*International Journal of Engineering & Technology*, 7 (3.19) (2018) 206-214

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*

***Research paper***

# Monitoring of the State of the Left-Bank Confluents of the Upper Yenisei Basin in the Zone Of Impact of the Coal Industry Enterprise

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**Abstract**

Mining leads to technogenic transformation of ecosystems and causes environmentally dangerous situations. A separate task in the field operation is the monitoring of aquatic ecosystems as reservoirs of phytoplankton and hydrobionts as well as a link between surface and ground water. Therefore, monitoring of ecosystems which are subject to technogenic factors is an urgent task for further forecasting of their transformation and will also allow selecting and adapting optimal technologies for their reclamation. The article presents the results of hydro-chemical indicators of the left-bank confluents of the Upper Yenisei basin for 2015-2017 in the conditions of influence of coal-mining enterprise "Mezhegeyugol". It has been revealed that the quality of surface waters (color, turbidity) deteriorates, the ionic composition and the pH level of the water are subject to seasonal fluctuations, exceeding MPC (maximum permissible concentration) of ammonium and total iron ions in the investigated waters is identified as well as contamination with coal dust while the content of chemical elements does not exceed MPC.

***Keywords:*** the Upper Yenisei basin, coal industry, monitoring of water ecosystems, hydro-chemical indicators of water.

## 1. Introduction

It is known that mining leads to technogenic transformation of ecosystems (violation of the integrity of geological massifs, vegetation and soil cover, changes in hydrological regimes) and causes environmentally dangerous situations [19; 20]. Mining and processing of coal carries a potential risk of negative impact on the environment - atmosphere, water, soil, bio resources. In connection with this, the role of monitoring studies in order to forecast changes in ecosystems as a result of industrial development significantly increases [2; 4; 8; 9; 10; 11]. A separate important task in the course of development and exploitation of deposits is the monitoring of aquatic ecosystems as reservoirs of phytoplankton and hydrobionts, as well as a link between surface and ground waters [3; 12; 14].
Monitoring of the state of watercourses was carried out within the licensed area of the coal company "Mezhegeyugol" [23] under the Program for conducting object environmental monitoring [21] in order to identify the degree of technogenic transformation of aquatic ecosystems under the influence of the coal mining enterprise.
The mining of coal seams at the Mezhegey field is carried out by an underground method. Based on the thicknesses of coal seams and existing mining equipment [25], all layers are worked out in one layer; development system - long poles (panels) along the strike with coal excavation by mechanized complexes with complete collapse of the roof; the formation exposing is done by vertical and inclined trunks.
The hydrographic network of the work area belongs to the basin of the Elegest River which is the left and largest confluent of the Upper Yenisei (Ulug-Khem) [18]. The Elegest river originates on the northern slopes of the western part of the range of the Eastern Tannu-Ola and has a fairly extensive network of confluents flowing from the central part of the ridge. On the right side, within the area of the works, it assumes the Mezhegey river which has several large left confluents flowing from the northern slopes of the eastern part of the range of the Eastern Tannu-Ola (the rivers Shangan and Mogai). In the upper and middle reaches of the Elegest and Mezhegei rivers (in the mountain part the river is called Durgen) there are all the features of mountain rivers flowing along a series of wooded valleys separated by narrowings, sometimes with rocky slopes. In the lower reaches, where the technological platform "Mezhegeyugol" is located, the watercourses acquire a character close to the flat one. The rivers feed is mixed, due to snowmelt, precipitation, and groundwater discharge.
The patented mining claim of the Mezhegey deposit is located in the southern part of the Ulug-Khem basin and has an area of 47, 8 $km^2$. The depth of the area from the surface is 700 meters.
Structurally, the deposit is confined to the gently sloping southwestern wing of the Kyzyl-Erbek trough. The geological structure is simple with a monoclinic fall of rocks to the north at angles 4-6 ° with gentle synclinal and anticlinal structures. In tectonic terms, the structure of the deposit is weakly and unevenly broken by natural fractures of separation, detachment and shearing.
The surface of the deposit is a hilly plateau with absolute elevations from 695 meters in valleys to 815 meters at the watersheds. Relative elevations up to 100 meters, steepness of slopes 5-10$^o$, rarely 30-40$^o$ (in the western part). Among the hilly surface there are ridged low ridges and small hills. In the south,

the plateau gradually turns into the floodplain valley of the Mezhegey River, sometimes significantly swamped. In this part of the field, relief forms are common, caused by the activity of temporary flows. These include various forms of ravine-gully relief.

On the area the site occupies the territory of the watershed, the right slopes of the valleys and floodplain parts of the Elegest River and its right confluent of the Mezhegey River.

The main waterway of the region is the Elegest River flowing in the north and northeast direction with a rapid current (up to 1.7 meters/sec.), flowing into the Yenisei river (Ulug-Khem). It takes from the starboard side of the Mezhegey river (begins with the Durgen river, originating from Tannu-Ola, which, after the confluence of the left confluent of the Shangan River, already becomes the Mezhegey River, into which the Mogai river also falls below the technological platform; see Fig. 1).

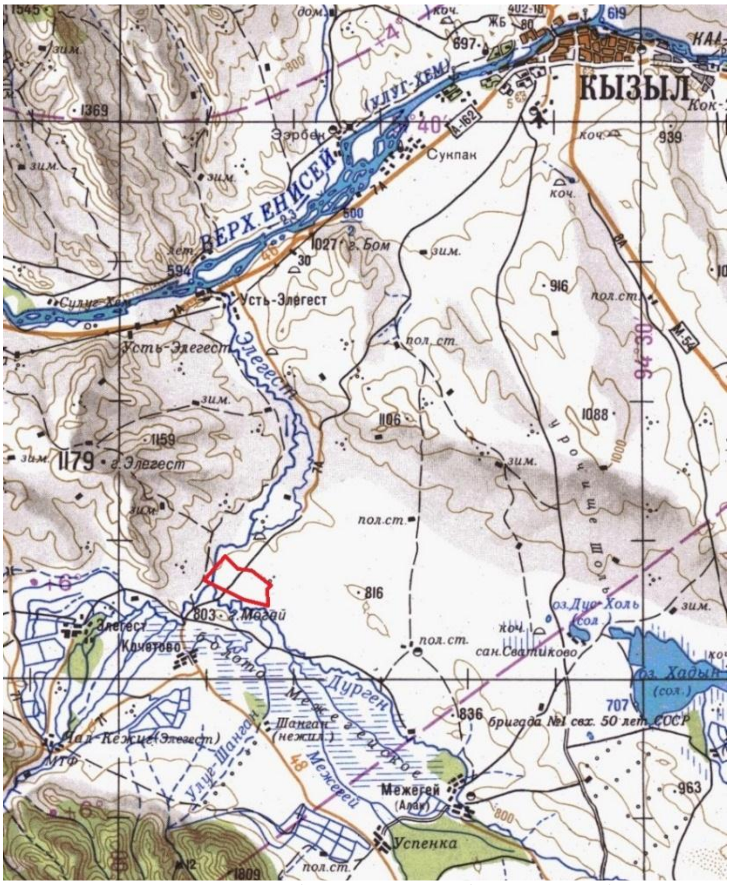


**Fig. 1**. Schematic map of the location area of the Mezhegey field
(the licensed area of the mining enterprise is marked in red)

The Mezhegey river is characterized by smaller dimensions, a more calm current. The depth reaches 2.5 meters, the channel width is 8-10 meters, the water discharge in the low-water period in the mouth area is 11.6 $m^3$ / sec. Absolute marks of the water edge in the river within the plot vary from 700 to 680 meters. The valley of the Mezhegey river is quite wide (up to 5 km); upstream of its confluence in the Elegest river only floodplain terrace is observed which is completely flooded with water in the flood period, at other times it is a marshy area with oppressed woody vegetation. The terrace is composed of alluvial sand and pebble deposits and reaches a height of 1.2-1.6 meters and it flows into the Elegest river.

The water flow in the Mezhegey field varies from 60 $m^3$/sec. in summer to 15.8 $m^3$/sec. in autumn; The average annual flow is 18 $m^3$/sec. The bed of the Elegest river has a width of 25 to 35 meters, the depth of the river reaches 2.0 meters, the valley has steep slopes and a wide bottom. Within the valley, the riverbed strongly meanders, forming numerous channels, streams and creeks which are the cause of the large swampiness of the valley. The absolute mark of the water edge in the river varies from 680 to 660 m within the site. In the valley of the Elegest River, within the Mezhegey deposit, two terraces are clearly distinguished: the floodplain and the first supra-floodplain. Floodplain terrace is developed along both banks of the Elegest river, it has a height of about 2.0 meters and is represented by alluvial deposits. The first supra-floodplain terrace which is above the floodplain, composed of alluvial, sand and pebble sediments, is developed only along the left bank of the Elegest river.

The bogging process manifested in the floodplain of the Mezhegey river has a local activity. The coal mining enterprise discharged industrial and sewage disposal into the Mezhegey river as well as retaining groundwater, accumulating in mine workings (the eastern dewatering discharge). At the point of spillways of mine water (southern and western sections) there is accumulation of coal dust, its subsidence to the bottom, accompanied by the formation of an oily water film. The zone of accumulation of coal dust on the marshy coast rises from the point of discharge upwards along the river by ~ 100 meters and extends downstream the Mezhegey river up to the confluence of the Elegest river.

Below in Table 1 a brief description of reference points is given.

**Table 1.** Brief characteristic of reference points

| № of points | Conventional names of control points and their brief characteristics | Coordinations |
|---|---|---|
| 1 | The Durgen river – a near-valley section of the river Durgen (background), the first terrace of which is characterized by a typical meadow, wetland and meadow-marsh vegetation with temporary (spring) and constant | N 51º20´174˝<br>E094º13´981˝ |

| | | |
|---|---|---|
| | small relatively isolated reservoirs, gradually turning into a grassy-fescue-chile solonized steppe. The second terrace is represented by a typical steppe with the predominance of xerophilic communities and is described as a low-bunchgrass-stemless-cinquefoil-cold-wormwood steppe with the presence of a pigmy pea tree. | Total hight – 694 meters |
| **2** | The Shangan river – on the site and just below the point where the left lateral confluent of the Mezhegey river (The Shangang River), it is a near-valley area with typical meadow vegetation, gradually turning to a grassy-chile solonized steppe, continuing on a typical xerophytic low-bunchgrass-stemless-cinquefoil-cold-wormwood steppe (background). | N 51º20´485″ E094º11´171″ Total hight – 684 meters |
| **3** | Kurgan - a section of a typical xerophytic steppe on the second terrace located near the mound of the Turkic time (background). | N51°23'42,2" E094°07'55,9" Total hight – 735 meters |
| **4** | Eastern dewatering well –the monitoring covers water discharged from mine cavities, adjacent terrain (soil, vegetation, areas of earth embankment enclosing the boundaries of the licensed area, snow cover, i.e. all parameters of the natural environment of the reference point.) A separate monitoring is organized on a temporary streamline , formed by natural depressions of the landscape and flowing into the Mezhegey river above the reference point No. 5 (southern discharge of industrial and domestic sewage) | N 51º23´497″ E094º07´260″ Total hight – 739 meters |
| **5** | The southern spillway is a place of discharge of domestic and industrial waters on the southern part of the technological platform. The project provides for discharge through special pipes - industrial runoff and runoff of domestic waters. During the year 2016, the system for discharging industrial and domestic sewage through the pipes did not work, and discharge into the Mezhegey river was carried out on an artificially created channel. | N 51º23´042″ E094º06´735″ Total hight – 678 meters |
| **6** | The Mogoy river (bridge) –the reference point is located near the bridge below the point of discharge (reference point No. 5) and the confluence of the river Mogoy, it is a marshy lowland with aquatic vegetation, sharply passing the typical stony and xerophytic structure vegetation of the steppe. | N 51º22´960″ E094º05´664″ Total hight – 677 meters |
| **7** | The mouth of the Mezhegey river. The confluence of the Mezhegey river in the Elegest river. Monitoring of the aquatic environment with bio indicator groups of aquatic biota dominated. | N 51º23´617″ E094º05´353″ Total hight – 677 meters |
| **8** | Heap - is storage of empty rocks and a fertile layer removed from the main technological platform. In 2016 the upper leveled storage site was also used as a coal storage site. | N 51º23´396″ E094º05´431″ Total hight – 707 meters |
| **9** | The western flank trunk is located at a distance of 500 meters from the main technological site, from where, in 2015 and early 2016, the mine waters were discharged into the old riverbed of Elegest. | N 51º24´514″ E094º06´076″ Total hight – 668 meters |
| **10** | Ust-Elegest village - water quality monitoring was carried out below the bridge of the Kyzyl-Ak-Dovurak motorway within the village of Ust-Elegest at a distance of 60 km from the main monitoring site. | N 51º23´813″ E094º07´443″ Total hight – 599 meters |

As of 2017 the monitoring system consists of 10 main reference points.

## 2. Material and Methods

**Analyzed indicators of surface water quality**. Water samples were analyzed in the physico-chemical laboratory of the Scientific and Educational Center for Collective Use of Tuvan State University. The following hydro-chemical indices were determined in the samples: organoleptic properties, macro component composition (cations and anions), total iron, nitrogen-containing components (nitrate ion, nitrite ion), general stiffness, pH, orthophosphates, fluorides, heavy metals (Zn , Cu, Pb, Ni, As, Hg), dry residue, mineralization in accordance with the "General requirements for the composition and properties of water bodies used for fishery purposes" as well as "Generalized list of maximum permissible concentrations (MPC) and tentatively safe levels of exposure (TSLE) of harmful substances for the water of fishery water bodies "(Minrybkhoz USSR, 1990).

**Objects of research and composition of hydrological works**. According to the Monitoring Program, the rivers Elegest and Mezhegey were the objects of the study.

1. The Elegest River was investigated from the place of confluence with the Mezhegey River for 4 km downstream. Observation points were recorded after 2 km with a description of the terrain, the nature of the watercourse, its shores, the measurement of the hydrological parameters of the river (the width and depth of the stream, the speed of the current, the flow of the river, the water temperature). On separated arms, the hydrological parameters were measured for each stream.

2. The Mezhegey River was studied upstream from the mouth along the southern boundary of the site at a distance of 8 km, also after 2 km with the measurement of the same hydrological parameters.

**Methods and timing of the collection of hydrological data**. The collection of hydrological data was carried out during field trips in the floodplains of the Elegest and Mezhegey rivers. To obtain reliable information on the nature of the watercourses and their hydrological regime, the observation points were fixed after 2 km along the route and supplemented with observation points at the spillway point and 500 meters from the spillway outlet point to the channel of the Mezhegey river in the south-western extremity of the enterprise.

Water samples were taken from the Elegest and Mezhegey rivers three times while the field season during water flow inspection periods in accordance with the requirements of the state standard GOST R 51592-2000.

A total number of water samples which were taken from surface watercourses was 42. The samples were analyzed using titrimetric, photometric, potentiometric, and atomic absorption methods [22].

To assess the existing state of the environment, the geochemical criteria proposed by Buks I.I. and Fomin S.A. were used. [15]. Their use is based on comparison of the existing pollution of the lithosphere and its components (together with groundwater) with MPC or background, taking into account the toxicity of pollutant. In general, such an assessment with ranking by classes is presented in Table 2. The proposed table allows to assess the state of the lithosphere and its components for any polluting substance or their sum.

**Table 2.** Geochemical criteria for assessing the state of the lithosphere

| Estimates | Classes of state of surface waters | | | |
|---|---|---|---|---|
| | I - normal (N) | II – risk (R) | III - crisis (C) | IV - disaster (D) |
| Concentrations of all identified elements and compounds | Background or lower than MPC | 1--5 MPC (2nd and 3rd danger class); 1 MPC (1st danger class) | 5--10 MPC (2nd and 3rd danger class); 1-5 MPC (1st danger class) | ≥ 10 MPC (2nd and 3rd danger class); More than 5 MPC (1st danger class) |

The classes of state of the lithosphere in the table correspond to:
N - normal pollution degree;
R - a small degree of excess of the pollution rate;
C - average degree of excess of the pollution rate;
D - catastrophically high degree of pollution.

**Hydro-chemical estimation of bottom sediments**. Samples of bottom sediments with a volume of 100 ml were taken at the same points where hydro-chemical samples were taken. The finest fractions of the bottom sediment were used as the analyzed material: silt, fine-grained sand or sludge. The samples were then dried at 450 ℃, triturated and analyzed on the S2 RANGER energy dispersive spectrometer for heavy metals (Cu, Pb, Zn) and toxic elements (As and Hg).

## 3. Results

Water samples in 2015-2017 were duplicated at different times of the year to reveal the influence of seasonal variations on the quality and chemical composition of natural waters in the Mezhegey coal field.

The chemical analysis of surface and mine waters in the area of the Mezhegey coal field began with the establishment of their quality as the water quality indicators strongly influence the organoleptic properties of water.

Below there are the characteristics of water samples taken in spring 2015.

**The Durgen River.** By the hydrological parameters the Durgen River is a weakly winding watercourse with an average width of 2.5 m, a depth of 1.25 m and an average flow velocity of 0.15 m/s, having a flat nature. The flow rate of the river Q is 0.421 $m^3$/s.

The water is clear, colorless, without taste, odorless, without sediment. By chemical composition – it is bicarbonate magnesium-calcium, fresh with a salinity of 0.3 g/l. The structure is neutral, pH = 7.3. The water is moderately hard; the total hardness is 3.54 mg-eq/liter. The presence of dissolved biogenic elements except nitrogen is not fixed. When assessing the background state of the Durgen river at the point there was marked a high enough content of nitrates - 6.4 mg/l.

The formula for the salt composition of water:

$$M0{,}3\frac{HCO_3^{-}82\cdot\left[SO_4^{2-}10\cdot Cl^{-}5\cdot NO_3^{-}3\right]}{Mg^{2+}51\cdot Ca^{2+}36\cdot\left[(Na^{+}+K^{+})13\right]}pH7{,}3$$

During the season no significant changes were observed in the hydrological and hydro-chemical parameters, except for the early spring of 2017. Closer to autumn, there is a slight increase in nitrates (up to 3.2 mg/l), sulfates (up to 11 mg/l), and pH - up to 8,7. In the samples selected on April 14, 2017 a decrease in pH was observed throughout the entire observation points along the Durgen, Mezhegey and Elegest rivers: 4.03 (No. 1) - 4.1 (No. 2) - 4.03 (No. 5a) - 4.99 (№5) - 4,03 (№6a) - 4,1 (№6) - 4,84 (№7) - 4,71 (№9).

The reason for the spring sharp decrease in the pH level of water bodies can be weather conditions. In the spring of 2017 (late March, April), early thaws caused a sharp melting of snow and ice which contributed to the intensification of biological and biochemical processes in water bodies. Further in the second half of April and in May, a sharp drop in temperature to stable 24-hour minus values led to a repeated shackling of the reservoirs by the ice cover and affected the pH of the water. Low temperatures led to the predominance of decomposition of organic matter with the formation of carbon dioxide and organic acids which led to a decrease in the pH of the water. In the samples taken on 5, May there were noted the establishment of water pH levels typical for the water in the region - weakly alkaline and close to neutral.

The content of heavy metals and iron does not exceed the norms for waters of fishery water bodies.

**The Mezhegei River.** The water of the Mezhegey river in the zone of discharge of industrial waters becomes turbid, oily-black in color, with the smell of hydrogen sulfide (Figure 2).


**Fig. 2.** The place of confluence of the right inflow of the Mezhegey river in its mainstream (the presence of contamination is noticeable)

According to the results of the chemical analysis the water is bicarbonate calcium-magnesium, fresh with a salinity of 0.354 g/l, an aqueous medium of neutral pH = 8.72. The water is moderately stiff, with a total hardness of 3.02 mg-eq/liter. The formula of salt composition is:

$$M0{,}35\frac{HCO_3^{-}88\cdot\left[SO_4^{2-}6\cdot Cl^{-}4\cdot NO_3^{-}2\right]}{Ca^{2+}64\cdot Mg^{2+}21\cdot\left[(Na^{+}+K^{+})15\right]}pH8{,}72$$

The content of anions and cations does not exceed the MPC for waters of fishery water bodies. The content of nitrates and nitrites is within the normal range. The content of heavy metals does not exceed the MPC.

At the beginning of winter, the color of the water becomes brownish-grayish, a specific smell of hydrogen sulfide is characteristic, a dark precipitate appears in the vessel. PH = 7.8 (slightly alkaline). Iron is common, nitrite in water is not found. The content of nitrates is 6.2 mg/l, ammonium ions - 6.60 mg/l, sulfates - 11 mg/l. Heavy metals are contained in water in minimum quantities.

**The Elegest River**. The Elegest River has an average width of 15 m, a depth of 1.5 m, a current velocity of 0.5 m/s and has the character of a typical mountain river. The flow rate of the river is (Q) 10,125 $m^3$ / s.

The water in September is unclear, a darkish precipitate is noticeable, the temperature is +7.2 ° C. According to the results of the chemical analysis, the water is bicarbonate calcium-magnesium, fresh with a mineralization of 0.263 g/l, an aqueous medium of neutral pH = 7.1. The water is soft, the total hardness is 2.9 mg-eq/liter.

The salt composition formula has the following form:

$$M0{,}26\frac{HCO_3^{-}87\cdot\left[SO_4^{2-}9\cdot Cl^{-}\right]}{Ca^{2+}67\cdot Mg^{2+}20\cdot\left[(Na^{+}+K^{+})13\right]}pH7{,}1;$$

The total iron content, ammonium ions in water is within the normal range. The content of anions and cations does not exceed the MPC for waters of fishery water bodies. The content of nitrates, nitrites and heavy metals is within normal limits.

According to the results of chemical analysis at the end of winter, the mineralization appreciably increases (0.337 g / l), the formula of salt composition

$$M0{,}34\frac{HCO_3^{-}79\cdot\left[Cl^{-}12\cdot SO_4^{2-}7\cdot NO_3^{-}2\right]}{Ca^{2+}55\cdot(Na^{+}+K^{+})28\cdot Mg^{2+}17}pH8{,}3$$

– becomes bicarbonate sodium-calcium, and pH = 8.3 - slightly alkaline. The total water hardness became 3.17 mg-eq/liter.

The content of cations and anions is within the limits of MPC. The content of ammonium ions in water is 3.6 mg/kg, sulfate 57 mg/kg, chloride - 50.7 mg/kg. The nitrate content is 4.7 mg/l.

In general, the surface waters in the study area are fresh with a salinity of 0.263 g/l to 0.360 g/l, moderately hard (stiffness in the range 3.30-3.58 mg-eq/l), the chemical composition is predominantly bicarbonate magnesium-calcium. The aqueous medium is from neutral to slightly alkaline. In some samples, a slightly increased content of nitrate ion is noted which is reflected in the formula of salt composition. But, in general, the content of nitrate ion does not exceed the requirements for waters of fishery water bodies. Orthophosphates in water are not found.

The samples from the reference points, starting from the reference point No. 5 (southern industrial spillway) and downstream (reference points No. 6, 7, 9, 10) have a yellowish tinge and chromaticity in the range from 25 to 49º which indicates a significant role discharges of industrial waters into physical indicators of surface waters of the monitoring area. The same pattern is also characteristic of the next indicator of water - turbidity in the spring period. Unlike chromaticity, high turbidity indicators were detected at the points of discharge of industrial waters in the early spring, when the water level is high due to melted waters and characterized by a relatively high flow rate of watercourses. In summer, autumn and winter, this indicator is not high. The water hardness index is more stable and the surface waters are characterized as soft. A slight increase and relatively noticeable seasonal amplitudes of stiffness are characteristic in the immediate vicinity of spillways of industrial waters (reference points No. 5 and 9) where the stiffness indicators can range from 1, 19 to 3.42, rarely reaching 4.0.

The indicators of water coloring everywhere at all observation points have higher values in spring than in winter samples. This is due to the ingress of natural impurities from the humus of the soil during the flood, as a result of the melting of the snow cover. It is also important that the water basin of the Mezhegey field is located in a zone where peat bogs and wetlands are observed.

The investigated samples differ significantly in cation composition. In the samples of waters taken from the river Elegest, characterized by a relatively high content of calcium ions - from 31.20 to 53.20 mg/l. More dynamic indicators of cations are characterized by the Mezhegey river. In this case, the maximum amplitudes of the cation oscillations are confined to the points of discharge of industrial waters (reference points No. 5 and 9). The maximum values of some cations are noted at the same points: chlorides - 13.83 to 54.95 mg/l; Hydrogen carbonates - from 158 to 259 mg/l; sulfates - 11,00-65,00 mg/l; magnesium - 25,4-30,02 mg/l; the sum of cations of sodium and potassium - from 25,4 to 30,02 mg/l.

The high content of ammonium and nitrate ions is characteristic of the waters of the river Elegest throughout the season, as well as in early spring time on the river. Durgen and Mezhegey, at the outlet points of industrial waters (reference points No. 5 and 9) and make for ammonium from 2.0 to 14.60 mg/l and exceeds the MPC (5 mg/l) at the spill points of industrial waters (reference point № 5) and in the river Elegest (4.40-15.60 mg/l). It should be noted that in the majority of water samples high concentrations of total iron were found, many times exceeding the MPC (0.10 mg/l).

For water samples taken in May 2016, the following formulas for the salt composition according to Kurlov were derived:

Reference point №1 (Durgen): – $M0{,}43\frac{HCO_3^{-}44\cdot Cl^{-}36}{64\cdot Mg^{2+}42Na+36\cdot\left[Ca^{2+}+21\right]}pH7{,}93$ – water is hydro carbonate-chloride magnesium-sodium, fresh;

Reference point №4 (eastern dewatering well): M $0{,}36\frac{HCO_3^{-}42\cdot SO_4^{2-}29\cdot Cl^{-}28}{Na^{+}48\cdot Mg^{2+}40}$pH 7,75 – water is hydro carbonate-sulphate-chloride sodium-magnesium, fresh;

Reference point №5 (southern discharge of industrial waters): M $0{,}22\ \frac{HCO_3^{-}85}{Ca^{2+}53\cdot Mg^{2+}34}$pH 7,95 – water is bicarbonate calcium-magnesium, fresh;

Reference point №7 (the mouth of the Mezhegey river): M $0{,}19\frac{HCO_3^{-}73\cdot[SO_4^{2-}19]}{Mg^{2+}64\cdot Ca^{2+}29}$pH 7,83 – water is bicarbonate magnesium-calcium, fresh;

Reference point №10 (Elegest): M $0{,}21\frac{HCO_3^{-}71\cdot[SO_4^{2-}18\cdot Cl^{-}10]}{Na^{+}35\cdot Ca^{2+}32[Mg^{2+}23]}$pH 7,70 – water is bicarbonate sodium-calcium, fresh.

Formulas of salt composition in comparison with 2015 have insignificant changes: the content of hydro carbonate ions, magnesium and calcium ions decreases, the concentration of chlorides and alkaline ions increases.

For the coal mining company at the Mezhegey deposit, the main polluting component of the lithosphere and the biosphere is coal slurry discharged from the mine waters into the river structure of the Mezhegey and Elegest rivers, as well as coal dust carried by air flows.

The amount of suspended material in water (including coal sludge) should not exceed in the fisheries waters, such as all the confluents and the river bed of the Elegest River, in addition to the background of + 0.25 mg/l. The background concentration of suspended solids in the Mezhegey and Elegest rivers during the year, except for the periods of snow melt and rainy days, is 50 mg/l, therefore, the maximum allowable concentration of coal slurry in water is 50 + 0.25 = 50.25 mg/l.

A serious problem in the area of research is the increase in the content of suspended solids in the surface waters of the Mezhegey and Elegest rivers below the outlet points of mine waters (Figure 3).

**Fig. 3.** Surface of water contaminated with suspended material.
Oily spots are noticeable (The Mezhegey River, below the spillway point of mine waters, September 2015)

Below there are the parameters of suspended particles in water samples from two points of spillways of mine waters (the southern spillway into the channel of the Mezhegey River and the western spillway to the old channel of the Elegest River - see Fig. 4, 5):

469 -8,62 g/l (particle size from 220 μm or less) point 7 (western flank trunk);
470 – 0,28 g/l (particle size from 26 μm or less) point 4 (southern spillway of mine waters).

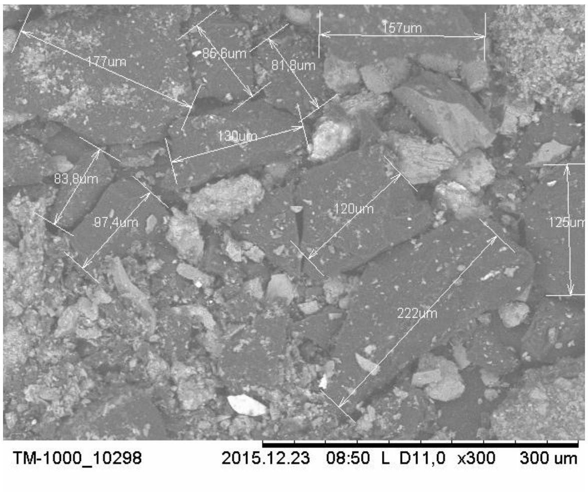


**Fig. 4**. Photographs of suspended particles (shape and size parameters) (southern spillway)

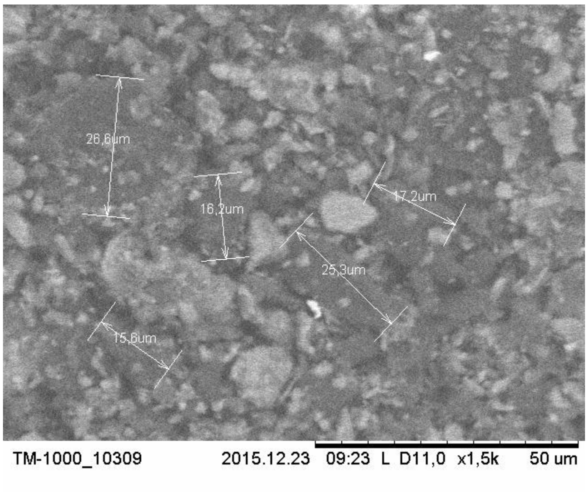


**Fig. 5**. Photographs of suspended particles (shape and size parameters) (western spillway)

Concentration of fine coal demolished by spillway of industrial waters as well as by air flows into the riverbed of the Mezhegey river according to calculations made in October 2015 was 880 and 1000 mg/l which corresponds to 17.5 and 19.9 MPCs.

According to the geochemical criteria of assessment, the state of the lithosphere in the area of the Mezhegey coal deposit, according to the content of coal dust in surface water samples, corresponds to class D (disaster) - a catastrophically high degree of contamination.

Concentration of coal dust on the discharge of industrial waters in the Mezhegey River (reference point No. 5) in May-March of 2016 decreased for several times compared to 2015 and amounted to 2.8 MPCs. At the reference point No. 9 (western spillway) in October 2015, the concentration of coal dust from 1000 mg/kg (19.9 MPCs) decreased to 52 mg/kg and hardly exceeded 1 MPC (1.04). By autumn of 2016, the discharge of water from the western flank trunk ceased. In 2017, in spring (February, April-May) at point No. 5, an increase in the concentration of coal suspended material which amounted to 5.6 MPC, was recorded, and in late autumn decreased significantly to 1.96 MPC.

To assess the behavior of heavy metals in the accumulating part of surface waters, hydro chemical studies of bottom sediments at reference points were carried out. The results of the analyses are shown in Table 3.

**Table 3.** Results of mean values of bottom sediments of the Durgen, Mezhegey, Elegest rivers (by reference points)

| № of the point | Defined indicator | The established quality standard of the OS in mg/kg of MPC | The obtained value in mg / kg | | | Background value in mg/kg |
|---|---|---|---|---|---|---|
| | | | Years and dates of sampling | | | |
| | | | 2015 23.10.15 | 2016 16.09.16 | 2017 14.04.17 | |
| Durgen (reference point №1) | Cu | 60 | 58 | 59 | 40 | 27 |
| | Pb | 110 | 18 | 15 | - | 18 |
| | Zn | 365 | 96 | 88 | 83 | 96 |
| | Hg | 1,2 | 0,004 | 0,013 | - | 0,004 |
| | As | 29 | 3 | 3 | 9 | 1 |
| Durgen (reference point №1); Enclosed pond | Cu | 60 | **80** | **70** | 37 | 27 |
| | Pb | 110 | 36 | 28 | - | 18 |
| | Zn | 365 | 129 | 89 | 68 | 96 |
| | Hg | 1,2 | 0,007 | 0,008 | - | 0,004 |
| | As | 29 | 2 | 3 | 7 | 1 |
| Mogai (reference point №2) | Cu | 60 | **82** | **80** | - | 27 |
| | Pb | 110 | 36 | 20 | - | 18 |
| | Zn | 365 | 125 | 88 | - | 96 |
| | Hg | 1,2 | 0,006 | 0,006 | - | 0,004 |
| | As | 29 | 10 | 14 | - | 1 |
| Elegest (№7) | Cu | 60 | **74** | **65** | 31 | 27 |
| | Pb | 110 | 21 | 20 | - | 18 |
| | Zn | 365 | 140 | 135 | 85 | 96 |
| | Hg | 1,2 | 0,016 | 0,012 | - | 0,004 |
| | As | 29 | - | - | 9 | 1 |
| Mezhegey Discharge of mine waters (reference point №5) | Cu | 60 | 27 | 30 | 36 | 27 |
| | Pb | 110 | 6 | 46 | - | 18 |
| | Zn | 365 | 105 | 115 | 50 | 96 |
| | Hg | 1,2 | 0,004 | 0,012 | - | 0,004 |
| | As | 29 | 15 | 18 | 4 | 1 |
| Sediment (reference point №5) | Coal slurry 2.10.15; 27.05.16 | 0,25+background | **880**<br>**17,5 MPC** | **147**<br>**2,8 MPC** | **280**$^{*}$<br>**5,6 MPC**<br>$^{*}$(05.06.17)<br>**98**$^{**}$<br>**1,96 MPC**<br>$^{**}$(10.11.17) | 50 |
| Sediment (reference point №9) | Coal slurry 23.10.15; 27.05.16 | 0,25+ background | **1000**<br>**19,9 MPC** | **52**<br>**1,04 MPC** | - | 50 |

The results of the bottom sampling assays indicate that the concentrations of arsenic, lead and zinc mercury do not exceed in accordance with the standards and criteria for the evaluation of the Committee on Environmental Protection and SPB of 22.07.1996, the established standards in bottom sediments, although in some cases exceed the background values. The concentration of copper in bottom sediments is slightly higher than the standards, due to the increased geochemical background of this element in the natural environment associated with the metallogenic specialization of the Paleozoic formations widely developed in Tuva.

## 4. Discussion

It is known that the chemical composition of both mine waters and waters within the coal-mining section is hydrodynamic; the content of sulfur, carbonates and dispersed elements is in coal-bearing rocks. At values of sulfur content greater than 4%, their oxidation leads to an acidic reaction of water (pH = 2-3) [6; 13]. According to our data, it is revealed that the surface waters in the study area have a neutral reaction, only once (April 2017) there was a spring decrease in pH throughout the entire observation points along the Durgen, Mezhegey and Elegest rivers. The reason for the sharp spring decrease in the pH level of water bodies can be weather conditions: early thaws caused a sharp melting of the snow and ice cover which contributed to the strengthening of biological and biochemical processes in them. The subsequent sharp drop in temperature to minus values led to a repeated shackling of reservoirs by ice, leading to the predominance of processes of decomposition of organic matter with the formation of carbon dioxide and organic acids which affected the lowering of the pH of the water. Further tests showed the establishment of routine for water reservoirs of the study of pH levels of water.

The indicators of chromaticity and turbidity of water showed widespread increases in their values in the spring period compared to samples at other seasons. The difference between these indicators is revealed by their location: high chromaticity values are confined to the southern industrial spillway and downstream, and increased turbidity was characteristic only of industrial water discharge points. An analysis of the hydro geochemistry of river waters has shown a significant difference in cation composition, and for mineralization and general rigidity the investigated waters are quite similar. For coal-producing enterprises, the main polluting component of the lithosphere and the biosphere is coal sludge [5; 24]. According to the geochemical criteria of assessment, the state of the lithosphere in the area of the Mezhegey coal deposit, according to the content of coal dust in surface water samples, corresponds to class D (disaster) - a catastrophically high degree of contamination.

An assessment of the behavior of heavy metals in bottom sediments showed that the As, Hg, Pb and Zn concentrations do not exceed the maximum permissible concentrations, only in some cases the excess of the background was recorded. For Cu, some exceedances of the standards are due to the natural elevated geochemical background of this element.

Comparison of the results we obtained with similar studies within the Fuel and Energy Complex as a whole showed that the

geochemical transformation of surface waters in the area of research is still subject to direct influence of the climatic parameters of the year and the lithological basis of the territory. An irreversible fact was the deterioration of water quality indicators characterized by an increased content of suspended solids in the waters represented by coal dust particles. Compared with our data, the results of similar studies of coal mines of adjacent regions showed a colossal ecological press from their impact confirmed by increased concentrations of chemical elements exceeding their normative or clarke indexes [1; 7; 16; 17]. Perhaps this fact is explained by the fact that the Mezhegey field was put into operation just a few years ago and the influence of the coal mining enterprise has not yet reached its peak.
The results of this research in the future will allow to determine the trend of changes in hydro ecosystems, to create a predictive model of the dynamics of river ecosystems as a result of coal mining, and as a consequence, to select and adapt optimal technologies for reclamation of disturbed ecosystems.

## 5. Conclusion

In the course of the studies, for the first time there was obtained data on the ecological and hydro chemical state of the watercourses of the left-bank inflows of the Upper Yenisei basin in the zone of impact of the coal-mining enterprise. The monitoring data is reduced to the following items:

1. There is deterioration in the quality of river water in the area of the Mezhegey Coal Deposit (chromaticity, turbidity) in the spring, which is due to the ingress of humic substances from the soil during floods and melting snow, as well as pollution by coal dust from spills of industrial and domestic waters, especially from the southern spillway.
2. The ion composition of the water samples studied, as well as the pH values of the water, are subject to seasonal variations, especially for river waters. Concentrations of cations and anions tend to decrease from February to May. In the river waters, magnesium and calcium ions predominate, and in the mine waters - sodium and potassium ions. All water samples studied have a hydro carbonate composition and are characterized by low mineralization which was noted for other surface waters of the region.
3. The excess of the maximum permissible concentrations of ammonium and total iron ions in the water samples studied was detected. High concentrations of Fe (II) and Fe (III) ions in water are due to oxidation processes in the mine workings. Also the increased content of ammonium ions is observed in sewage industrial waters.
4. The analysis of bottom sediments which have been carried out indicates that the concentrations of arsenic, mercury, lead and zinc do not exceed the MPC in accordance with the standards and criteria for assessment in bottom sediments, although in some cases they exceed the background values. The concentration of copper in bottom sediments is slightly higher than the standards due to the increased geochemical background of this element in the natural environment associated with the metallogenic specialization of the Paleozoic formations widely developed in Tuva. In the bottom sediments there is still a significant excess of the MPC of coal dust, but in comparison with the indicators of 2015 there was an almost 10-fold decrease in this indicator.

In general it can be concluded that numerous physico-chemical parameters of surface waters are directly dependent on the climatic parameters of the year and the lithological basis of the territory.

## Acknowledgement

The study was carried out with the financial support of the grant from the Russian Foundation for Basic Research (project No. 17-44-170696)

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