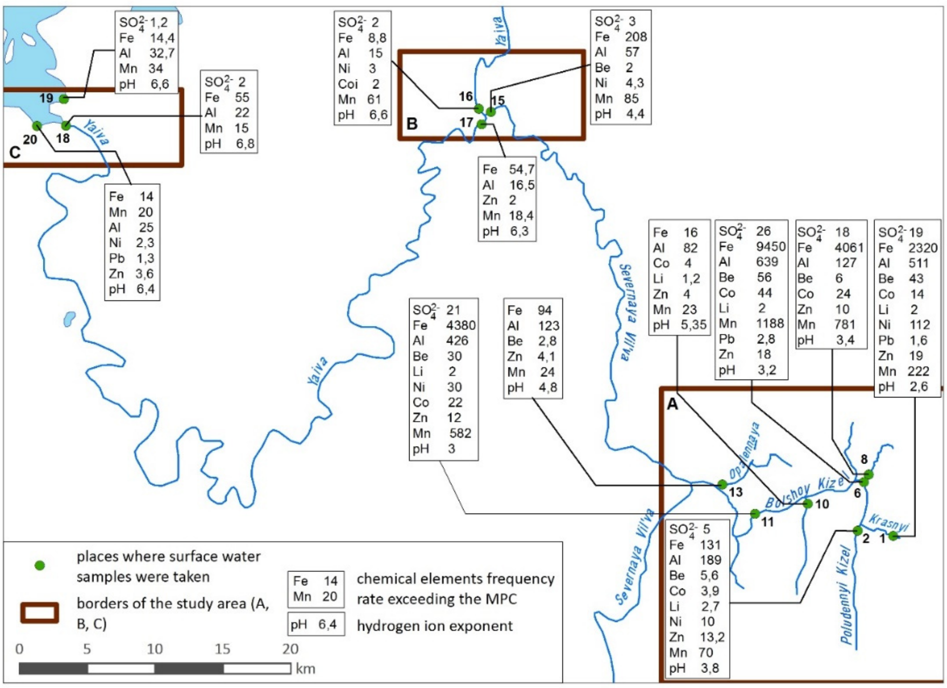

Figure 3. The Schema of monitoring sections location after the mines closure in the Yaiva basin.

Figure 4. Mine water discharge.

To characterize pollution sources that influence the Bol'shoi Kizel and its tributaries we have analyzed the mine water discharge and tailingspiles' drainage water data (table 2).

Table 2. Volume of mine water discharge into the Bol'shoi Kizel and its tributaries

The location of mine water discharge	River	Average discharge m^3/h	Maximum discharge, m^3/h	Minimum discharge, m^3/h
Subshaft of the Lenin Mine	The Bol'shoi Kizel	21.2	86.0	5.0
Shaft № 8 of the Lenin Mine	The Bol'shoi Kizel	268.0	587.0	94.0
The Volodarskii Mine adit	The Bol'shoi Kizel	13.4	40.0	1.0
Pit of 2-bis Kospashskaya Mine	The Poludennyi Kizel river and the Krasnyi stream	165.5	337.0	42
Pit № 63 of the Belyi Spoi Mine	The Poludennyi Kizel river and the Krasnyi stream	59.7	147.0	22.0
Total		527.8	1197	164

The overall rates of mine water that discharges immediately into the Bol'shoi Kizel (we do not consider the tributaries catchment) is on average 302 m^3/h, at that 89% of polluted mine water is discharged from shaft No 8 of the Lenin Mine. The maximum recorded discharge of mine water from this mine is a significant number– 587 m^3/h. The mine water discharge is acid (pH of 3-4), sulphate and has a high concentration of particular elements, first of all iron, aluminium, manganese, berylliu-m. The concentration of these elements significantly exceeds MPC_{OP}.

Annually on average 15,300 tons of sulfates, 6,000 tons of iron, 400 tons of aluminium and 57 tons of manganese come into the Bol'shoi Kizel directly (we do not consider the polluted tributaries); the amount of other pollutants is significantly low.

Tailingspiles' drainage water composition and volume surveys were made at 15 measuring sections. The maximum range of tailingspiles' drainage water was observed at the Vilodarskii Mine and at the Kospashskaya Mine – 20 and 22 m^3/h correspondingly.

Tailingspiles' drainage water has a high concentration of pollutants and is acid (pH < 3). High concentration of iron, aluminium, beryllium and manganese comes into water as a result of atmospheric precipitation infiltration. The concentration of these elements in tailingspiles' drainage water 100-1,000 times exceeds MPC_{OP} that leads to landscapes degradation. Heavy metals (cadmium, cobalt, nickel) were discovered practically everywhere but in low quantity. From time to time lead and zinc were revealed in tailingspiles' drainage water samples. The concentration of these elements 2-70 times exceeds MPC_{OP}.

Mostly polluted is the tailingspiles' drainage water from a cone-shaped and flat tailingspiles from the Kospashkaya Mine. Concentration of main pollutants of mine waters is enormous: iron – 2083 - 6157 MPC_{OP}, aluminium – 5245 – 10955 MPC_{OP}, manganese – 250 – 880 MPC_{OP}, pH constantly < 3.0.

A pond at the Kizel river is of a particular interest. Its area is 30 hectares and it has been existing for a long time. Currently the pond is drained, however it has accumulated a lot of sediments (about 1.2 million m^3).

There a 2-km part of the Bol'shoi Kizel channel passes through a huge amount of sediments that are the pollution sources for the environment (figure 5).

Figure 5. Degraded landscape and bottom sediments at the Bol'shoi Kizel river's pond.

Thus, the Yaiva rive is greatly polluted by the sources located on its catchment area although they are tens of kilometres away from the river and are limited with watersheds. The Severnaya Vil'va river being the Yaiva river tributary and polluted by the Bol'shoi Kizel greatly impacts the Yaiva river. When the Bol'shoi Kizel flows into the Severnaya Vil'va river, the water of the latter changes the colour that is observed at the satellite image (figure 6).

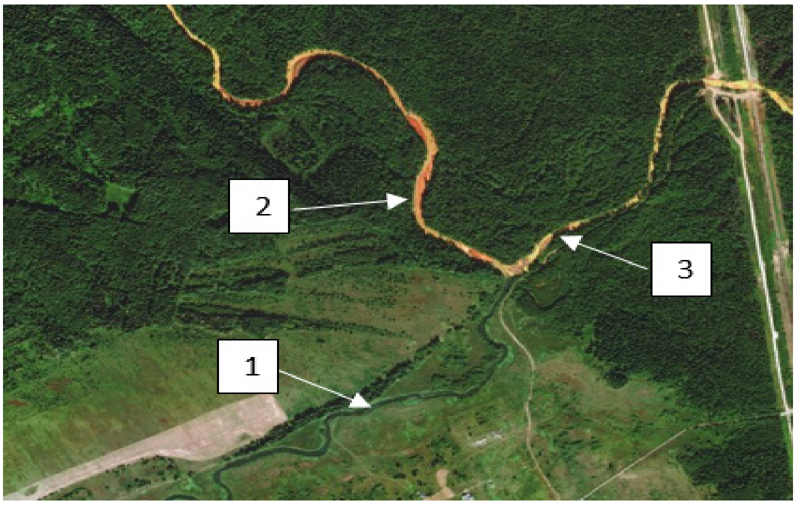

Figure 6. Place where the Bol'shoi Kizel flows into the Severnaya Vil'va.
(1 – the Severnaya Vil'va river; 2 – the Severnaya Vil'va after the Bol'shoi Kizel has flown into it; 3 – the Bol'shoi Kizel river)

The concentration of iron, aluminium and manganese naturally increases below the place where the Bol'shoi Kizel flows into the Severnaya Vil'va. These elements amount decreases in the Yaiva river mouth but unfortunately does not achieve the background level of measuring sections (above the Severnaya Vil'va mouth) and exceeds MPS_{FWO}. Long-term observations of the dynamics of iron, aluminium and manganese concentration do not demonstrate the improvement of the Yaiva water quality.

Thus, the quality and the quantity characteristics of the water objects running at the KCB territory significantly change:

- Chemical composition of rivers changes (the hydrochemical phase changes from hydrocarbonate-calcium-natrium to sulfate, chalybeate-aluminium, the mineralization increases from 90-159 mg/L to 640-6,000 mg/L and close to neutral hydrogen ion exponent becomes acid;
- Mine water discharges supply rivers, small ones in particular;
- Bottom sediments of many rivers and ponds are anthropogenic, acid and enriched with iron, aluminium, sulfates and heavy metals, as a result they are the sources of secondary pollution.

Under these circumstances the amount and quality of biota in rivers is low at some places. We argue, that rivers lose their natural characteristics and are considered to be new anthropogenic formations.

To assess the general hydroecological conditions of watercourses is necessary to determine the maximum anthropogenic load on the whole hydrological network of the Kizel coal basin. Further, a complex approach to a river system recovery will include the construction of artificial geochemical barriers [16] with the determination of their optimal location. Also the complex approach will include the development of an environment monitoring system based on both remote sensing images and field observations.

Acknowledgments
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