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HYDROBIOLOGICAL IMPLICATIONS OF AND METHODS FOR DETERMINING DUST POLLUTION LEVEL OF NIVAL-GLACIAL SYSTEMS

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The global pollution is one of the main causes of degradation of nival-glacial systems. The consequences of this process have been studied by the example of alpine lakes of the Big Zelenchuk Basin. It has been found that the dusting of snow and ice caused an adequate increase in the mineralization of alpine lakes. The accumulation of chemicals has been marked in the lacustrine organic oozes. The increased mineral nutrition base in these lakes was responsible for a noticeably higher productivity level of the phytoplankton; beetles, caddisflies and other aquatic animals have become numerous. This allowed developing a novel method for remote determinations of the degree of dust contamination of nival-glacial systems by defining the color of water in alpine lakes.

Atmospheric dust, glacial lakes, nival-glacial systems, chemical composition, phytoplankton, the remote scan of color

INTRODUCTION

The Arkhyz region in the upper reaches of the Bolshoi Zelenchuk river is very popular and highly valued for its scenic and recreational qualities. However, despite its potential for fish farming, there have not thus far been built any salmon fisheries. One reason for the fish farmers' concern is the water quality due to the fact that in the river, particularly in winter time, certain metals and petroleum products as often as not are found in excess of maximum allowable concentrations (MAC), prescribed by the fishery regulations [*Federal Agency..., 2010*] (Table 1). In searches for pollutants we ended up exploring the high mountain region of the study area.

As viewed from afar, the ice caps of high mountains seem to be immensely white and glittering. However, the picture is seen in a different light in the immediate vicinity of the glaciers and snowfields. Although the glacier ice appears more or less homogeneous and monochrome, the snowfields near them look steel-gray with visually observed inclusions of dirt particles, at times, to a depth over 0.05 m. There is increasing evidence of contamination in the form of multi-colored stains, which represent by themselves pockets of snow with thriving snow algae.

Moreover, aquatic life in glacial lakes (in August, with floating ice floes) has begun to manifest itself quite actively for such oligotrophic reservoirs. Given that the water of glaciers was considered lifeless, most closely resembling distilled water (which used to be good enough for the battery-filling), the topicality of the research into the high altitude pollution effects appears obvious.

RESEARCH METHODS

The research was carried out on high altitude lakes in the Bolshoi Zelenchuk basin, mainly on its tributaries – the Sofia, Dukka, Pshish – and on the adjacent glaciers and snowfields. Over fifty 50 lakes and surrounding areas have been examined thereby. Beginning from 2000 to 2010, during the periods from May through September, Zapyataya and Bolshoe Sofiiskoye lakes in the Sofia catchment were used as stationary points for the research [*Dementyev et al., 2000; Dementyev and Dolaeva, 2000, 2001, 2004, 2005; Dolaeva, 2004; Dolaeva and Dementyev, 2004*].

The species composition and abundance of the living organisms (phytoplankton, zooplankton, nekton and benthos) were studied by conventional hydro-biological methods. The chemical composition of water and oozes of lakes, and that of snow and ice were studied in the Vodokanal laboratories and determined by standard methods applicable to each group of chemical elements.

The observations were carried out on the basis of the analog grouping approach, whereas the sampling was done with application of the systematic random sampling method [*Parchevskaya, 1969*]. The statistical analysis was performed using IBMPC – based Microsoft Excel 5.0a and the Biostatics version 4.03 software.

Table 1. **Chemical composition of glacial systems in high mountain areas of the Bolshoi Zelenchuk river basin (mg/dm^3)**

Element	Ice	Snow	Water of lakes	MAC for FW
TDS	22.3 ± 0.2	32.7 ± 0.4	47.7 ± 0.4	–
Ammonium ion	0.015 ± 0.005	0.02 ± 0.006	0.03 ± 0.005	0.5
Natrium	4.1 ± 0.8	5.5 ± 0.9	10.0 ± 1.1	120
Nitrate-anion	0.4 ± 0.05	0.4 ± 0.05	1.0 ± 0.07	40
Nitrite-anion	0.001 ± 0.0002	0.001 ± 0.0002	0.001 ± 0.0002	0.08
Sulphate-anion	2.8 ± 0.3	3.2 ± 0.4	5.5 ± 0.3	100
Fluoride-anion	0.021 ± 0.004	0.038 ± 0.003	0.034 ± 0.003	0.05
Phosphates	traces	0.001 ± 0.0004	0.003 ± 0.0003	0.05
Ferrum	0.10 ± 0.02	0.13 ± 0.01*	0.18 ± 0.02*	0.1
Cadmium	traces	traces	traces	0.005
Potassium	1.1 ± 0.009	1.5 ± 0.01	2.5 ± 0.02	50
Calcium	1.3 ± 0.2	1.5 ± 0.2	2.8 ± 0.1	180
Cuprum	0.0009 ± 0.0001	0.001 ± 0.0001	0.0012 ± 0.0002*	0.001
Plumbum	0.002 ± 0.0001	0.003 ± 0.0002	0.006 ± 0.0002*	0.006
Zinc	0.009 ± 0.0001	0.012 ± 0.002*	0.016 ± 0.003*	0.01
Petroleum products	0.001 ± 0.0003	<0.07*	<0.09*	0.05

Note. Chemical determinations were performed at the Vodokanal Laboratory by standard methods applicable for each group of chemical elements. MAC for FW means maximum allowable concentrations in fishery waters.

* In excess of MAC for FW.

RESEARCH RESULTS

The first priority in the studies was given to the chemical composition of the contaminated surface layer of ice, snow and the epilimnion waters of glacial lakes [*Dementyev et al., 2000; Dementyev and Dolaeva, 2000, 2004*]. It has been established that their chemical composition was substantially identical, however, quantitatively, most chemical components proved higher in the lakes (Table 1).

Some indicators of the chemistry analysis results were pointedly negative at a high statistical significance level of ($p \le 0.01$). The most critical and surprising were the encountered elements of petroleum products, though, amounting in some samples to 0.09 mg/L at MAC 0.05 mg/L. Generally, unstable organic matter was found markedly abundant (in August, five-day biological oxygen demand (BOD$_5$) reaching 0.5–0.8 mgO^2/L, given that MAC for Fishery Waters (FW) is 3.0.

All this can be largely accounted for the said chemical substances falling with precipitation, in particular, with atmospheric dust. The elevated concentrations of chemicals in the lakes are also linked with their additional input from the rocky slopes free of glaciers and snowfields (rocky masiffs in themselves are not prone to extensive leaching). Such examples of allochthonous transport of various chemical substances into the highlands at the expense of atmospheric processes have been known for fairly long time [*Dikikh, 1975; Rikhvanov et al., 2008*].

Unlike the lowland water bodies, the water temperature of high mountain lakes is low and, hence, unfavorable for the bacterial flora activity, which to some part can be inferred from the research results and findings obtained by *V.A. Akimov* [*1971*], ascertaining that the bacteria produce in Lake Sevan is an order of magnitude less (<0.005 mgC/L) versus that of the lowland water reservoirs. Lake Sevan, in the meantime, is located substantially lower, than the studied glacial lakes.

According to our observations, the so-called “burial sites” of land insects were often found in these high mountain reservoirs – in turbulent bottom depressions – where these organisms remained virtually intact during time periods spanning a few months and maybe even years. At the basal part of the chained lakes (ca. 1.5–2.0 thousand m a.s.l.), we came across a dead trout stuck in the discarded fishing net, with its carcass fairly well-preserved in shape and hardly affected by decomposition processes in the water within about three years. These facts imply that in a high montane area, the bacterial fauna is not capable of utilizing the ever-increasing input of various organic chemicals.

On the contrary, a marked growth in populations and biodiversity of phytoplankton communities was evoked in response to an increase in the allochthonous sources of mineral nutrition. People with good color vision began to differentiate high-mountain lakes for their color shades, which is partially reflected in their names.

It should be noted that the phytoplankton species diversity, in general, is highly representative in the high mountain water bodies [*Fedorov, 1977; De-*

mentyev and Dolaeva, 2000], with phytoplankton being specific in each of them and often limited to a few species. Furthermore, its diversity is not stable and may significantly vary in different seasons and years. And it's only in larger lakes that planktonic microflora is found to be relatively constant, bearing, nevertheless, specific features in each individual water body. On average, microalgae included in the plankton may amount to 7,000 pcs/m^3 (June–August) in the high mountain lakes and wetlands.

According to the literature data [*Fedorov, 1977*], the total number of as many as fifty five species of microalgae thriving in the snow and glacial bodies of water in the Caucasus mountains are divided into the following groups: diatoms (26); green algae (18); blue-green (10); red algae (1). Over the study period, the authors observed only 32 species of phytoplankton with the potential absorption spectra ranging from 400 to 550 nm in the high altitude area.

The organisms proved the most massive and constantly present in the phytoplankton of all of the high mountain water bodies are listed below:

1. Blue-green algae (*Cyanophyta*), Chaemisiphon genus (*Chamaesiphonophyceae*) – *Chamaesiphon* sp. (probably *Ch. curvatus*).
2. Blue-green algae (*Cyanophyta*), Chorooccales genus (*Chroococcophyceae*) – *Microcystis* sp. (probably *M. pulverea*).
3. Diatoms (*Bacillariophyta*), Pennate genus (*Pennatophyceae*) – *Gomphonema* sp.
4. Green algae (*Chlorophyta*), Volvocales genus (*Volvocophyceae*) – *Volvox* sp. (dominance class).
5. Green algae (*Chlorophyta*), Protococcus genus (*Protococcophyceae*) – *Scenedesmus* sp.

Apart from these, the following algae species were encountered in the high montane areas (glacial lakes, streams, lakes and highland wetlands), however, with no apparent distribution patterns and few in numbers, representing: blue-green algae – *Gloeocapsa alpina*, *Gloeothece palea*, *Eucapsis alpina*, *Nostoc* sp., *Rivularia* sp.; Pyrrhophyta – *Peridinium* sp., *Gloeodinium montanum*; diatoms – *Tabellaria fenestrata*, *Synedra* sp., *Pinnularia* sp., *Amphora* sp.; yellow-green algae – *Tetraedriella* sp., *Vaucheria* sp.; green algae – *Spondylomorum quaternarium*, *Stephanosphaera pluvialis*, *Haematococcus* sp., *Chlamydomonas nivalis*, *Chlorella* sp., *Ancylonema* sp. (probably *A. nordenskioeldii*), *Spirogira* sp. (probably *S. varians*), *Micrasterias* sp. and some others.

On average, more than 15–20 phytoplankton species may be present in each high mountain body of water, differing in light absorption spectra. No vascular plants (macrophytes) were found in high mountain lakes.

The secondary level of phytoplankton production is represented by various animals [*Dolaeva, 2004*]: testate amoebae, flagellates, hydras, bryozoans and other organisms, predominantly microscopic in size. The top of the food chain is taken by insects – beetles, caddisflies and springtails. The detailed composition of the animal population, however, is not provided here, seeing as not principal for the purpose this article. One thing to be pointed out here, though, is that the biomass of this trophic level tends to be steadily increasing at a rate 5–10 % per year.

DISCUSSION OF RESULTS

In the opinion of *Yu. Efremov* [*1984, 1988*], the high mountain waters in the studied region should be classified as ultrafresh with total mineralization (TDS – Total Dissolved Solids) up to 0.1 g/L. Low TDS values of the glacier water are attributed to the poorly leachable coarse crystalline rocks – granite, gneiss, amphibolite – widely spread in the area. As was shown, however, total mineralization of high mountain water flows has substantially increased versus the anticipated and previously observed levels. This therefore may have caused the booming growth of phytoplankton. Presumably, both its biomass and species composition (water color index) are associated with the amount of dust pollution in high montane areas.

With regard to physicochemistry, phytoplankton pigments are known for absorbing energy primarily in the red and blue segments of the spectrum and generally but not always reflect light in the green portion. A relationship thus exists between the spectral reflection of the epilimnion water and the contained phytoplankton with a specific set of pigments. Their ratios for different spectral zones serve as a defining factor for the thereby imparted "color" to high mountain water (color rendering index – CRI).

Taking into account the implied relation between dust pollution and the phytoplankton growth rate, the application of the remote sensing method for analyzing the pollution level in high montane regions, given the availability of appropriate tools (e.g., spectroradiometers), appears most suitable for glaciological studies, inasmuch as they have long been applied in oceanological and hydrobiological research. In practical terms, spectral characteristics of individual types of phytoplankton and their combinations are envisaged to be given a detailed analysis to, as further research into the problem.

CONCLUSIONS

1. In recent decades, quantities of the chemicals transported with dust have grown due to the global atmospheric pollution, affecting the high mountain environments inter alia, which has led to a visually observable contamination of nival-glacial systems.
2. Given that it is technically challenging to determine the intensity and composition of dust pollution in hard-to-access mountainous glaciated areas, the study of the pollution level of glaciological sys-

tems using remote sensing methods appears more viable, for example, by defining the color of water in alpine lakes.

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