Water as a thermodynamic parameter of biosphere evolution

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Abstract. Water has a profound influence on the evolution of the biosphere and can be regarded as a thermodynamic parameter. The priorities and objectives in this research include determining the hydrological features of rivers and lakes in the region as indicators of the thermodynamic activity of water in the evolutionary processes; hydrology and ecology of the cryptobiosphere; the effects of water on the evolutionary adaptations and strategies in living organisms in biogeochemical systems of different origins; and the hydrology of possible alternative stable states of biogeochemical systems.

Water is a unique substance with abnormal physical, chemical, biochemical, and ecological qualities [1], which makes it stand out in the biosphere’s evolutionary processes and, in terms of the contemporary concepts of nature, promotes its status to a thermodynamic parameter as the cornerstone of natural sciences.

It is indubitable that water has played a major part in the Earth’s evolution. Its availability, abundance, or deficiency can be considered the main factors driving the biosphere’s evolution. Yet, many aspects of this issue have not been thoroughly covered, as has been noted by distinguished scientists such as Zavarzin G A [2, 3] and Rozanov A Yu [4]. However, until now water has surprisingly not been considered as a thermodynamic factor (parameter).

The occurrence of considerable amounts of gravitational water on Earth, as long ago as the Early Proterozoic, have caused sedimentation processes and contributed to the geological conditions of the biosphere. Water deficiency leads to low biodiversity and interferes with cause and effect chains, while the chemical and biological contamination of water weaken its thermodynamic activity, which in turn determines biodiversity dynamics on local and regional levels. Water deficiency caused by ill-considered human activity such as river controls can result in international conflicts. Indeed, deforestation disturbs water balance and leads to desertification.

The thermodynamic activity of water is reduced by the anthropogenic load which affects biodiversity and comes with the contamination of surface and subterranean waters. For example, one of the large-scale human impacts on the aquatic ecosystems of the Transbaikalia is the dredge mining of placer gold, which leads to the degradation of watercourses and for a long time disrupts the natural evolution of aquatic ecosystems (figure 1, 2).

Another significant indirect factor for the hydrological systems in the area is the occurrence of wildfires both in the past and in the present. The most dangerous type is a massive crown fire [5, 6] which consumes material above the surface and ignites the whole stand of trees with a redistribution of chemical elements in the soil.
Part of the elements including those with a high degree of toxicity (As, Hg, Pb and others) is then transferred to the atmosphere and other territories. Geochemical contamination by transported elements in new areas is inevitably followed by the contamination of water ecosystems and reduction of water thermodynamic activity in them.

The abovementioned issues are well known, but require further investigation especially in the ecosystems of Transbaikalia (part of Central Asia) which is a region which is subjected to significant climate forcing. The research on Transbaikalia is particularly relevant in terms of different landscapes and water ecosystems [7, 8].

These aspects were partially covered in the project "Biodiversity of Natural and Technogenic Ecosystems of Transbaikalia (Central Asia) as an Indicator of Regional Climate Changes". The project aimed to identify biogeoindicators which showed climatic changes at various scales from the Pleistocene up to modern times; the conclusion was drawn that climate changes in space and time are the main triggers for evolutionary processes on the planet.

The findings revealed that bivalve molluscs represent an ancient group of species as the most susceptible components of water ecosystems which consistently respond to climate changes and anthropogenic effects [9, 10].
The reconstruction of paleogeographic maps of the Baikal area and Transbaikalia territories showed the variability of the number and area of periglacial basins during the Neopleistocene period, which arose in the main river valleys during the Samarov, Taz, Murukta, and Sartan glaciations, and were caused by large climatic “glaciation - interglacial” cycles [7].

The increase in wildfires in the Chita-Ingoda Depression over the last 400 years and in the Beklemishevo Depression over the last 100 years were most likely due to their higher anthropogenic load and active development of the territory [11]. Further investigations and more data in this sphere can facilitate the modelling and prediction of wildfires as complicated phenomena that depend on numerous physical and chemical factors, as well as random ones.

During periods of water level changes, the observed water bodies (both natural and natural-technogenic) demonstrated greater biodiversity [12] which is stipulated by thermodynamic activity, since greater biodiversity increases the number of direct and inverse relationships and enhances ecosystem resilience.

The data of the project can contribute to paleoclimate reconstruction in different parts of the world and latitudinal zones, as well as providing further research into regional peculiarities of biosphere evolution.

Regional features and spatial heterogeneity are not only typical for the climate but for the biosphere itself, which can vary in space, being interconnected with climate. Those peculiarities depend on the laws of non-equilibrium thermodynamics and possible alternative stable states of the biogeochemical systems of lakes and rivers that we regard as regional indicators of climate and biosphere evolution. For example, the Amur River serves as a special ecological and geographical axis with its ecological state being dramatically influenced by the whole basin’s geosystem.

The new project "Hydrology of Inland Waters as the Factor of Evolution of Biogeochemical Systems" brings up to date and develops the previous findings in compliance with non-equilibrium thermodynamics. The contemporary issues and purposes of this scientific area relevant for studying in the Transbaikalia include the following:

- The stages of dynamics for lakes and rivers as regional hydrological indicators of climate evolution and biodiversity;
- Hydrological and ecological peculiarities of the cryptobiosphere which are difficult to observe directly; such areas feature particular physical and chemical properties and specific species;
- The evolution of freshwater pearl mussels as a biological indicator of natural waters dynamics, their tolerance as a factor of biodiversity, and an indicator of climate changes;
- The effect of water on the evolutionary adaptations and strategies of living organisms in biogeochemical systems of different origin (water bodies and watercourses with freshwater and mineral waters, underground mineral waters, and acid drainage);
- The hydrology of possible alternative stable states of biogeochemical systems;
- The hydrology of inland waters as an important factor of the evolution of non-equilibrium water systems.

Certain investigations have already been conducted in this field: possible alternative states of the ecosystem based on different water levels were described [12] for the natural and natural-technogenic lakes in the south of Transbaikalia.

The interrelations between the biodiversity of a particular area and the abundance of water were showed for different landscapes of Transbaikalia [11].

The variety of lakes of different origins formed during the ancient ice ages could have facilitated the biodiversity of modern limnic systems [7].

The indicative capabilities of slow-moving bottom invertebrates can be used to effectively pinpoint contamination sources, since the chemical composition and accumulation of toxic elements in certain biological objects provide information on contaminated localities for a short period. Such findings, when compared with current data on the background concentrations of heavy metals in natural and natural-technogenic water bodies across a wide environmental gradient, can contribute to water quality
assessment and provide solutions for the degradation of water ecosystems within different geochemical provinces [13].

The sacred Buddhist site of Alkhanai is distinguished by supposedly sanative springs called “arshans” which contain cold ultra-fresh oligotrophic underground waters that outflow at the left bank of the Sukhoe Ubzhogoe Brook. Notably, even closely located arshans can differ in treatment goals such as those for individuals with heart, stomach, kidney, or eye problems. The conventional microbiological culture techniques showed that each spring has its own unique combination of four dominant cultures of bacteria. The bacteria feature pigments of violacein, prodigiosin, and phenazine derivatives which are known for their therapeutic effects. We can suggest that various curative properties of water in different arshans are due to the specific microorganisms coming from particular underground cold waters. It makes microbiological studies especially significant in terms of Earth’s cryptobiosphere.

The microbial diversity of the unique natural ecosystem of the stratified meromictic soda lake of Doroninskoye was studied with modern molecular and genetic methods. It was found that the microbial diversity of the lake is driven by its environmental parameters. The dominant components of the microbial community change in a particular area of the chemocline where oxygen and sulfide-containing waters merge, which can provide a key condition for the stable state of the ecosystem in time and space. The observations can be applied in projection models for the transformations of ecological conditions in natural ecosystems [14, 15].

It was shown that the ichthyocenoses structure is not only defined by the environmental factors based on regional and local trends, but also depends on diverse anthropogenic effects. The issue can be addressed by the complex and regular monitoring of the lake’s state using modern techniques and approaches, which can prevent early stages of mass infections of fishes [16].

It stands to reason to focus further research on the functional evolution of particular biogeochemical systems of lakes and rivers in connection with the hydrological dynamics of their habitats, regional climatic changes over time, and pertinent fluctuations of the thermodynamic activity of water in the evolutionary processes of the ecosystems.

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References
[1] Ptitsyn A B 2018 Lectures in Geochemistry (London: Taylor &Francis Group) p 100
[2] Zavarzin G A 2015 Selected works ed N N Kolotilova et al (Moscow: MAKS Press) p 512
[3] Zavarzin G A 2011 Prokaryotic Evolution of the Biosphere «Microbes in the Cycle of Life» 120 years later: Reading SN Winogradsky (Moscow: MAKS Press) p 144
[4] Rozanov A Y 2010 Her. Russ. Acad. Sci. 80 305–12
[5] Shcherbov B L 2011 Science First Hand 3 120–27
[6] Zhurkova I S and Shcherbov B L 2016 Bull. Irkutsk State Univ. Ser. Earth Sci. 16 30–41
[7] Enikeev F I 2018 Russ. Geol. Geophys. 59 1109–19
[8] Enikeev F I 2021 The origin and evolution of the lakes of Transbaikalia ed A B Ptitsyn and G A Yurgenson (Novosibirsk: Science) p 132
[9] Klishko O K, Kovychev E V, Vinarski M V, Bogan A E and Yurgenson G A 2020 Plos One 15 e0235588
[10] Klishko O 2020 IISJ 22-1 3–15
[11] Reshevoya S A 2018 Geogr. Nat. Res. 1 186–96
[12] Bazarova B B, Itigilova M Ts, Dulmaa A, Matafonov P V, Tsybekmitova G Ts, Tashlykova N A, Afonina E Yu and Ayuchsuren Ch 2017 Biol. Bull. 44 193–02
[13] Klishko O K, Golubeva E M and Avdeev D V 2007 Dokl. Biol. Sci. 413 115–17
[14] Matyugina E and Belkova N 2015 Chin. J. Oceanol. Limnol. 33 1378–90
[15] Matyugina E, Belkova N, Borzenko S, Lukyanov P, Kabilov M, Baturina O, Martynova-Van Kley A, Nalian A and Ptitsyn A 2018 *J. Oceanol. Limnol.* **36** 1978–92

[16] Mikheev I E and Matyugina E B 2010 *Izvestia RAS SamSC* **12** 1317–20