Coal-fired power plant and aquatic ecosystems

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Abstract. Coal industry remains one of the top electric energy sources in the world. Due to the substantial water demand, thermal power plants are built on the coasts of water bodies and rivers, which causes anthropogenic pressure on surface water. Aquatic ecosystems belong to the most vulnerable environmental compartments that reflect changes within the system itself and its watershed. The impact of coal-fired power industry on aquatic ecosystems is investigated on the example of the natural and anthropogenic complex of “Lake Kenon – TPP-1”. Lake Kenon is a natural freshwater lake of the Amur River basin. The results of research on the technoecosystem showed that a coal-fired power plant with incomplete coal combustion pollutes the reservoir. Chemicals enter Lake Kenon with emissions and effluents from TPP-1, ash dump leakages, and the flow of the Kadalinka River. Those affect both macro- and micro-component composition of the water and sediments of Lake Kenon with its hydrobionts accumulating toxic elements. To maintain the aquatic ecosystem of Lake Kenon, it is necessary to isolate surface watercourse of the ash dump leakage and control the flow of substances and energy in the lake and its watershed.

1. Introduction
The Russian Federation ranks the world’s second largest coal reserve (3.8 trillion tons) and the fifth coal producer (mining more than 320 mln tons annually). An increase in coal share in the Russian power industry is planned to change from 20% to 40% by 2025. In the USA, coal power share is 50%, in China – 75%, in Japan – 25% (with minimal mining), in South Africa – 93%, in Poland – 87%, in the Czech Republic – 51%, in Serbia -72%, in India 68%, and in Israel – 58% [1-4]. In the future, coal will remain the major fuel for electricity generation. Coal industry using methods of incomplete coal combustion is responsible for environmental pollution [5, 6].

In terms of growing anthropogenic pressure on the environment, it is essential to assess and predict all possible changes in aquatic ecosystems under external and internal factors: flows of substances and energy as well as an assessment of optimum conditions and use of ecosystems [7-9]. However, those issues remain underexplored or unexplored for most chemical elements [7]. Aquatic ecosystems are the most vulnerable environmental compartments that reflect changes within the system itself and its watershed, being geochemically interrelated [10-12].

The idea of technoecosystem of cooling ponds as one of the elements of a complex system was suggested by [13, 14]. In technoecosystems, technical objects influence ecosystems around them and vice versa: the functionality of hydrobionts inhabiting the cooling pond affect the performance of technical systems, equipment, mechanisms, and facilities.

The example of the impact of the coal industry on aquatic ecosystems is the technoecosystem of “Lake Kenon – TPP-1”. In 1965, a regional hydroelectric power plant was built on the shore of the
lake; it was further transformed into a thermal power plant No. 1 using brown coal from local deposits as fuel. In this natural and anthropogenic complex, Lake Kenon is utilized as a cooling pond. The interrelation between natural and anthropogenic systems affects the thermal regime of the lake and causes its chemical pollution. Additionally, coal-fired power plants feature ash dumps located within the watershed of water bodies and water streams [15-17].

This research aims to summarize certain negative effects on Lake Kenon by TTP-1 and positive solutions to improve the interoperation.

2. Material and methods
Lake Kenon is a natural freshwater lake of the Amur River basin situated in the limits of the city of Chita, Transbaikal Territory, (52°02'19" N 113°22'50" E) at an altitude of 653 m above sea level. The watershed of the lake is 227 km², the surface area is 16 km², the average depth is 4.4 m, the largest depth is 6.8 m, the length is 5.7 km, the average width is 2.8 km, and the shoreline length is 17.4 km [16]. The ash wastes are collected in a pond located 3 km (1.9 miles) northwest of TTP-1 and the lake. In the west, the Kadalinka River flowing by the ash dump falls into the lake (figure 1).

The pond was constructed without a liner. The leakage rate is approximately 550 m³/hour. Due to the water seepage from the ash dump, the area to the lake is represented by bicarbonate and sulphate underground and surface water with a salinity of more than 1.0 g/L and total hardness of up to 16-17 mg/L [18].

This study is based on field research conducted on Lake Kenon from 2014 to 2016. During this period, migration and heavy metals accumulation in the ecosystem of Lake Kenon was investigated.
using an integrated ecosystemic approach with biogeochemical, hydrobiological, and hydrochemical techniques by the technicians of the laboratory of aquatic ecosystems (Institute of Natural Resources, Ecology and Cryology, Siberian Branch of the Russian Academy of Sciences). Heavy metals in water, hydrobionts and bottom sediments were detected using the methods of atomic emission spectrometry and mass spectrometry in the laboratory of the Institute of Microelectronics Technology and High-Purity Materials of the Russian Academy of Sciences (Chernogolovka, Moscow, Russia). Reference materials used for the quality control were as follows: for water – Certified Reference Material “Trace Metals in Drinking Water” (National Institute of Standards and Technology – NIST, US); Elodea canadensis Michx. (1803) (SRM, EK-1, Reg. No. KOOMET 0065-2008-RU); for bottom sediments – Certified Reference Material No. 521-84П “SGD-1A”, Essexite; for fish material – muscle tissue of Perca fluviatilis (Linnaeus, 1758) from Lake Baikal (SRM, Baikal perch tissue, BOk-2, Reg. No. COOMET CRM 0068-2009-Ru).

3. Results and discussion

3.1. Changes in the composition and quality of the water in Lake Kenon

Before the hydroelectric power station was launched, hydrocarbonates outweighed sulphates in the hydrochemical composition of the lake. Hydrocarbonate composition of surface and underground waters is typical of these zonal and climatic conditions [19-21]. Currently, sulphates predominate over bicarbonates in the anion composition of the water in Lake Kenon [22]. The water composition change was due to the ash dump leakage. The sulphate content is 534.1 mg/L. Approximately 2.2-2.4 thousand tons of sulphates enter the lake annually [20].

The ash dump leakage and waters from the Kadalinka River rich in S, Ca, Mg, Mn, Zn, Sr, Hg, Mo, and W flow into the lake. Due to contamination, the contents of microelements exceeding the maximum permissible limits (MPL) in the central part of Lake Kenon are distributed in the following descending order: Mg > Ca > Sr > Fe > Zn > Pb > Cd > Mo > W. According to the comparative analysis of Clarke concentrations of the elements in Lake Kenon and in the Ingoda River (the water from the river is pumped to the lake), the water in the lake, as compared to that of the river, has shown exceeding contents of the following elements: Mg – by a factor of 25, Ca – 97, Sr – 12.5, Pb – 4.5, As – 4, Cd – 3.6, W – 2.3, Fe – 1.9, Mo – 1.8. The most contaminated areas of the lake are the northwest zone (affected by wastewaters from TPP-1 and ash dump leakage) and west zone (the estuary of the Kadalinka River). Those negative effects of the coal industry on the water quality are described by [11, 15].

Thus, the industry-related conditions caused by TPP-1 significantly influence the composition and quality of the water in Lake Kenon. The ecological status of the natural and anthropogenic complex “Lake Kenon – TPP-1” can be improved through monitoring investigation of the heavy metal contents in the water of Lake Kenon. Such investigations are carried out by the monitoring organizations in an insufficient manner.

3.2. Bottom sediments of Lake Kenon

Bottom sediments not only accumulate heavy metals but also potentially contaminate the ecosystem with heavy metals [24-26]. Due to the sedimentation of suspended organic matter capable of adsorbing ions and mineral particles from water, Mn, Zn, Hg, and Pb are concentrated in the bottom sediments of Lake Kenon [27].

3.3. Hydrobionts as indicators of the ecosystem of Lake Kenon

Hydrobionts, as constant residents of the aquatic environment, are indicators of all changes occurring in the water body for a long period of time including accumulated heavy metals [28-31].

The current qualitative composition of hydrobionts in Lake Kenon includes 110 varieties and forms of algae, 28 species of high aquatic plants and 56 species of plankton invertebrates [32, 33]. The findings on plankton capable of heavy metals sorption and bioaccumulation from the aquatic
environment of Lake Kenon have demonstrated that phytoplankton is more likely to accumulate Zn and Sr, whereas zooplankton tends to accumulate Fe, Co, Mn, Cd, Hg, and Pb [34]. High contents of Al, Sr, Zn, Ti, Ni, Cu, Mo, Hg, and Cr in Phragmites australis (Cav.) Trin. En Steud were detected in high aquatic plants of the Kadalinka River [35]. Heavy metals accumulated in fishes cause various anomalies and morphological abnormalities [36]. The occurrence of the morphological deformities in the structure of the oral cavity was established in Chironomus larvae [37]. Carassius gibelio, as a benthic species, had higher levels of Zn, Mn, and Cu, whereas Perca fluviatus, as a pelagic euryphagous predator, demonstrated higher contents of Hg and Pb. Changes in the thermal regime led to the transformation in the trophic structure of ichthyocenosis [38].

3.4. Planktonic production in the technoecosystem
The ratio of the rate of photosynthesis to the rate of destruction of organic matter (OM) is essential for the measurement of the self-purification ability. If the ratio is <1 the system is considered to be able to self-purify and resilient to the pressure; if the ratio is >1 the system produces more OM than it can destruct [39]. During the years of research on Lake Kenon, basically, positive balance in the ratio A/R was not detected (table 1).

| Years       | A/R    | Authors                  |
|-------------|--------|--------------------------|
| 1970-1972   | 0.75   | [40], [41]               |
| 1970-1986   | 0.25 – 0.45 | [42]                 |
| 2010        | 0.15 – 0.45 | our findings             |
| 2015        | 0.12 – 0.58 | our findings             |
| 2019        | 0.46 – 1.11 | our findings             |

In 1970-1972, in the central part of the lake, the production of OM ranged from 122 to 178 g C/m³ and the A/R ratio was 0.75 [40, 41]. Further observations indicated that from 1972 to 1986, OM was produced 2.6 times more intensely with a fivefold increase in destruction. However, in total, the growth of production and destruction processes did not result in positive balance [42]. In the dry climatic period of 2019, at particular sampling stations, the A / R ratio had positive balance (1.11), which indicates the input of dissolved organic matter into the lake from flooded coastal areas and with the water from the Ingoda River pumped by TPP-1. Consequently, it is crucial to maintain the regime of the design basis level of the lake constantly (654.8 m abs.) to control its production and self-purification ability.

3.5. Reduction of anthropogenic pressure on the ecosystem of Lake Kenon
Large amounts of cooling water are required for thermoelectric power plants to support the generation of electricity. Moreover, power plants also use water for the operation of flue gas desulfurization devices, ash handling, wastewater and rinse water treatment. Thus, quality water availability represents a growing concern for meeting future power generation needs [1]. Regular water supply pumped into the water body during the construction of a thermal power plant near natural water bodies does not contribute to the sustainability of their ecosystems. The ecosystem of such water bodies depends on the ecological and hydrological state of a donor watercourse.

The main issue of the interrelation between TPP-1 and Lake Kenon is chemical pollution of the lake ecosystem through the ash dump leakage and TPP-1 emissions and discharge. It is important that surface watercourse of the ash dump leakage be isolated and the contents of macro- and micro-elements in TPP-1 discharge to Lake Kenon be controlled.

The ecosystems exposed to the negative anthropogenic factors (heavy metals contamination) are to be monitored in an integrated manner with the analysis of abiotic indicators as well as the measurement of the resistance of such key species as Charophyta algae responsible for stable bottom sediments; predominant fish species (Carassius gibelio, Perca fluviatus and Rutilus rutilus lacustris)
used for recreational fishing; and other hydrobiont indicators of the ecosystem. A series of fishing and fish farming regulations should be developed to comply with the procedures and to prevent biological contamination of water bodies with alien species of hydrobionts (*Perccottus glenii*, *Elodea Canadensis*, etc.).

4. Conclusion
The results of research on the technoecosystem of “Lake Kenon – TPP-1” have shown that the coal-fired power plant with incomplete coal combustion pollutes the water body. Chemicals enter Lake Kenon with emissions and effluents from TPP-1, ash dump leakages, and the flow of the Kadalinka River. Those affect both macro- and micro-component composition of the water and sediments of Lake Kenon with its hydrobionts accumulating toxic elements.

The stable state of a water body depends on the self-purification ability of the ecosystem provided by ecosystem integrity and biodiversity of hydrobionts. Under anthropogenic pressure, abiotic changes lead to transformations in the quantitative development of aquatic organisms and species diversity. Current load of TPP-1 can activate production and destruction processes in the ecosystem of Lake Kenon. Organic matter produced in the lake catalyzes chemical reactions boosting the conversion of substances and energy [10]. To sustain the aquatic ecosystem of Lake Kenon, it is necessary to control the flow of substances and energy in the lake and its watershed.

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References
[1] Feeley T J, Skone T J, Stiegel G, McNemar A, Nemeth M, Schimmoller B, Murphy J and Manfredo L 2008 Water: A critical resource in the thermoelectric power industry Energy 33 1-11 doi:10.1016/j.energy.2007.08.007
[2] Alekseev K Yu 2011 Coal industry development in Russia (On the Long-term program for the development of the coal industry in Russia for the period up to 2030) Coal 8 6-15 (in Russian)
[3] Frantál B and Nováková E 2014 A curse of coal? Exploring unintended regional consequences of coal energy in the Czech republic Moravian Geographical Reports 22(2) 55-65 doi: 10.2478/mgr-2014-0012
[4] Zholobova Yu S, Kushchiy N A, Savon D Yu, Safronov A E 2016 Minimization of ecological impact by application of new technologies of coal preparation and mining waste disposal Gornyi Zhurnal 5 109-12 doi:10.17580/gzh.2016.05.18 (in Russian)
[5] Balat M 2007 Influence of Coal as an Energy Source on Environmental Pollution Energy Sources Part A: Recovery, Utilization and Environmental Effects 29(7) 581-9 doi:10.1080/15567030701225260
[6] Kolker A, Senior C L and Quick J C 2006 Mercury in coal and the impact of coal quality on mercury emissions from combustion systems Applied Geochemistry 21(11) 1821-36 doi:10.1016/j.apgeochem.2006.08.001
[7] Alimov A F 2000 *On the Theory of Water Ecosystem Operation* (St Petersburg: Nauka) p 147 (in Russian)
[8] Alimov A F, Bogatov V V and Golubkov S M 2013 *Production Hydrobiology* (St Petersburg: Nauka) p 339 (in Russian)
[9] Scheffer M and Van Nes E H 2007 Shallow lakes theory revisited: various alternative regimes driven by climate, nutrients, depth and lake size *Shallow Lakes in a Changing World. Developments in Hydrobiology* ed R D Gulati, E Lammens et al. (Dordrecht: Springer) 196 pp 455-66 doi:10.1007/978-1-4020-6399-2_41
[10] Shilkrot G S 2008 Biogeochemical processes and flows of matter and energy in disturbed water
ecosystems Izvestiya Rossiiskaya Akademii Nauk, Seriya Geograficheskaya 3 35-44 (in Russian)
[11] Pokale W K 2012 Effects of termal power plants on environment Scientific Reviews & Chemical Communications 2(3) 212-5
[12] Nikanorov A M, Minina L I, Bryzgalo V A, Kosmenko L S, Kondakova M Yu, Reshetnyak O S and Danilenko A O 2016 Long-term variability of pollution of water and river ecosystems of different latitudinal zones of the European part of Russia Water Resources 43(5) 515-27
[13] Protasov A A and Silaeva A A 2013 Technoecosystem of NPP and its biotic elements Nuclear Power and Environment 2 43-6
[14] Protasov A A 2017 The findings and perspectives on the technoecosystems of NPP and TPP Ecology of Cooling Ponds of Power Stations. Proc. of Russian Research and Practical Conf. with Int. participation (Chita: Publishing House of Zabaikalsky State University) pp 235-43 (in Russian)
[15] Anderson W L and Smith K E 1977 Dynamics of mercury at coal-fired power plant and adjacent cooling lake Environ. Sci. Technol. 11(1) 75-80 doi:10.1021/es60124a008
[16] Chechel A P and Tsyganok V I 1998 Physical and geographic conditions and level regime of Lake Kenon Ecology of an Inner-City Water Body (Novosibirsk: Publishing House of the SB RAS) pp 5-13 (in Russian)
[17] Mandal A and Sengupta D 2006 An assessment of soil contamination due to heavy metals around a coal-fired thermal power plant in India Environ. Geol. 51 409-20 doi:10.1007/s00254-006-0336-8
[18] Usmanova L I and Usmanov M T 2010 An influence of ash dumps of the CHPP-1 and CHPP-2 on the natural waters of the adjacent areas Vestnik KRAUNTs, Earth Science Series 2 167-78 (in Russian)
[19] Zamana L V, Strizhova T A and Chechel L P 1998 Hydrochemical parameters of a lake and its catchment area Ecology of an Inner-City Water Body (Novosibirsk: Publishing House "Science" SB RAS) pp 29-36 (in Russian)
[20] Zhuldybina T V 2010 Hydrochemical regime of water streams of Chita Oblast Geography and Natural Resources 1 99-102 (in Russian)
[21] Shesterkin V P 2016 Seasonal and spatial variations in water chemistry in the Upper Amur Regional Problems 19(2) 35-42 (in Russian)
[22] Zamana L V, Usmanova L I and Usmanov M T 2011 Ecological and geochemical assessment of underground waters used by residents of the outskirts of Chita for decentralized supply Water: Chemistry and Ecology 12 105-9 (in Russian)
[23] Zamana L V, Usmanova L I and Usmanov M T 2010 Hydrochemistry of the TPP-1 ash dump nad underground water composition within its filtration effect Bulletin of Buryat State University 3 28-33 (in Russian)
[24] Wright P and Mason C F 1999 Spatial and seasonal variation in heavy metals in the sediments and biota of two adjacent estuaries, the Orwell and the Stour, in eastern England Sci. Total Environ. 226 139-56
[25] Hou D, He J, Lü Ch, Ren L, Fan Q, Wang J and Xie Zh 2013 Distribution characteristics and potential ecological risk assessment of heavy metals (Cu, Pb, Zn, Cd) in water and sediments from Lake Dalinouer, China Ecotoxicology and Environmental Safety 93 135-44 doi:10.1016/j.ecoenv.2013.03.012
[26] Zerizghi T, Yang Yu, Wang W, Zhou Y, Zhang J and Yi Y 2020 Ecological risk assessment of heavy metal concentrations in sediment and fish of a shallow lake: a case study of Baiyangdian Lake, North China Environmental Monitoring and Assessment 192 154-70 doi:10.1007/s10661-020-8078-8
[27] Tsybekmitova G Ts, Kuklin A P, Tsyganok V I 2019 Heavy metals in bottom sediments of Lake Kenon (The Trans-Baikal Territory, Russia) Bulletin of Environmental Contamination and Toxicology 3(2) 286-91 doi: 10.1007/s00128-019-02645-7
[28] Wood J M 1974 Biological cycles for toxic elements in the environment *Science* **183** 1049-52
[29] Moiseenko T I, Kudryavtseva L P and Gashkina N A 2006 Trace elements in surface waters of the land: Technophilia, Bioaccumulation and Ecotoxicology (Moskov: Nauka) p 261 (in Russian)
[30] Tulonen T, Pihlström M, Arvola L and Rask M 2006 Concentrations of heavy metals in food web components of small, Boreal Lakes *Boreal Env. Res.* **11** 185-94
[31] Tsybekmitova G Ts, Kuklin A P, Tashlykova N A, Afonina E Yu, Bazarova B B, Itigilova M Ts, Gorlacheva E P, Matafonov P V and Afonin A V 2017 Ecological state of Lake Kenon as a cooling pond of the Thermal Power Plant-1 (TPP-1) (Zabaykalsky Krai) *Novosibirsk State Pedagogical University Bulletin* **3** 194-209 doi:10.15293/2226-3365.1703.12
[32] Afonina E Yu, Tashlykova N A and Bazarova B B 2017 Modern species composition and structure of hydrobiont communities in the Kenon Lake (Zabaikalsky Krai) *Bulletin of Moscow Society of Naturalists Biological series* **122**(1) 71-83 (in Russian)
[33] Tashlykova N A and Afonina E Yu 2017 The current conditions of the plankton communities in the Kenon Lake under anthropogenic load *Ecological Monitoring and Ecosystem Modelling* **28**(6) 36-51 doi:10.21513/0207-2564-2017-6-36-51
[34] Itigilova M Ts, Tashlykova N A and Afonina E Yu 2016 Heavy metals in phyto- and zooplankton of Lake Kenon (Transbaikalia) *Contemporary Problems of Ecology* **9**(6) 783-9 doi:10.1134/S1995425516060056
[35] Bazarova B B 2014 The content of heavy metals in Phragmites australis (Cav.) Trin. En Steud Lake Kenon (Zabaikalsky Region) *International Journal of Fundamental and Applied Research* **10**(3) 46-8 (in Russian)
[36] Gorlacheva E P and Afonin A V 2017 Silver Crucian Carp Carassius Auratus Gibelio (Bloch, 1782) as an indicator of ecosystem health in Lake Kenon *Scholarly Notes of Transbaikal State University, Series Biological Sciences* **12**(1) 6-12 (in Russian)
[37] Deliberalli W, Rogerio L, Albanin C A, Pereira M, Loureiro R Ch, Hepp L U, Rozane M and Restello R M 2018 The effects of heavy metals on the incidence of morphological deformities in Chironomidae (Diptera) *Zoologia* **35** 1-7 doi:10.3897/zoologia.35.e1294
[38] Gorlacheva E P 2015 Ichthyocenoses caratterizzazione trofici alcuni laghi Chitines-Ingodinsky depression *Italian Science Review* **8**(29) 40-9
[39] Odum Yu P 1975 *Fundamentals of Ecology* (Moscow: Mir) p 740 (in Russian)
[40] Shishkin B A, Spiglazova G N and Lokot L I 1972 Primary production of Lake Kenon *Thermal Regime and Biology of Lake Kenon (Cooling Pond of Chita Power Plant)* (Chita: Editorial and publishing sector of Zabaikalsky Department of Geographical Society of the USSR) pp 24-37 (in Russian)
[41] Shishkin B A and Lokot L I 1973 Biogenic elements and phytoplankton production of Lake Kenon *Limnological Studies in Zabaikalye* (Chita: Editorial and publishing sector of Zabaikalsky Department of Geographical Society of the USSR) pp 29-48 (in Russian)
[42] Ogly Z P 1998 Phytoplankton and primary production *Ecology of an Inner-City Water Body* (Novosibirsk: Publishing House "Science" SB RAS) pp 44-68 (in Russian)