Technogenesis and Ecological State of Natural Waters in Eastern Transbaikalia

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Abstract. The research on the state of water ecosystems is significant in terms of future biological impacts of natural and anthropogenic effects. The key branches of natural resources management in Eastern Transbaikalia (agriculture, hydraulic power industry) are based on using water resources. The findings show that technogenesis affects surface waters of the region. Alluvial gold mining represents a significant part of mining industry. Gold mining in river channels results in run-of-stream diversion and interferes with the ecosystem of watercourses. A newly formed structure of a water ecosystem is not favourable for self-purification capacity of rivers. This leads to pollutants accumulation in water objects and deteriorates ecological state of watercourses. Natural components in the technoecosystem of hydropower objects in Eastern Transbaikalia are Lake Kenon and the Kharanor Reservoir. Although the catchment area is polluted by TPP-1, the ecosystem of the lake is still capable of self-purification due to biodiversity of hydrobionts. Under the dry climate in recent years, the Kharanor Reservoir ecosystem turned as rather unstable due to constant refilling from the Onon River. However, generally, pigment indices show physiological activity of primary producers of organic matter.

1. Introduction
The research on the state of water ecosystems is significant in terms of future biological impacts of natural and anthropogenic load. The key branches of natural resources management in Eastern (agriculture, mining industry, hydraulic power industry) are based on using water resources. With this background, the ecological state of surface waters tends to change due to such anthropogenic factors as water extraction from surface and subterranean sources, and contamination of water bodies by different pollutants. Thus, monitoring of changes in water ecosystems under internal and external factors constitutes the priority [1].

Heavy metals (HM) that affect water ecosystems appear as the main environmental hazard, as they deteriorate water quality, accumulate in hydrobionts, interfere with biodiversity and the structure of populations [2–10].

We consider the issues of ecological states of water objects in terms of exposure to alluvial gold mining and operations of power plants. The impacts from alluvial gold mining were summarized during the complex field research in the Middle Borzya River. The chemical composition of the Middle Borzya and other watercourses flowing into the cross-border Argun River is of the main priority for the assessment of contaminant transfers. Coal-fired power industry remains one of the leading sphere of power production in the world. The ecological impacts from power plants were
analyzed in the case study of the cooling ponds of Lake Kenon and the Kharanor Reservoir. Natural and industrial systems have significance for consideration in both research and management due to mutual effects with natural systems affecting an industry and industrial processes interfering with an ecosystem [11].

Due to considerable water consumption, power plants are constructed near water bodies and rivers. The Kharanor Reservoir is a man-made water body designed for water supply of the Kharanor State District Power Plant (SDPP). The reservoir bed was formed within the natural channel of the Turga River (the Amur basin) and was filled with water in 1995. The reservoir water level is maintained by pumping water from the Onon River [12]. Unlike the Kharanor Reservoir, the lake in the natural and industrial complex of “Lake Kenon-Thermal Power Plant-1” is a natural freshwater body of the Amur basin.

Long-term studies of the above objects have been conducted by the Laboratory of Water Ecosystems at the Institute of Natural Resources, Ecology and Cryology SB RAS. Future development of the land of Eastern Transbaikalia can have a negative effect on water ecosystems of the region. Deeper understanding of the processes in water ecosystems at the planning stage will reduce environmental risks.

2. Materials and Methods
The field materials were collected in August 2013, 2015 and 2019 during the highest annual precipitation. The elemental composition of water was determined using Test Method NSAM No.520-AES/MS “Determination of Elements in Natural, Drinking, Waste and Sea Waters by Atomic Emission Spectrometry and Mass Spectrometry with Inductively Coupled Plasma” in the laboratory of Institute of Microelectronics Technology and High-Purity Materials of the Russian Academy of Science in the city of Chernogolovka, Moscow Oblast. Quality control was performed using Certified Reference Material “Trace Metals in Drinking Water”.

Planktonic primary production in the lake’s ecosystem was measured by the O2 bottle method [1, 13–15]. Phytoplanktonic pigments in water sample were estimated in compliance with GOST 17.1.4.02-90 as amended on 13/07/2017 [16]. The plankton was concentrated on membrane filters and extracted using 90% acetone. The extract was identified with SPECOL-1300 Spectrophotometer. Statistical and mathematical analyses of the findings were conducted using Microsoft Excel 2010 programs: Microsoft Excel and XLSTAT (Addinsoft, USA).

3. Results and Discussion

3.1. Ecological problems caused by alluvial gold mining
The Middle Borzya River starts on the southeastern slope of the Nerchinsky Mountain Range and flows into the Argun River at 511 km from the river mouth. The length of the river is 118 km. The catchment area is 1,410 km² [17]. The river bed has been exposed to alluvial gold mining over many years that deteriorated most of its channel. The undisturbed part of the river only constitutes 10-15 km.

Toxic elements in the studied areas of the Middle Borzya are shown in table 1. We determined 64 elements and selected those exceeding MPC for fishery water bodies (MPC_f) at the sampling stations.

| Stations     | Mn  | Fe  | Ni  | Cu  | Zn  | As  | Sr  | Mo  | Hg  | Pb  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Upstream     | 31.3| 293 | 0.00| 1.33| 9.50| 0.51| 99.48| 0.78| 0.00| 3.38|
| Downstream   | 170.9| 4994| 15.65| 65.81| 101.7| 7.28| 331.6| 3.36| 0.02| 13.07|
| MPC_f        | 10  | 100 | 10  | 1   | 10  | 5   | 400 | 1   | 0.01| 6   |

Table 1. The concentrations of elements in the Middle Borzya (2013, µg/L⁻¹).
In the upstream of the Middle Borzya, which was not exposed to alluvial gold mining, Mn, Fe and Cu exceed MPC 2–3 times. These values can be taken as the natural background typical for mining areas of Transbaikalia.

The downstream of the Middle Borzya (upstream from the village of Yavlenka and downstream from the tailing pond) features water that, in 9 elements out of 10, is not compliant with the standards of fishery watercourses and is higher than natural background for the following elements: Mn – 5 times, Fe – 17 times, Cu – 49 times. The concentrations of toxic elements correspond to or sometimes exceed those typical for industrial waters of ore mines. For example, the tailing pond of the Kadai Mine contains high contents of such toxic elements (µg/L) as Mn – 161, Fe – 1067, Zn – 1548, Cu – 73, Ni – 20, As < 0.52 [18].

The range of toxic elements detected in the downstream of the Middle Borzya draws a closer focus on monitoring and technology compliance. The tailing pond designed on the Middle Borzya in the last century for the purposes of alluvial gold mining must comply with the standards for contaminants trapping. Bottom dredging operations have not been performed over 30–40 years. The pond is practically filled with silt deposits. The depth of the pond at the time of study was from 25 cm on the left bank to 100 cm in the centre. Due to silting-up, the water flows over the dam directly towards the Argun River.

The impacts of alluvial gold mining and water ecosystem contamination interfere with the hydrobiology of the watercourse. The ichthyological findings in the Middle Borzya show that the abundance of fishes below water monitors and dredges reduced 3-5 times with transformation of fish communities and occurrence of alien species. The quarries formed in the river are inhabited by the invasive Percottus glehni, which facilitates further spreading of alien species [19].

3.2. Environmental impacts caused by power industry operations

Complex investigations of power plant operations affecting ecological state of cooling ponds are one of the key measures to provide natural resource users, state administration, and experts with data for protection and conservation efforts. The Kharanor Reservoir is referred to as a eutrophic water body [20] with high production ensured by thermal effect from the Kharanor SDPP. Temperature among other factors favours bloom of the planktonic community with further transformation of the ecosystem including production and decomposition of organic matter [11, 21]. The bloom leads to lower water transparency and reduces the dissolved oxygen [22]. Natural and anthropogenic impacts eventually change the processes of production and decomposition of organic matter in the ecosystem.

With anthropogenic load, the water self-purification capacity can be estimated with the ratio of the rate of organic matter (OM) production (A) to the rate of OM decomposition (R). If the ratio is <1, the ecosystem is capable of self-purification and resistant to pressures. If the ratio is >1, the system produces more OM than can be decomposed [23] which can increase a trophic status of water bodies.

The comparison of A/R ratios for different periods of investigations in Lake Kenon is given in table 2.

| Years       | A/R   | Authors  |
|-------------|-------|----------|
| 1970–1972   | 0.75  | [24–26]  |
| 1970–1986   | 0.25–0.45 | [27]   |
| 2010        | 0.15–0.45 | our data |
| 2015        | 0.12–0.58 | our data |
| 2019        | 0.46–1.11 | our data |

The research on Lake Kenon in 2016 and 2019 showed that the ratio A/R does not have positive balance. In 2019, it is only on the northern coast of the lake where the ratio A/R has positive balance (1.11). In the summer 2019, due to the drought the water level was forcibly increased by pumping water from the Ingoda River, which, under warm conditions, contributed to the destruction of
submergent coastal vegetation and intensive growth of the dissolved OM in the littoral zone of the lake.

In 1970–1972, in the centre of the lake, OM production was 122–178 gC / m³ with A/R 0.75 [24–26]. Further study showed that from 1970 to 1986 the OM production grew 2.6 times and the decomposition increased 5 times, however, in general, the increase in production and decomposition did not result in positive balance [27]. In the summer 2010, the highest level of production was detected in August and was 255 gC / m³. In this period, the highest values of photosynthesis were registered in the top layers of water column (0.4–0.7 mgO₂ / L per day). The ratios A/R obtained in 2015 and 2019 are within the previous findings. Positive ratio A/R in the littoral zone of Lake Kenon (northern coast) in August 2019 was due to the TPP-1 operations on maintaining the water level. Generally, the ratio A/R is within the ecological capacity of the lake.

Consequently, although the catchment area of Lake Kenon is polluted by TPP-1 [28–30], the ecosystem is yet capable of self-purification due to biodiversity of hydrobionts.

Currently, it is impossible to define maximum chemical load on Lake Kenon at which the capacity of self-purification can become unrecoverable. However, it is obvious that toxic elements, through trophic chain, have reached the ichthyofauna. For example, high contents of Hg and Pb were found in the muscles of Perca fluviatus and Carassius gibelio [10].

The ecological state of the Kharanor Reservoir is based on the values of photosynthetic activity of phytoplankton. The phytoplankton pigments values obtained in different periods of 2019 are shown in table 3.

In July, as compared to the observations in April and October, negative values of concentrations of pheophytin were registered in all sampling stations, which show that active forms of photosynthetic pigments are dominant in production during summer period. The significant amount of chlorophyll b in total amount of chlorophylls indicates green algae dominance. The observed concentrations of chlorophylls c₁+c₂ imply the absence cryptophytic algae.

The ratio between carotenoids and chlorophyll higher than 1 indicates that yellow pigments prevail over green pigments, which happens when the ecosystem is unstable [31–33]. This ratio in the ecosystem of the Kharanor Reservoir is slightly above 1 (table 3).

### Table 3. The phytoplankton pigments in the Kharanor Reservoir (µg/L⁻¹).

| Months     | Cchl a | Cph a | Cchl b | Cchl c₁+c₂ | Ck (cyanobacteria) | Ck (diatoms) | I (430/664) rel.units |
|------------|--------|-------|--------|------------|-------------------|--------------|---------------------|
| April      | 0.27±0.09ᵃ | 0.07±0.06ᵇ | 0.93±0.43ᶜ | -0.84ᵈ | 1.4±0.65ₑ | 3.5±1.68ᶜ | 1.2±0.16ᵍ |
| July       | 0.87±0.35ᵃ | -0.23ᵇ | 0.91±0.31ᶜ | -0.71ᵈ | 1.6±0.36ₑ | 2.7±0.83ᶜ | 1.3±0.13ᵍ |
| October    | 0.44±0.18ᵃ | 0.14±0.08ᵇ | 0.28±0.08ᶜ | -0.05ᵈ | 0.6±0.25ₑ | 3.6±0.85ᶜ | 1.4±0.12ᵍ |

ᵃ concentration of chlorophyll a as corrected for the presence of pheophytin a.
ᵇ concentration of pheophytin a.
ᶜ concentration of chlorophyll b.
ᵈ concentration of chlorophyll c₁ and c₂.
ᵉ concentration of carotenoids.
ᵍ pigment index.

Under the dry climate in recent years, the reservoir ecosystem was observed as rather unstable due to constant refilling from the Onon River. Water renewal in the reservoir occurs 34 times a year [34]. However, generally, pigment indices show physiological activity of primary producers of OM. Based on the concentration of chlorophyll a, the ecosystem of the Kharanor Reservoir remains mesotrophic.

### 4. Conclusion

The findings show that economic use of water objects affects surface waters of the region, since environmental issues in terms of their ecological, economic and social value are inadequately addressed by natural resources users, whereas the compliance with environmental regulations is not
duly controlled. To improve the current ecological situation, it is important to develop concepts and methods of ecological monitoring and analysis in natural and man-made water ecosystems, which will reduce ecological risks and facilitate resource-saving and energy-efficient technologies.

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