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REGIONAL PROBLEMS OF ENVIRONMENTAL STUDIES AND NATURAL RESOURCES UTILIZATION

# Chemical Composition of Glacial Meltwaters and River Waters within the Aktru River Basin (Gornyi Altai)

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**Abstract—**An assessment was made of the mean levels of major and trace elements and of biogenic and organic matter in glacial and river waters within the Aktru river basin (Gornyi Altai, Russia). The analysis showed a general tendency for an increase in mineralization along the direction from the region of alimentation of glaciers to the mouth of the river. A relatively abrupt increase was revealed in Al, Zn, Cu, Pb, Si, $NO_2^-$ and $NH_4^+$ concentrations in the source of the Aktru river and its glacial tributaries, with their subsequent decrease downstream. The mechanism for such changes is governed by the conditions of interaction of rocks with meltwaters and river waters.

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*Keywords:* hydrochemistry, glacial and river waters, Gornyi Altai, Aktru river basin.

## INTRODUCTION

The last several decades saw an increase in mean temperatures of the ground-level atmospheric air layers in many regions of Northern Eurasia, including on Altai [1, 2]. This was responsible for a marked reduction in the area of mountain glaciation [2–5], and for changes in the volumes of annual and seasonal discharge of some rivers rising in the glaciers of Altai [6]. Accordingly, one might also expect changes in the formation conditions for chemical composition and for the quality of surface waters.

The objective of this paper is to estimate the chemical composition of melt glacial and river waters, and their formation conditions in the mountain-glacier basin of the Aktru river on the northern slope of the Northern Chuiskii range in the Bish-Iirdu mountain knot (Gornyi Altai). This selection of the object for study was motivated by the representativeness of the Aktru river basin forming part of the Altai-Sayan mountain system and constituting an element of the Aktru – Chuya – Katun' – Ob' river system as well as by the available body of glaciohydrological observations, which would make it possible to construct future models for changes in hydrochemical conditions [3, 7, 8].

The Aktru basin is the home for seven glaciers with the total area of about 16 km$^2$. Three glaciers of the valley type: Pravyi, Levyi and Malyi Aktru (previously, Prav. And Lev. Aktru formed a single glacier, Bol'shoi Aktru); two glaciers of flat summits: Vodopadnyi and Kar Mal. Aktru; one hanging glacier on the summit of the Karagash mountain, and one cirque-hanging glacier, Stazher. The main glacial area corresponds to the altitude range 3200–3400 m, and the snow line runs at an altitude of 3200 m and higher [9].

## INPUT DATA AND TECHNIQUE

The investigations were made on the basis of data which we obtained as part of field itineraries during 1997–2000 and in 2012 and which were partly published [8]. Work was done in several steps: 1) sampling of ice from the 0.4–0.6 m layer below the surface in the feeding region of the Mal. Aktru glacier, and in the ablation region of the Mal. And Lev. Aktru glaciers and of the Vodopadnyi glacier; 2) sampling of water from the Aktru river from the 0.2–0.5 m layer below the surface in the section from the source (outcrops of several glacial flows from beneath the tongues of the Lev. And Mal. Aktru glaciers) to the discharge site 0.2 km from the confluence with the Chuya river; 3) preparation of samples for transportation, and determination of rapidly changing elements in the river and melt water (pH, $CO_2$, $CO_3^{2-}$, $O_2$, $Fe^{3+}$, $Fe^{2+}$, $NO_2^-$, and $NH_4^+$); 4) determination of chemical composition of water samples (macroelements, trace elements, biogenic substances, fulvoacids (FA), humic acids (HA), and permanganate oxidability (PO)) in the stationary certified laboratory operated by Tomsk Polytechnic University; determination of concentrations of organic macro-impurities in river water samples at the Institute of Petroleum Chemistry, Siberian Branch, Russian Academy of Sciences, by means of the Nermag quadrupole chromate mass spectrometer R–10–10C; and 5) thermodynamical calculations with the aid of the Solution software package [10] for assessing the conditions of the interactions in the water – rock material system, and analysis of data obtained.

River water and ice samples were collected in accordance with the requirements [11, 12], and statistical analysis of materials from laboratory studies was done according to [13]. The technique for determining the content levels of dissolved substances is given in [14], and the structure of the Solution software package and the description of its application procedure are provided in [10].

## DISCUSSION

Analysis of the data obtained showed that, according to O.A. Alekin's classification and in accordance with the guidelines [15, 16], the glacial waters are generally fresh, with very low mineralization (according to [17] – xenohalobic), hydrocarbonate calcium, weakly acidic (according to [17] – acidulous); the river waters are fresh, with very low mineralization (fresh xenohalobic and moderately mineralized [17]), hydrocarbonate calcium, neutral or weakly alkaline (Tables 1 and 2).

**Table 1.** Mean chemical composition of glacial and river waters within the Aktru river basin for 1997–2012

| Indicator | Glaciers | | | Aktru river | | | |
|---|---|---|---|---|---|---|---|
| | feeding region | ablation region | mean for glaciers | source | mountain area | mountain-steppe area | mean for all areas |
| pH | 5.80 | 5.21 | 5.43 | 8.27 | 7.17 | 7.92 | 7.80 |
| | | | | mg/dm$^3$ | | | |
| $\sum_i$ | 20.1 | 22.1 | 21.3 | 51.2 | 81.5 | 156.9 | 102.6 |
| $Ca^{2+}$ | 1.7 | 2.6 | 2.3 | 9.0 | 15.3 | 30.0 | 19.3 |
| $Mg^{2+}$ | 0.5 | 0.4 | 0.5 | 1.2 | 2.4 | 4.7 | 3.0 |
| $Na^+$ | 0.6 | 0.6 | 0.6 | 0.4 | 0.9 | 1.5 | 1.0 |
| $K^+$ | 0.3 | 0.3 | 0.3 | 0.6 | 1.0 | 1.7 | 1.1 |
| $HCO_3^-$ | 14.2 | 13.9 | 14.0 | 29.3 | 39.9 | 91.8 | 57.5 |
| $CO_3^{2-}$ | 0.0 | 0.0 | 0.0 | 3.2 | 2.4 | 2.7 | 2.8 |
| $SO_4^{2-}$ | 0.7 | 1.3 | 1.0 | 5.3 | 17.3 | 23.1 | 16.0 |
| $Cl^-$ | 2.1 | 2.9 | 2.6 | 2.3 | 2.2 | 1.4 | 1.9 |
| $NO_3^-$ | – | 1.24 | 1.24 | 0.52 | 0.68 | 0.73 | 0.66 |
| $NO_2^-$ | – | 0.010 | 0.010 | 0.013 | 0.006 | 0.006 | 0.007 |
| $NH_4^+$ | – | 0.092 | 0.092 | 0.100 | 0.038 | 0.071 | 0.066 |
| $PO_4^{3-}$ | – | 0.044 | 0.044 | – | – | – | 0.060 |
| Si | 0.21 | 0.61 | 0.46 | 11.40 | 1.44 | 1.77 | 4.56 |
| PO, mgO/dm$^3$ | – | – | – | 3.6 | 0.5 | 1.2 | 1.7 |
| FA | – | 1.02 | 1.02 | – | – | – | 1.32 |
| HA | – | 1.30 | 1.30 | – | – | – | 0.77 |
| | | | | μg/dm$^3$ | | | |
| $F^-$ | 25 | 47 | 39 | 53 | 33 | 98 | 65 |
| Fe (total) | 393 | 280 | 329 | 1650 | 2630 | 2568 | 2311 |
| Li | 3.7 | 3.4 | 3.5 | 1.6 | 2.1 | 4.9 | 3.1 |
| Hg | 0.030 | 0.412 | 0.248 | 0.053 | 0.005 | 1.410 | 0.380 |
| Zn | 101.2 | 10.7 | 44.7 | 15.5 | 5.4 | 21.1 | 14.7 |
| Cd | 0.1 | 0.5 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 |
| Pb | 1.3 | 0.7 | 0.9 | 0.9 | 0.5 | 4.9 | 2.4 |
| Cu | 0.9 | 2.1 | 1.7 | 1.3 | 1.3 | 7.0 | 3.5 |
| Al | – | 135 | 135 | 838 | 1124 | 571 | 814 |
| Number of samples | 3 | 5 | 8 | 3 | 3 | 4 | 10 |

Note. $\sum_i$ – sum of major ions; PO – permanganate oxidability; FA – fulvoacids; HA – humic acids.

**Table 2.** Characteristic of the hydrochemical type and quality of glacial and river waters within the Aktru river basin

| Object | Area | Kurlov's formula | | Quality category acc (GOST 77), acc [17] | | $\sum_{1-2}(S/MPC_{ec})$ |
|---|---|---|---|---|---|---|
| | | | | mean | range | |
| Glaciers | Feeding region | $M_{0.020}$ | $\frac{HCO_3^- \; 76 \quad Cl^- \; 20}{Ca^{2+} \; 43 \quad Mg^{2+} \; 38 \quad Na^+ \; 14}$ | xs | xs | 0.24 |
| | Ablation region | $M_{0.022}$ | $\frac{HCO_3^- \; 63 \quad Cl^- \; 22}{Ca^{2+} \; 58 \quad Mg^{2+} \; 25 \quad Na^+ \; 14}$ | xs | xs – bm | 1.40 |
| | Total | $M_{0.021}$ | $\frac{HCO_3^- \; 68 \quad Cl^- \; 21}{Ca^{2+} \; 52 \quad Mg^{2+} \; 30 \quad Na^+ \; 14}$ | xs | xs – bm | 0.92 |
| Aktru river | Sources | $M_{0.051}$ | $\frac{HCO_3^- \; 69 \quad Cl^- \; 14 \quad SO_4^{2-} \; 12}{Ca^{2+} \; 77 \quad Mg^{2+} \; 17}$ | o | xs – bm | 0.29 |
| | Mountain | $M_{0.083}$ | $\frac{HCO_3^- \; 61 \quad SO_4^{2-} \; 33}{Ca^{2+} \; 75 \quad Mg^{2+} \; 18}$ | o | xs – o | 0.14 |
| | Mountain-steppe | $M_{0.157}$ | $\frac{HCO_3^- \; 67 \quad SO_4^{2-} \; 25}{Ca^{2+} \; 73 \quad Mg^{2+} \; 22}$ | bm | o – p | 3.46 |
| | Total | $M_{0.103}$ | $\frac{HCO_3^- \; 66 \quad SO_4^{2-} \; 23}{Ca^{2+} \; 74 \quad Mg^{2+} \; 19}$ | o | xs – p | 1.11 |

Note. xs – pure xenosaprobic; o – pure oligosaprobic; bm – polluted betamesosaprobic; p – dirty polysaprobic; $\sum_{1-2}(S/MPC_{ec})$ – sum of concentration ratios of hazard classes 1−2 substances to respective values of maximum permissible concentrations for economic-purpose water bodies ($MPC_{ec}$).

The general tendency of changes in the sum of the major ions $\sum_i$ in the surface waters across the territory of the Aktru basin implies its gradual increase from the feeding region of the glaciers to the mouth (see Table 1); However, an examination of the diurnal longitudinal profiles reveals a more complicated pattern of distribution of the value of $\sum_i$ as well as of the concentrations of separate elements and compounds.

Overall, the following regularities were identified: an increase in the content level of most of the substances under study, occurring in the near-glacier zone at the contact of glacial waters with rock materials, and some decrease in the content level at a distance of 3–5 km from the source of the Aktru, followed by a stabilization at the entry of the river into the mountain-taiga zone (16.9 km from the source), and further downstream as far as the mouth (Table 3). Similar, albeit not as obvious (perhaps because of the smaller number of samples analyzed) tendencies in changes of mineralization and macrocomponents were revealed earlier, during 1997–1998 [8].

Variability in concentrations of trace elements, silicon, nitrogen compounds and PO along the compounds glacier – river system also experiences rather abrupt fluctuations characterized by a marked increase at the source of the Aktru river and its glacial tributaries, a decrease along a section of 3–5 km from the source, and by formation of a relatively constant level, or by intermittent variations in concentrations within a certain range of values (Fig. 1; see Table 3).

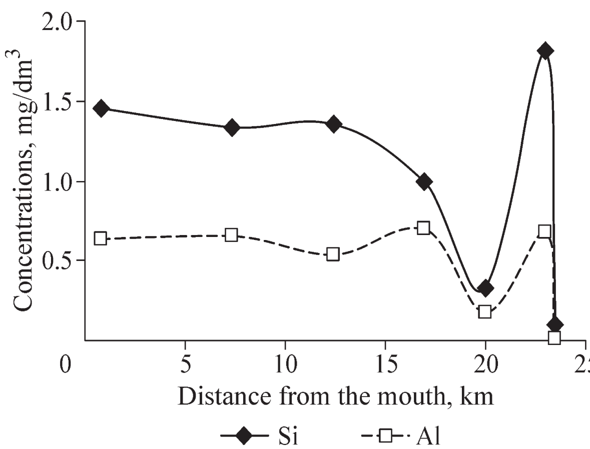


**Fig. 1.** Variation in silicon and aluminum concentrations along the length of the Aktru river.

It should be noted that the differences in the chemical composition reveal themselves not only in river waters but also in glacial waters. In this case, there occurs some increase of the sum of the major ions, the concentrations of $Ca^{2+}$, $SO_4^{2-}$, $Cl^-$, Si, Hg and Cu and of some other substances within the ablation zone when compared with the feeding zone, which appears to be accounted for by dissolution of dust particles and fine-dispersed morainal material which are presented within the ablation zone in large amounts. The

**Table 3.** Concentrations of chemical elements in glacial and river waters within the Aktru river basin for July 2012

| Indicator | Levyi Aktru glacier (ablation region) | Aktru river | | | | | |
|---|---|---|---|---|---|---|---|
| | | sources (subglacial flow of Levyi Aktru) | Gauging station; 20 km from mouth | Lower part of floodplain; 16.9 km from mouth | Crossing; 12.4 km from mouth | 0.15 km upstream of mouth of Korumdu river; 7.4 km from mouth | 0.2 km from mouth |
| | 20.07.12 | 22.07.12 | 21.07.12 | 24.07.12 | 24.07.12 | 24.07.12 | 24.07.12 |
| pH | 6.2 | 8.32 | 8.47 | 8.05 | 8.02 | 8.1 | 8.07 |
| | | | | $mg/dm^3$ | | | |
| $\sum_i$ | 16.7 | 81.3 | 51.4 | 110.1 | 139.6 | 140.3 | 113.5 |
| $Ca^{2+}$ | 1.2 | 15.0 | 10.0 | 20.0 | 24.0 | 23.0 | 21.0 |
| $Mg^{2+}$ | 0.10 | 1.83 | 1.22 | 4.88 | 5.49 | 6.71 | 4.27 |
| $Na^+$ | 1.61 | 0.46 | 0.95 | 0.98 | 2.36 | 1.38 | 1.45 |
| $K^+$ | 0.24 | 0.8 | 1.37 | 0.72 | 1.3 | 0.81 | 0.81 |
| $HCO_3^-$ | 9.76 | 45.14 | 24.4 | 52.46 | 70.76 | 74.42 | 63.44 |
| $CO_3^{2-}$ | 0 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| $SO_4^{2-}$ | 2.33 | 13.69 | 9.42 | 26.6 | 31.07 | 29.52 | 18.25 |
| $Cl^-$ | 1.5 | 0.73 | 0.39 | 0.84 | 1.06 | 0.89 | 0.67 |
| $NO_3^-$ | 0.13 | 0.47 | 0.51 | 0.74 | 0.79 | 0.78 | 0.66 |
| $NO_2^-$ | 0.005 | 0.020 | 0.012 | 0.005 | 0.003 | 0.010 | 0.005 |
| $NH_4^+$ | 0.050 | 0.100 | 0.053 | 0.036 | 0.025 | 0.033 | 0.025 |
| Si | 0.10 | 1.81 | 0.33 | 0.99 | 1.35 | 1.33 | 1.45 |
| PO, $mgO/dm^3$ | <0.1 | 0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | | | | $\mu g/dm^3$ | | | |
| $F^-$ | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 |
| Fe (total) | 20 | 2770 | 280 | 760 | 650 | 980 | 390 |
| Li | 0.3 | 0.4 | 0.6 | 0.7 | 0.7 | 0.5 | 0.4 |
| Zn | 3.1 | 13.0 | 5.1 | 7.2 | 4.9 | 9.8 | 4.6 |
| Cd | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Pb | 0.3 | 0.9 | 0.3 | 0.5 | 0.5 | 0.7 | 0.6 |
| Cu | 0.5 | 1.6 | 0.5 | 1.2 | 0.7 | 1.5 | 0.7 |
| Al | 10 | 676 | 171 | 701 | 540 | 657 | 636 |

question logically arises as to the relationship of the natural and anthropogenic components of atmospheric depositions.

A preliminary answer to the question as to the Ob' river basin [18–20] implies a substantial influence of the economic activities on the content level of a variety of substances in the atmospheric air, such as sulfur dioxide, nitrous oxide, radionuclides, and some organic compounds. In particular, in the subglacial flow of the Lev. Aktru glacier, typically anthropogenic substances were discovered in August 1998: phthalates (0.630 $\mu g/dm^3$), and chlororganic compounds (0.015 $\mu g/dm^3$), the supply of which to the river waters is most likely associated with pollution of the snow, firn and surface ice layers. On the other hand, a significant excess of the concentrations of Si, $Ca^{2+}$ and some other elements in the ablation zone of the Aktru glaciers over the region of their alimentation would be more straightforwardly attributed to dissolution of particles of local rocks arriving at the glacier tongue from the open surface of the adjacent territory (see Tables 1 and 3).

To explain in greater detail the aforementioned changes, thermodynamical calculations of the interaction of melt glacial and river waters with a number of minerals and organomineral compounds were carried out. Results showed that, first, along almost the entire length of the Aktru river there occurs undersaturation of the rivers waters with respect to most of the substances

**Table 4.** Values of the saturation index (*L*) of glacial and river waters within the Aktru river basin for July 2012

| Reaction number | Formula | Mean | Minimum | Maximum |
|---|---|---|---|---|
| 1 | $CaCO_3$(calcite) = $Ca^{2+} + CO_3^{2-}$ | –1.65 | –4.24 | –0.76 |
| 2 | $CaCO_3$(calcite) + $CO_2 + H_2O = Ca^{2+} + 2\times HCO_3^-$ | –0.98 | –4.22 | –0.28 |
| 3 | $CaMg(CO_3)_2$(dolomite) = $Ca^{2+} + Mg^{2+} + 2\times CO_3^{2-}$ | –3.04 | –8.51 | –1.14 |
| 4 | $CaMg(CO_3)_2$(dolomite) + $2\times CO_2 + 2\times H_2O = Ca^{2+} + Mg^{2+} + 4HCO_3^-$ | –1.70 | –8.47 | –0.06 |
| 5 | $MgCO_3$(magnesite) + $CO_2 + H_2O = Mg^{2+} + 2\times HCO_3^-$ | –4.66 | –8.20 | –3.73 |
| 6 | CaHA = $Ca^{2+}$ + HA | 0.38 | –0.58 | 0.65 |
| 7 | MgHA = $Mg^{2+}$ + HA | 0.34 | –0.92 | 0.82 |
| 8 | $CaAl_2Si_2O_8$(anorthite) + $3\times H_2O + 2\times CO_2 = Al_2Si_2O_7\times 2\times H_2O$(kaolinite) + $Ca^{2+} + 2\times HCO_3^-$ | –257.1 | –261.4 | –256.0 |
| 9 | $SiO_2$(quartz) + $2\times H_2O = H_4SiO_4^0$ | –0.51 | –1.38 | –0.14 |
| 10 | $2\times NaAlSi_3O_8$(albite) + $11\times H_2O + 2\times CO_2 = AlSi_2O_7\times 2\times H_2O$(kaolinite) + $2\times Na^+ + 2\times HCO_3^- + 4\times H_4SiO_4^0$ | –14.60 | –21.14 | –12.77 |
| 11 | $3\times KAlSi_3O_8$(orthoclase) + $2\times H^+ + 12\times H_2O = KAl_3Si_3O_{10}OH_2$(muscovite) + $2\times K^+ + 6\times H_4SiO_4^0$ | –27.71 | –37.29 | –24.62 |
| 12 | $2\times KAl_3Si_3O_{10}OH_2$(muscovite) + $2\times H^+ + 3\times H_2O = 3\times Al_2Si_2O_7\times 2\times H_2O$(kaolinite) + $2\times K^+$ | –0.24 | –4.60 | 1.43 |
| 13 | $CaAl_2Si_2O_8$(anorthite) + $2\times H^+ + H_2O = Al_2Si_2O_7\times 2\times H_2O$(kaolinite) + $Ca^{2+}$ | –21.18 | –29.80 | –18.95 |
| 14 | $NaAlSi_3O_8$(albite) + $7\times H_2O + H^+ = Al_2O_3\times 3\times H_2O$(gibbsite) + $Na^+ + 3\times H_4SiO_4^0$ | –207.0 | –211.2 | –205.8 |
| 15 | $ZnCO_3$(smithsonite) = $Zn^{2+} + CO_3^{2-}$ | –4.20 | –50.9 | –3.56 |

Note. Negative values of the index *L* indicate potential undersaturation, and positive values indicate oversaturation of solution with respect to minerals, the interaction with which is considered.

under study, except for humic acids with calcium and magnesium as well as some reactions with the production of kaolinite. The largest undersaturation of the solution for all the 15 reactions used in the study (Table 4) was observed for the glacier tongue. Second, even in the near-glacier zone there seems to be the largest oversaturation of the surface waters with respect to some clay minerals (Fig. 2, reaction IV), which suggests the possible formation of clay fraction of river sediments not only due to mechanical erosion but also directly during the interaction of water and rocks, especially in places of relative decrease in the river grade and of an expansion of its channel. And, third, maximum values of the saturation index occur most frequently within the confines of the mountain-steppe area: at 12 km from the mouth – reactions nos. 1, 3, 6, 10 and 14, and at 7.4 km from the mouth – reactions nos. 2, 4, 5 and 7 (see Table 4). Furthermore, as regards the reactions of production of compounds of humic acids with calcium and magnesium, there seems to be oversaturation of the solution and, hence, the removal of these substances from the water environment, especially at the time of flood decline on the floodplain.

These conclusions are in agreement with earlier similar assumptions, based on analyzing data on

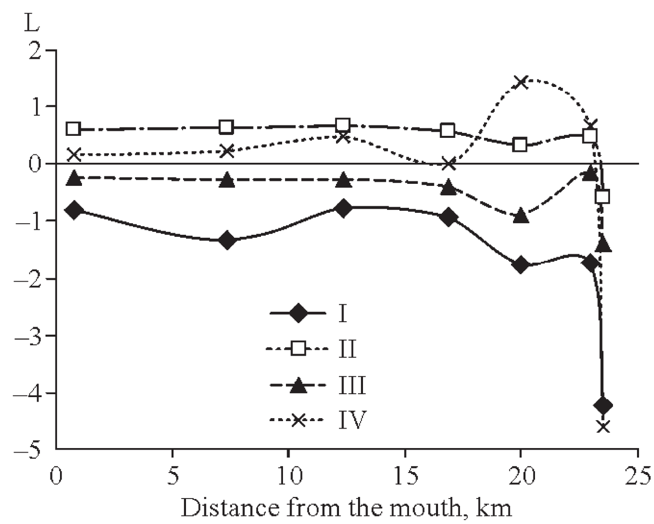


**Fig. 2.** Variation in the saturation index (L) of surface waters along the length of the Aktru river for July 2012.

Reactions: (I) $CaCO_3$(calcite) = $Ca^{2+} + CO_3^{2-}$; (II) CaHA = $Ca^{2+}$ + HA; (III) $SiO_2$(quartz) + $2\times H_2O = H_4SiO_4^0$; (IV) $2\times KAl_3Si_3O_{10}OH_2$(muscovite) + $2\times H^+ + 3\times H_2O = 3\times Al_2Si_2O_7\times 2\times H_2O$(kaolinite) + $2\times K^+$.

chemical and microbiological composition of the water-glacier objects within the Aktru basin [8]. In particular, it was shown that as a result of the interaction of ultrafresh acidic and weakly acidic melt waters with rocks (mostly in the ablation region, and in the near-glacier zone), the water solution produces the substrate necessary for the development of microflora. This leads to an increase in the total content of organic matter, and to the intensity of biogeochemical processes, so that the sources of the river and of its tributaries experience an increase in the values of permanganate oxidability which is a proxy indicator of the content level of organic matter and products of its transformation (see Table 3).

The aforementioned processes are taking place in the presence of the changing (along the length of the river) hydrodynamical conditions, regular and occasional fluctuations in streamflow, atmospheric air temperature, atmospheric precipitation, wind regime as well as of substantial changes in topography as a result of the endo- and exogenous geological processes, which generally determines not necessarily unambiguous changes in chemical composition and quality of surface waters.

## CONCLUSIONS

The research reported in this paper involved assessing the mean concentrations of the major ions, trace elements and biogenic and organic matter in glacial and river waters within the Aktru river basin. The study revealed a general tendency for an increase in mineralization (from the sum of the major ions) along a direction from the feeding region of the glaciers to the mouth of the river, and a relatively abrupt increase in the concentrations of Al, Zn, Cu, Pb, Si, $NO_2^-$, $NH_4^+$ and PO in the sources of the Aktru river and of its tributaries, with their subsequent decrease and/or stabilization with the movement of the river waters.

The main features of the mechanism of such changes are determined by dissolution of rocks during their interaction with melt waters in the near-glacier zone and by the formation, on the one hand, of poorly solvable organomineral compounds and clayey materials and, on the other, by accumulation in the water environment of substances contributing to the development of microflora and an enhancement of biogeochemical processes, with the water solution subsequently receiving new organic compounds and products of their transformation.

An important factor for formation of chemical composition of river waters could be represented by the processes of atmospheric transport of anthropogenic and natural-anthropogenic materials from economically developed regions. Nevertheless, the surface waters within the Aktru river basin are generally characterized, according to hydrochemical indices, as "clean", while the ecologo-geochemical state of the water-glacial objects in the area is estimated as satisfactory.

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