Pollution and biodiversity: a case study of the Argun River Basin

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Abstract. We analyzed the studies on the hydrochemical composition in the Argun basin and evaluated the level of pollution. We found that the water of the Argun River was contaminated by organic substances and toxic elements. We distinguished 9 major types of the ecosystems based on the prior findings. The prevalent species of Cladophora fracta was chosen as an indicator for the monitoring of the Argun drainage basin pollution by toxic elements. The concentrations of toxic elements in algae remained unchanged for a long term and they appeared to be more informative for the assessment of pollution than the rapidly changing water quality. It is necessary to determine indicator hydrobionts for each type of the ecosystems within such a vast territory as the Argun basin. Our findings showed that current mining production produces a negative ecological impact on the quality of the water ecosystems which should be considered during further developments. It is necessary to conduct a research on the regional background concentrations for toxic elements in water and hydrobionts, and to enlarge the list of indicator hydrobionts for water quality assessment.

1. Introduction
The annexation left bank part of the Argun River basin marked the transition from artisanal mining to industrial production with ash wastes being discharged and stored within floodplains of rivers (Kutomara River) and increasing use of timber as a fuel. The sites of metal extraction and processing of metals ensured the population influx. The above factors altered the natural complexes including water ecosystems. Currently, the Argun drainage basin lies in a significant agricultural zone and belongs to the territory of the development of new ore deposits (Bystrinsky project). However, ecological problems that occurred throughout the history of the area are still relevant. Numerous tributaries of the Argun River were destroyed by placer gold mining operations extensively interfering with the river ecosystem and affecting such river channels as the Gazimur, the Urov, the Urymkan, and the Middle Borzya. The total length of disturbed areas is 3–5 % of the total length of the river system. The percentage of ecological consequences in river networks of the Russian Federation is 3–6 times higher than those in the People’s Republic of China [1] and Russia’s mining sites are hardly recultivated after their development [2]. Today, there is a pressing need for reclaiming, conservation and sustainable management of the water ecosystems of the Argun basin.

Although the territory has a long history of development, the prior studies on the Argun ecosystems are rather inadequate. The findings of the Amur ichthyological expedition of 1945–1949 are still used for reference [3]. A series of recent papers have focused on particular hydrobiont communities [4]. The
importance of hydrobiological survey in addition to hydrological and hydrochemical monitoring techniques in transboundary waters have been mentioned in [5].

The purpose of this study is to analyze the data on hydrochemical composition, biological diversity and spatial distribution of the hydrobiont communities in the Argun basin’s ecosystems.

2. Materials and Methods
We used the results of field studies of water bodies and water currents of the Argun basin in July 2006, 2014, and 2016, conducted by the Laboratory of Water Ecosystems at the Institute of Natural Resources, Ecology and Cryology, Siberian Branch of the Russian Academy of Sciences (INREC SB RAS). Additionally, the recent findings on hydrochemistry [6–10] and hydrobiology [9, 11–16].

In the field, at sampling sites, the physical and chemical properties of water such as pH, total dissolved solids, temperature, and dissolved oxygen content were measured using the Portable AQUA Meter (Germany), and the contents of nitrogen and phosphorus were determined using the DR 2800 Spectrophotometer (Germany). The measurement of toxic elements (TE) in the water and macroalgae was performed using the hydride generation – atomic absorption spectrometry (HG–AAS) technique (PerkinElmer) at the Kosygin Institute of Tectonics and Geophysics of the Far East Branch of the Russian Academy of Sciences (ITiG FEB RAS).

3. Results and Discussion
3.1. Hydrochemical composition
River water constantly responds to the processes in atmosphere, lithospheric substratum, terrestrial and aquatic organisms affecting water quality and contents of chemicals. We found that the Argun water is calcium- and bicarbonate-bearing. Our findings from July 2014 showed that TDS contents in the water bodies of the Argun basin ranged from 57 mg/L in the Argun, downstream the mouth of the Genhe, to 555 mg/L in the Urulyunguy 0.2 km downstream the village of Dosatuy. The Zabaikalsky Department for Hydrometeorology & Environmental Monitoring observed that the average annual TDS (total dissolved solids) concentrations in the Argun from 2000 to 2010 varied from 165 to 424 mg/L with minimal values of 111–283 mg/L throughout the high-water seasons from April to June and from August to September. During the ice-cover periods, the TDS concentration reached 950 mg/L as detected in the Prorva Creek in February 2003 [2]. The data of 1966 [7] indicated that the TDS concentration increased from 87.9 to 181.1 mg/L when river discharge rates increased from 546 to 1200 m³/s; the values reached 173.6 mg/L in November 2014 with decline to 162.5 mg/L in January 2014.

Hydrochemical studies of different years have revealed the deterioration of the water quality in the Argun [6, 8, 10]. The middle reaches contained high concentrations of Fe, Zn, Mn and Cu in 2013 [17]. In 2016, high contents of Cr, Pb, Ni and Al were determined in particular cross sections, while Mn, Cu, Fe, and Mo were detected in all cross-sections of the Argun [9].

In July 2014, the river water in the Argun was slightly alkaline with regard to the pH level. The oxygen concentration ranged from 4.4 mg/L in the Argun upstream the village of Starotsurukhaituy to 13.5 mg/L in the Urulyunguy 0.2 km downstream the village of Dosatuy. A wide range of the TDS and oxygen variations was due to different levels of anthropogenic load in the objects under study. The oxygen deficit in the Argun was caused by contaminants from China’s sources [6]. In July 2014, the chemical oxygen demand (COD) test in the Mutnaya Creek yielded high values of 17 mg/L. The high COD levels in the Argun in summer 2016 were observed within 250 km from the border [8].

Phosphate levels (mg/L) indicated the additional input of organic matter into the water ecosystem with the values of 0.37 in the Prorva Creek, 0.13 in the village of Olochi, 0.40 in the Urulyunguy, and 0.12 in the Srednyaya Borzya. The average ratio of $P_{\text{min}}/P_{\text{total}}$ in the Argun water was 0.31±0.02, which showed that organic phosphorus was dominant in the river. The low contents of mineral phosphorus were measured in the Urov and the Gazimur (0.06–0.07) and were presumably due to Fe that caused the precipitation of mineral phosphorus in insoluble compounds [18]. According to our observations, the content of total Fe in the Urov and the Gazimur equaled 0.3 mg/L, whereas the maximum permissible
limits (MPL) of total Fe in fishery water bodies attain 0.1 mg/L [19]. The ratio of \( \text{Fe}_{\text{total}}/\text{P}_{\text{total}} \) in the water is < 2 due to high levels of organic phosphorus compounds exceeding 50 percent of \( \text{P}_{\text{total}} \).

We have revealed that chemically the Argun water is calcium- and bicarbonate-bearing and slightly alkaline with high TDS levels, organic contaminants and toxic elements. Abiotic factors determine biological diversity of the river ecosystem.

3.2. Characteristics of ecosystems of water streams within the Argun basin
Biodiversity contributes to the resilience of ecosystems to environmental changes and anthropogenic pressure. It is essential to conduct zoning for the assessment of water ecosystems in the Argun basin, the extent of their transformations under the anthropogenic impact, and further economic use.

Drainage basin topography and climate are the factors that determine the types of water ecosystems, where topographic features regulate the flow rate, which in its turn constitutes the sizes of bottom sediments, while climate, through precipitation and temperature, affects the abiotic parameters of a water body. Species and ground vegetation within the drainage basin are also dependent on climate and terrain. Ground vegetation forms river channels and is a source for allochthonous organic matter in rivers. The underlying terrain along with ground plants within the drainage basin contribute to heterogeneous landscape properties and geochemical qualities of the basin zones. The geochemical qualities in the water bodies are reflected in the variability of biogenic compounds (nitrogen and phosphorus) flow. Bottom sediments also significantly affect water communities: river alluvium and body of river constitute the major substratum for living organisms. The patterns of erosion, transportation and accumulation of sediment loads in rivers depend on the slopes, river discharge rates, floodplain width and forest coverage. The following are the properties of the ecosystem of the Argun and its water streams.

The Argun’s reach between the village of Molokanka and the village of Priargunsk was braided over its course with abundance of creeks, abandoned channels, and oxbow lakes. Such morphology of the watercourse is determined by a wide alluvial plain with complex ecosystem and most diverse aquatic vegetation, benthic organisms and fishes. This ecosystem can be denoted as the large steppe braided river flowing across a flat alluvial plain. During the low-water period, only the main channels functioned. The riverbanks were colonized by reed stands. The qualitative and quantitative diversity of zoobenthos in the channels and creeks was rather low due to the mobile bottom soils mainly represented by sand bed. Higher diversity was observed in the inundated water bodies and where the banks were protected by rock pitching. The wide plain was flooded in high-water periods giving rise to overgrowth of reed stands and diverse alage, and abundant zoobenthic and zooplanktonic organisms. The flooded plain was actively used as a fish spawning and feeding ground. Carassius gibelio (Bloch, 1782), Cyprinus carpio (Linnaeus, 1758), Pseudorasbora parva (Temminck et Schlegel, 1846) dominated the ichthyofauna in the channels of the Argun near the village of Molokanka. Percottus glenii (Dybowski, 1877), Gobio gobio (Linnaeus, 1758), Cobitis taenia (Linnaeus, 1758), Silurus asotus (Linnaeus, 1758) were observed sporadically.

The next reach of the Argun between the villages of Priargunsk and Olochi featured the narrowing of the valley with the lesser role of the flooded plain and significant amount of suspended solids from placer gold mining operations. Aquatic vegetation was unlikely to root and develop in heavily silted substrata. The biomass of zoobenthos was lower. Pseudorasbora parva, Carassius gibelio, Hemiculter (Bleeker, 1860), Percottus glenii were detected in the reach. The ecosystem of this zone can be denoted as a large submontane steppe river with significant pressure of sediment loads and typical inhabitants of the sand-and-shingle bottom being replaced by less productive psammophils.

The reach between the village of Olochi and the Argun and Shilka confluence is located in a V-shaped valley where embryophytes were not observed with rare occurrences of Potamogeton (Linnaeus, 1753) in the river mouths. The vegetation only included benthic microalga. This ecosystem of the Argun lower reach can be denoted as a large submontane taiga river meandering across a narrow valley and composed of boulder-and-pebble bottoms and benthic microalgae in the riparian area. Being the
longest reach with scarce aquatic vegetation, this type of the ecosystem is rather prone to the penetration and transportation of contaminants.

The reach near the village of Priargunsk featured large tributaries flowing to the Argun from the People’s Republic of China and the intermittent Urulyunguy River from the Russian Federation. The water remained in the channels only in the deepest areas during low-water periods with overgrowth of aquatic plants and algae. The vegetation utilized biogenic elements from the livestock that actively used the rivers as a watering point. The zoobenthos was mainly represented by gastropods; fish were not observed. The Urulyunguy was connected to the Argun during high-water periods receiving the Argun’s juvenile *Pseudaspis leptoccephalus* (Pallas, 1776), and small species of *Rhodeus sericeus* (Pallas, 1776), *Percottus glenii*, *Rynchocypris lagowskii* (Dybowski, 1869). The ecosystem of the Urulyunguy can be denoted as a small steppe river with aquatic vegetation, *Cladophora* and *Charophytes* on the mud-and-sand bottom. This ecosystem is typical for other small water streams with the specific runoff not exceeding 2 L s\(^{-1}\) km\(^{-2}\).

The ecosystem of the Gazimur River in the lower reach was formed within a narrow valley with fewer tributaries bringing sediment loads and steeper slopes, which ensured higher transparency and flow rate and boulder-and pebble river bed. White water ripples were interchanged with deep pools. Aquatic vegetation was observed in the riparian zone with macroalgae growing no deeper than 1 m. The ecosystem of the Gazimur lower reach can be denoted as a *large submontane taiga river meandering across a narrow valley with boulder-and pebble river bed and scarce aquatic vegetation*.

Small water streams of the Argun basin have the highest overall length. These shadowed streams of low temperatures drained taiga areas with predominant larch and were loaded with allochthonous organic matter. The bottoms at the spots of rock exposure were coarse with frequent areas of sand and rotted rocks. Aquatic mosses dominated the vegetation with rare occurrences of macroalgae mainly represented by Ohrophyta. Fish were not observed. The ecosystems of such water streams can be denoted as *small rivers of mountainous taiga valleys with mosses on rocky bottoms*.

The properties of the ecosystems are altered as river discharge rates increase and the reaches become longer. Small channels featured flood plains with predominant shrub vegetation. The flood plain affects the biogenic compounds flow, regulates the regime of runoff and sediment loads during flood periods. The river channels featured steep banks with rare ripples. The bottoms were mainly rocky with occurrences of sand and rotted rocks. Aquatic mosses dominated the vegetation, yet macroalgae became more diverse with Nostocales, Oscillatoriales, Chaetophoraceae, Tribonemataceae and Váucheriales. The ichthyofauna was composed of *Barbatula toni* (Dybowski, 1869), *Rynchocypris lagowskii*, and *Phoxinus phoxinus* (Linnaeus, 1758). The ecosystems of such areas can be denoted as *small water streams of bushy valleys with mosses and algae on rocky bottoms*.

Small rivers to the north of the basin in the lower reach and those to the south of the basin in the upper reach flow across the wetlands and banks with willow shrubs. Water temperatures in the summer reached 10–12 °C, which was conducive to biodiversity and production. Mosses were less observed while sand beds featured *Batrachium divaricatum* (Schrank) Schur. and *Potamogeton species* were rarely detected in deep pools. Fresh-water macroalgae were predominant in the reaches that drain the wetlands and were observed as developing epiphytically on mosses and growing in the epilithon on boulders and pebbles. The streams of the Urov valley and the middle reach of the Uryumkan were noted as habitats for predominant Oedogoniceae and Nostocales. The ichthyofauna was represented by rheophilic stenobiotic species of *Thymallus grubii* (Dybowski 1869), *Barbatula toni* (Dybowski, 1869), *Lota lota* (Linnaeus, 1758), *Phoxinus phoxinus* that give affinity for clear water with low temperature and fast flow [20]. The ecosystems of these river areas can be denoted as *small rivers of the wetlands and floodplains with willow thickets, mosses, algae and wild grasses on gravel bottoms*.

The middle reach of particular water streams such as the Budyumkan, the Uryumkan, the Urov, the Gazimur, the lower stream of the Upper, Middle and Lower Borzya, was characterized by a more complex biotopic structure, slower flow rate, deep broads, more prominent channel lines, developed meanders and oxbow lakes. High anthropogenic disturbance in the steppe rivers due to gold mining however does not allow for giving a clear description of their ecosystems. Such areas require further
research. Macroalgae dominated within the ripples in the mountainous and taiga reaches, while embryophytes were detected in the pools and oxbows. Significant amounts of rheophilic ichthyofauna such as *Thymallus grubii*, *Brachymystax tumensis* Mori, 1930, *Lota lota*, *Barbatula toni* still remained, although they mainly inhabited the ripples of the rivers. The areas with slow flow rate and higher temperature are more conducive to the species of boreal and lowland and authchthonic China’s fauna complexes [20]. The ecosystem can be denoted as the medium rivers with algae and wild grasses within the water course and wild grasses in the creeks and oxbow lakes of the flood plain.

Our classification of 9 major types of subsystems with the description of the hydrobionts contributes to sustainable management, more accurate assessment of the pressure on the water ecosystems and thorough monitoring of their quality.

3.3. Hydrobionts as ecological indicators of water streams

The list of flora and fauna of the Argun basin contains 179 taxa of macroalgae, 49 species of aeroaquatic and aquatic plants, 60 species and subspecies of rotifers, 6 Calanoida species, 13 Copepoda species, 32 Cladocera specie, 31 Chronomida species, and 35 pisciform species and fishes [4]. The production and consumption of the organic matter in the water streams were only observed in benthic food chains [21]. The benthic communities as the most spatially and temporally stable indicate pollution by biogenic and toxic substances [22].

We evaluated the water quality in the Argun River and its streams on the basis of indicator organisms of plankton and benthos using the Saprobity Index and the Trent Biotic Index [8, 12]. Regional indicator organisms were identified to assess heavy metal concentrations in the ecosystems of the Argun River basin [17, 13]. According to the prior findings, we measured average values of toxic elements in the algae of the Zabaikalsky region [24].

![Figure](image)

*Figure.* Assessment of water pollution (N times) in the Argun River basin: I – MPL [19], II - background in *C. fracta* [17].

The elements exceeding permissible limits in *C. fracta* from the Argun were few, and their excessive values were insignificant (Figure). Mo values were 2.5–3.0 times higher than the background concentration, whereas the Hg values within the reach of Molokanka-Priargunsk (Stations 1–5, Figure) exceeded the background by 1.7 times. Toxic elements in *C. fracta* in the water bodies of the Argun basin were significantly different from the background elements for the Zabaikalsky region. The most noticeable differences were detected in algae samples from the backup reservoir in Krasnokamensk (Station 14) (Zn, As and Ni), in the Middle Borzya River (Station 10) (Mo, Cd and Pb), and in the Kalga
River (Station 15) (Mn, Co and Mo) (Figure). The results compared to the MPL values and the values exceeding the background have revealed that the list of elements exceeding the average background concentration in *C. fracta* for most stations was bigger than the list of elements compared to the MPL values. However, the excessive values were insignificant and were induced by the geochemical environment of the area. The toxic element concentrations in algae remained unchanged for a long term and were more informative for the assessment of pollution than the rapidly changing water quality.

It is necessary to conduct a research on the regional background concentrations for toxic elements in water and hydrobionts, and to enlarge the list of indicator hydrobionts for water quality assessment.

4. Conclusion
The Argun basin is a historical ore mining area with numerous tributaries affected by placer gold mining development. The findings showed an anthropogenic pressure on the water ecosystems of the Argun River. The water is polluted by organic substances and various toxic elements (Mn, Cu, Fe, and Mo were detected in all cross-sections of the Argun). The largest contribution to the pollution of the Argun River is made by tributaries where alluvial gold is mined, for example, the Srednyaya Borzya River, where the excess of Cu over the MPL attains 68 times. It is essential to conduct zoning for the assessment of water ecosystems in the basin, the extent of their transformations under an anthropogenic impact, and further economic use. As a result of the analysis of expeditionary studies in the Argun River basin, a characteristic was given of 9 major subsystems, the distribution of ecosystems over the territory was established and the composition of aquatic organisms living in them was determined. In the Argun River, characteristics are given to 3 subtypes of ecosystems, small watercourses are represented by 4 subtypes, ecosystems of medium rivers and the lower reaches of large tributaries are distinguished separately. It is important to determine hydrobiont indicators for each type of ecosystem to assess such a vast territory as the Argun basin. It was found that the list of heavy metals in *C. fracta* exceeding the average background concentration level is wider than the list of elements in the MPL estimate for the same stations. Algae appear to be more informative compared to the relatively rapidly changing state of water.

Our findings have revealed specific negative ecological consequences of mining production that should be considered during further developments.

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