Hydrology and Ion Sink of the Arctic River Alazeya

V N Makarov¹, D D Nogovitsyn², Z M Sheina²

¹Geochemistry laboratory, The P.I. Melnikov Institute of Permafrost SB RAS, Merzlotnaya str., 36, Yakutsk 677010, Russia
²Department of Energy, The V.P. Larionov Institute of Physical and Technical Problems of the North SB RAS, Oktyabrskaya str., 1, Yakutsk 677980, Russia

E-mail: dmitry-nogovitzyn@yandex.ru

Abstract. The features of hydrology and flow of dissolved substances of the Alazeya River located above the Arctic Circle in the area of continuous distribution of permafrost are considered. As starting materials the results of field studies and laboratory analyses of water samples made by the complex research expedition were used. The Alazeya River in hydrological and hydro chemical relation is a little-studied river of the Arctic zone. The river basin is characterized by minimal human pressure. The territory of the Alazeya basin is one of the hard-to-reach Arctic regions of the North-East Yakutia with natural complexes. Precipitation, groundwater and underground ice of active layer and permafrost are the primary power supply of surface waters. Annually 0.5 million tons of dissolved substances are removed by the processes of fluvial denudation from the Alazeya basin to the East Siberian Sea. Module of the ion sink is very low - 6.8 tons/km². It is typical for the sluggish rivers of the Arctic regions. Minimum value is a result of the Arctic climatic and landscape parameters affecting the intensity of chemical weathering of rocks. The ion sink of the Alazeya River is almost independent from human influence and determined by the geochemical properties of elements, lithological features of rocks and soil composition of the river basin, climatic conditions, and vegetation.

1. Introduction

Rivers of the Arctic belong to one of the most untouched ecosystems around the world. Despite this, they are under the threat of global and regional anthropogenic impact [1]. The learning of causes and consequences of the climate change in the Arctic is still limited by the lack of data on hydrological characteristics of water basins [1]. In these circumstances, it becomes apparent the need to develop a sound approach to the problem of the Arctic region natural resources development that takes into account not only economic interests of the country, but also the necessity to preserve the unique natural environment [2]. The environmental studies, the role of processes related to irreversible alterations, the genesis of dangerous processes, the impact of economic activities at reception basin and riverbeds on the ecological state of the estuarial regions of rivers, freshwater bays and sinuses are becoming more acute [2]. In addition, the global warming increases problems related to the hydrology of the Arctic rivers [2]. It becomes evident that it is necessary to conduct environmental studies of the current state of vulnerable rivers in the Arctic Russia [3].
The study of the characteristics of the formation of the ion runoff of rivers in the context of global climate change and anthropogenic load has been considered in many papers by Russian scientists [4,5,6]. Works [7,8] are devoted to quantitative differences of ion flow and assessment of its anthropogenic component. Kirsta Y B, Puzanov A V [9] note that the formation of the ion discharge occurs mainly by the cations calcium Ca2+, magnesium Mg2+, sodium Na+, potassium K+, the anions bicarbonate HCO₃⁻, sulfate SO₄2⁻, chloride Cl⁻. Studies of a number of authors[10,11]are devoted to the variability of ion flow modules and the formation of hydrochemical flow of rivers in the Arctic regions of Russia. The problem of ion flow variability is also considered in [12] Abduev M A. The article considers the ionic runoff of the river of the North-East of Yakutia on the example of Alazeya. The territory of the river basin is one of the remote Arctic regions in North-Eastern Yakutia with natural complexes. The main sources of surface water supply are precipitation, groundwater and subterranean ice of the active layer and permafrost. The river Alazeya was chosen to determine the possible effects of the global warming and the anthropogenic impact.

The river in hydrological and hydrochemical relation is a little-studied river of the Arctic. Its basin is characterized by minimal anthropogenic pressure. The main goal of the study is to determine the dependence of the Alazeya ion sink on natural factors.

2. Methods and materials
In the basin of the Alazeya River the authors made a complex hydrometric and hydrogeochemical observations. As starting materials the results of field studies and laboratory analyses of water samples made during the complex research expedition were used. Methods of field works, determination, calculations, and analysis of hydrological characteristics of surface waters are performed in accordance with the guidelines developed in the State Hydrological Institute (SHI) of Goskomgidromet of the Russian Federation [13,14]. Analyses of water samples were carried out in the specialized accredited laboratory: the Central geological and analytical laboratory of state unitary enterprise of the Sakha Republic (Yakutia) - "Tsentrgeoanalitika".

3. The hydrological regime of the Alazeya River
The river basin is located on the North-East of Yakutia. It is located entirely within the Arctic Circle; it flows along the Kolyma lowlands and falls into the East Siberian Sea [15]. The largest tributaries are: Rassokha (790 km) – on the left, and Buor-Yuryakh (244 km) – on the right. For about 100 km in the upper reaches the river has a mountain character, in the lower reaches – flat, flows through the tundra zone [15]. The Alazeya River with the length of 1 590 km is formed from the confluence of the Nelkan and Kadylchan rivers on the Alazeya plateau [16]. The catchment basin area is 74,700 km² and by its size it ranks the 7th place among the rivers of Yakutia and the 27th in Russia [17]. In the basin of the Alazeya there are 3 734 watercourses and 24 391 lakes with a total surface area of 9,330 km² [17]. The surface waters of the district are concentrated mainly in the river Alazeya and numerous lakes. In the middle and the lower reaches the river is often meandered and is reported with numerous lakes through its ducts-"whiskey". Seasonal distribution of the Alazeya runoff also reflects the relatively well-regulatedness by lakes. Winter runoff (from November to April) is 4%, and for the entire limiting period (from September to April) – 20% [18]. By the presence of continuous permafrost with a capacity of up to 500 m, the value of the rivers runoff reliant on the degree of lake percentage of the catchment.

Spring flood begins on May 25-26; the maximum water consumption is formed in the last days of June, and ends on August 10-11. Thus, more than half (60%) of the Alazeya annual runoff is formed during the spring flood. In low water years the end of the flood falls at the end of July, the summer low water is observed in August-September. In high-water years with heavy rains on the flood fall it is difficult to determine the timing of its completion. In this case, the highest water consumption during the flood can be determined in the middle of the second decade of August. The maximum water levels for the year are observed on average in June-July, but in the last years they increasingly have become indicated in August-September. The rise of the water level above the minimum winter in the upper reaches of the river is 5 m, in the middle – 4.5 m, and in the lower – 2 m. In high-water years, the
water goes to the floodplain and floods settlements and a significant area of the surrounding area. The increase in the water content of the Alazeya and the sizes of floods are caused by increased rainfall.

Conditions for the runoff formation in the upper and middle reaches of the river are similar. Flow regimes and water levels of the estuarine section of the river are affected by the sea.

In view of the sparse network of hydrometeorological observations in the Alazeya basin to study the relationships between the flow value and the factors that determine it the method of regression (correlation) analysis was used. The correlation code of runoff and winter precipitation relation is 0.22, summer – 0.51, which shows much more effect on summer precipitation runoff. The analysis showed that the variability of the annual amount of precipitation is high enough. Precipitations for the warm season and the amount of runoff are more changeable. The variation of precipitation for the warm period of a year is significantly higher than the variation of precipitation for the cold period. Thus, precipitations over the warm period of a year are the determining factor of the variability of annual runoff of the river Alazeya. And also the precipitations of the warm period of a previous year have the greatest influence on the river flow.

4. Hydro chemical regime of the river

In the distribution of river water mineralization in the Asian territory of our country there is a general increasing tendency of water mineralization from North to South which is connected with greater moisture of catchments in the North with the predominance of less water-mineralizing soils (tundra, swamp, forest), and the presence of large areas of permafrost.

The chemical composition of river waters in the Alazeya basin is determined by soil-bioclimatic features and composition of rocks. The main sources of natural water supply are precipitation (237 mm/year) and subterranean ice of the active layer and permafrost layers. The anthropogenic component of the flow is minimal: practically no urbanization and low population density. In the river basin there are about 2.5 thousand people working mainly in agriculture (Table 1).

| Village     | Population, people | Economy                                      |
|-------------|--------------------|----------------------------------------------|
| Andryushkino| 732                | Agriculture (cattle breeding,                |
|             |                    | horse breeding, reindeer husbandry, fishing |
|             |                    | trade                                        |
| Argakhtakh  | 502                |                                              |
| Svatai      | 534                |                                              |
| Ebyakh      | 486                |                                              |

Mineralization of precipitation is very small - 6-11 mg/l and is 20-30% of salt composition of surface waters. Chloride-bicarbonate mainly sodium on the composition of cations rainfalls bring the bulk of marine salts – sodium chloride into the surface drain.

Fossil ice and ground sub permafrost waters are close in their chemical composition to predominantly low-mineralized hydrocarbonate magnesium, slightly acidic, with low values of redox potential and high content of ammonium and iron. Significant influence on the chemical composition of sub permafrost waters: the increasing role of manganese and ammonium, a noticeable shift of Eh values to the side of regenerative values are provided by cryogenesis processes.

The leaching of rocks and significant amounts of water contained in lakes and active layer, determine the chemical composition of river waters of the Alazeya river basin. The role of groundwater flow in the formation of salt composition of river waters is insignificant.

Throughout the river Alazeya its water remains low mineralized (23-38 mg/l), bicarbonate mixed in composition of cations with some predominance of calcium, slightly acidic, very soft (0.4-0.7 mg-eq), with high values of Eh (average 519 mV) and high content of Fe and heavy metals (Cu and Mn).
5. Research results
Ion sink is one of the components of geo flow off [19] and qualitative characteristics of hydrological, geochemical and geoeological processes in river basins. Ion sink of the Alazeya River is almost independent of human influence (if population density is about 0.033 people/km$^2$) and determined by natural factors: geochemical properties of elements, lithological features of rocks and composition of soils in the river basin, climatic conditions, vegetation.

The magnitude of ion sink of macro- and microcomponents and the variation of these indicators from the upper reaches of the Alazeya to the mouth are shown in Table 2.

| Components | Ion sink, tons per day | Distance from the estuary, km | River estuary rate, tons per year km$^{-2}$ (%) |
|------------|------------------------|------------------------------|-----------------------------------------------|
| HCO$_3^-$  | 108,9                  | 1272                         | 1376,8                                       |
| Cl$^-$     | 53,6                   | 1060                         | 612,4                                        |
| SO$_4^{2-}$ | 3,2                    | 825                          | 529                                           |
| Ca         | 7,5                    | 521                          | 44,3                                         |
| Mg         | 2,2                    | 788,1                        | 17,1                                         |
| Na         | 0,9                    | 796,4                        | 95,7                                         |
| K          | 0,91                   | 1382                         | 1,44                                         |
| Fe         | 0,33                   | 238,6                        | 0,58                                         |
| NH$_4^+$   | 0,37                   | 38,5                         | 0,25                                         |
| NO$_3^-$   | 0,7                    | -                            | 0,025                                        |
| Cu         | 0,03                   | -                            | 0,025                                        |
| Mn         | 0,014                  | -                            | 0,046                                        |
| Pb         | 0,007                  | -                            | 0,037                                        |
| Ni         | 0,007                  | -                            | 0,244·10$^3$                                 |

Annually 0.5 million tons of dissolved substances are removed from the Alazeya basin to the East Siberian Sea by the processes of fluvial denudation. The module of ion sink is very low - 6.8 tons/km$^2$, typical for lowland rivers in the Arctic regions. Minimum drain values are caused by the Arctic climatic and landscape parameters affecting the intensity of chemical weathering of rocks. Ion sink of the Alazeya is almost independent of human influence. It is determined by the geochemical properties of elements, lithological features of rocks and soil composition of the river basin, climatic conditions, and vegetation.

From the Alazeya basin (Table 2) about 0.5 million tons of substances in the dissolved form is removed annually. As a part of soluble products of denudation origin the main anion throughout the river is bicarbonate ion (66%). Among cations the main role belongs to calcium (14%) and magnesium (7%). The contribution of other macro components in the soluble drain accounts for a total of about 13%. The role of metacompontents of natural waters in the flow is quite significant: iron is about 1% and compounds of nitrogen – 0.5%. The module of ion sink of heavy metals (Cu, Mn, Pb, Ni) is in the range of n·10-3 tons per year km$^2$.

By reducing the value of ion sink the chemical components are grouped in the following line: HCO$_3^-$ > Ca > Mg > SO$_4^{2-}$ > Na, K, Cl > Fe > N (NO$_3^-$ + NH$_4^+$ + NO$_2^-$) > Cu > Mn > Pb, Ni.

The small size of the ion sink module on the river Alazeya is 6.81 t/km$^2$·year [20]. It is typical for the lowland rivers of the subarctic zone, the zone of very weak chemical denudation. The minimum
values of the flow of dissolved substances are caused by the location of the river basin in the cold and wet tundra, the widespread of low terrigenous sediments within the Kolyma lowlands, by climate and landscape parameters of the Arctic region affecting the intensity of chemical processes of dissolution and leaching of rocks, continuous distribution of permafrost rocks that restrict groundwater runoff.

The chemical flow of the river over its length is not the same. From upstream to the mouth it increases and the maximum salinity of the water and the most intense removal of chemical elements are observed in the mouth of the Alazeya (Figure 1).

Figure 1. The change in water salinity of the river Alazeya from upstream (Lip) to the mouth.

There is a spatial change in the value of ion sink reflecting the features of geological structure of the Alazeya basin. The main source of dissolved substances in the upper reaches is the Devonian carbonic carbonates, the most strongly destructible when in contact with water, and the Upper Cretaceous dacites of the Alazeya plateau, which determines a significant role in the flow of sulfates, magnesium and iron (see Table 2).

In the middle and lower reaches the Alazeya drains the upper quaternary and modern terrigenous sediments represented by sands, pebbles, sandy loam, loam, peat, subterranean ice. Here the river flows through the swampy tundra, the plain which rich in organic matter. Abundance of organic matter (peat, plant residues) and stagnant mode provide a weakly reductive environment. On this stretch of the river there is a kind of "tundra" geochemical barrier: organic and possibly mechanical (associated with a slight decrease in the velocity of the river). The impact of the tundra barrier affects the decrease in the ion sink of a number of macro- and micro components, and the most intense for heavy metals - lead and nickel, and minimal for hydro carbonates (in brackets the value of ion sink reduction on the geochemical barrier, %): Pb(49)>Ni(30)>SO_4^{2-} (7)>Cu(6)>HCO_3^{-} (2).

6. Summary
The increase in the water content of the Alazeya River and the size of floods are caused by the growth of precipitations. The variation of precipitation during the warm season is much higher than the variation of precipitation during the cold period. Thus, precipitation during the warm period of a year determines the variability of the river annual flow. In addition, the flow of the river depends on the amount of precipitation during the warm period of a previous year.
Ion sink of the Alazeya does not depend on anthropogenic influence (if the population density is about 0.033 people/km²) and is determined by natural factors: geochemical properties of elements, lithological features of rocks and composition of the river basin soils, climatic conditions, vegetation.

The minimum values of the dissolved substances flow are caused by the location of the river basin in the cold and wet tundra, the widespread within Kolyma lowlands of low terrigenous sediments, climatic and landscape parameters of the Arctic region, affecting the intensity of chemical processes of dissolution and leaching of rocks, continuous distribution of permafrost rocks that restricts groundwater flow. The chemical flow of the river over its length is not the same. From the upper reaches to the mouth it increases and the maximum water mineralization and the most intense removal of chemical elements are observed at the mouth of the Alazeya.

References

[1] John E Brittain, Ludmil G Khokhlova, Kjetil Melvold, Angelina S Stenina, Gisli M Gislason, Sturla Brørs, Sergei K Kochanov, Jon S Olafsson, Vasily I Ponomarev, Arne J Jensen, Alexander V Kokovkin and Lars-Evan Pettersson 2009 Arctic Rivers. Rivers of Europe pp 337-79
[2] Gudmestad O T 2015 Hydrology of Arctic Rivers Ecology and Environment River Basin Management YII 225 pp 225-34
[3] Bryzgalo V A, Tretyakov M V, Rumyantseva E V, Shestakova E N and Muzhtaba O V 2018 Problems of the Arctic and the Antarctic Regions 4 vol 64 pp 365-79
[4] Ushakov M V 2012 Water: Chemistry and Ecology 10 pp 17-20
[5] Tairov A Z 2015 Questions of geography and geocology 1 pp 67-71
[6] Savichev O G 2004 News of Tomsk Polytechnic Institute 6 vol 307 pp 40-44
[7] Kolmakova E G Features of the processes of transformation of the ion flow of the rivers of the Neman River basin under conditions of anthropogenic load URL: http://elib.bsu.by/handle/123456789/178811
[8] Parfenova G K 2010 Anthropogenic changes in hydrochemical indicators of water quality Tomsk: Agraf Press 204 p
[9] Kirsta Yu B, Puzanov A V 2018 Polzunovsky Almanac 4 pp 113-6
[10] Potapova T M, Mysina O S 2017 Geochemical runoff of the rivers of the Arctic zone of Western Siberia Proc.the proc. Modern problems of geography and Geology: the 100th anniversary of the opening of the natural branch in Tomsk state University (Tomsk) pp 383-7
[11] Romanov S G, Markov M L, Potapova T M 2018 To the question of hydrochemical flow formation of rivers in the polar regions of Russia On Sat Third grape readings The verge of hydrology Collection of reports of the international scientific conference in memory of the outstanding hydrologist Yuri Borisovich Vinogradov Edited by O.M. Makarieva pp 127-131
[12] Abduev M A 2014 Russian Meteorology and Hydrology 7 vol pp 3943-490
[13] 1978 Manual to hydrometeorological stations and posts vol 6 Part 1 (L. : Gidrometeoizdat) 384 p
[14] 1972 Manual hydrometeorological stations and posts Issue 6 part 2 (L. : Gidrometeoizdat) 251 p
[15] Gotovtsev S P, Kopyrina A P, Efimova A P, Zakharova V I, Nogovitsyn D D, Poryadina L N, Zabolutnik P S, Syromyatnikov I I, Ivanova A Z., Egorov N N., Desyatkin R V., Okhlopkov I M, Ivanova E I, Mikhailova L G, Kirillin E V, Gabyshcheva O I, Salova T A and Kilmyaninov V V 2018 Cryo-ecosystems of the Alazei river basin (Novosibirsk, Geo) 211 p
[16] 1966 Surface water resources Hydrological knowledge T 17 Leno-Indigirsy vol 7 (L., Gidrometeizdat) 328 p
[17] Arzhakova S K, Zhirkov I I, Kusatov K I and Androsov I M 2007 Rivers and lakes of Yakutia: short / right Edited by V I Ageev (Yakutsk: Bichik) 136 p
[18] Makarov V N, Nogovitsyn D D, Kilmyaninov V V 2010 Science and Education 157 84-90 p
[19] Paromov V V, Savichev O G, Shantykova L N and Torgasheva T A 2014 Bulletin of Tomsk State University 383 226–31 p
[20] Makarov V N 2018 Ionic flow of the Arctic River Alazey On Sat Third grape readings The verge of hydrology Collection of reports of the international scientific conference in memory of the outstanding hydrologist Yuri Borisovich Vinogradov Edited by O.M. Makarieva pp 86-91