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The genetic structure of the chloride ion runoff on the example of karst and non-karst geosystems of Arkhangelsk oblast

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Abstract. This paper deals with the estimate the structure of the chloride ion runoff from the karst (on the example of the Sula river basin) and non-karst (on the example of the Vaga river basin) geosystems of Arkhangelsk oblast. The contribution of the surface component predominates in the structure of the chloride ion runoff. For example, the input of surface ion runoff is 49% (for the Sula river basin), 55% (for the Vaga river basin). In time aspect the highest values of variability of the components of the chloride ion runoff are noted for karst geosystems and vary from 38.5% to 55.4% and from 24.7% to 42.9% – for non-karst geosystems. Finally, there is prevalence of the local factors influence because the atmospheric component decreases while ion runoff increases.

1. Introduction

Quantitative indicators of natural-anthropogenic geosystems can reflect the anthropogenic intensification of geochemical cycles of elements.

So, the ion runoff reflects the geosystems state. Moreover, the assessment of its genetic components helps to assess the factors of its formation. The chloride ions (in particular, highly mobile water migrants) are the most indicative ions.

Entirely, the investigated rivers are located in different natural and anthropogenic conditions.

So, the Sula river basin has an area of 8500 km². As a rule, the river basin is located in the closest proximity to the Barents Sea (100 km) within the tundra zone. Groundwater of the river basin belongs to the fractured waters of Canino-Timan basin. On the one hand the middle annual precipitation is less than 400 mm, on the other hand 300 mm evaporates. The middle annual air temperature is 1.5°C, and the relative humidity is 85%. The middle height of the river basin is 97 m, the middle slope is 0.94%. The forest cover is 35%, bogging is 1%.

The Vaga river basin has an area of 1410 km². The river basin is the most remote from the Onega Bay, the distance is 400 km. The river basin is located within the Onego-Vagsky protrusion of the northern part of the Moscow syneclyse. Moreover, river basin drains the Permian rocks of the Sukhona horizon represented by dolomites, marls, clays. The middle height of the river basin is 172 m. 550 mm of precipitation falls out every year, 350 mm evaporates. The middle annual air temperature is about +2 °C, relative humidity is 70%. The forest cover is 84%, bogging is 5% [1].

Actually, river basins are characterized by a low proportion of groundwater feeding (to 27%) as a result of the influence of both climatic (the presence of permafrost rocks and taliks in the Sula river basin) and geological factors [2, 3].



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The aim of research is to estimate the space-time variability of the structure of chloride ion runoff in the basins of the Sula and the Vaga rivers.

There is a number of problems:

1. Estimation of the atmospheric, underground and surface component of chloride ion runoff of the Sula and the Vaga river basins.
2. Analysis of space-time variability of the structure of chloride ion runoff.

2. Material and methods

The paper based on the materials of the Northern Department for Hydrometeorology and Environmental Monitoring of meteorological stations in the cities of Belozersk and Naryan-Mar and hydrological posts on the Vaga river (Gluboretskaya village) and the Sula river (Kotkina village) for the period from 1978 to 2007.

The methodology is based on the balance equation (1), proposed by V.P. Zverev (1971):

$$W_{\text{total}} = W_{i,\text{atm}} + W_{i,\text{underground}} + W_{i,\text{surface}} + W_{i,\text{accum}}, \quad (1)$$

where W_{total} – the total ion runoff; $W_{i,\text{atm}}$ – the ions of atmospheric precipitation supply; $W_{i,\text{surface}}$ – the surface ion runoff; $W_{i,\text{underground}}$ – the underground ion runoff; $W_{i,\text{accum}}$ – the ion accumulation in the surface horizons of the drainless regions (according to V.P. Zverev (1971) for the river basins of the Barents Sea and the White Sea this index is zero) [4].

The ions of atmospheric precipitation supply ($W_{i,\text{atm}}$) are calculated using the coefficient of runoff calculated by formula (2):

$$W_{i,\text{atm}} = n \cdot \frac{C \cdot S}{10^3}, \quad (2)$$

where S – the amount of atmospheric precipitation, mm, C – the ion concentration of atmospheric precipitation, mg/l, n – the runoff coefficient calculated by formula (3):

$$n = \frac{h}{S}, \quad (3)$$

where h – the layer of water flow from the territory of the river basin for the hydrological year, mm; S – the amount of atmospheric precipitation falling on the territory of the river basin for a hydrological year, mm [5-9].

The underground ion runoff was calculated by the formula (4):

$$W_{i,\text{underground}} = \frac{k \cdot a \cdot C_{\text{winter}} \cdot W_{\text{water}} \cdot 1000}{F}, \quad (4)$$

where k – the proportion of underground water runoff [4, 5]; a – a correction coefficient defined as the ratio of the middle long-time water flow for hydrological year to the water flow for particular year; C_{winter} – the ion concentration during the winter low water period when the minimum water flow rates are known, mg/l; W_{water} – total water flow in this hydrological year, km³; F – the area of the river basin above the hydrological post, km² [10-14].

The total ion runoff was calculated by the formula (5):

$$W_{\text{total}} = \frac{\sum_{i=1}^n (Q_i \cdot C_i) \cdot a \cdot W_{\text{water}} \cdot 10^3}{F}, \quad (5)$$

where C_i, Q_i – the ion concentration (mg/l) and discharge (m³/s) on the day of taking a water sample; n – number of samples per year [15-17].

Surface ion runoff was calculated using formula (6):

$$W_{i,\text{surface}} = W_{\text{total}} - (W_{i,\text{underground}} + W_{i,\text{atm}}), \quad (6)$$

The variability of ion concentrations in water and water discharge depends on an exponential law (figure 1a).

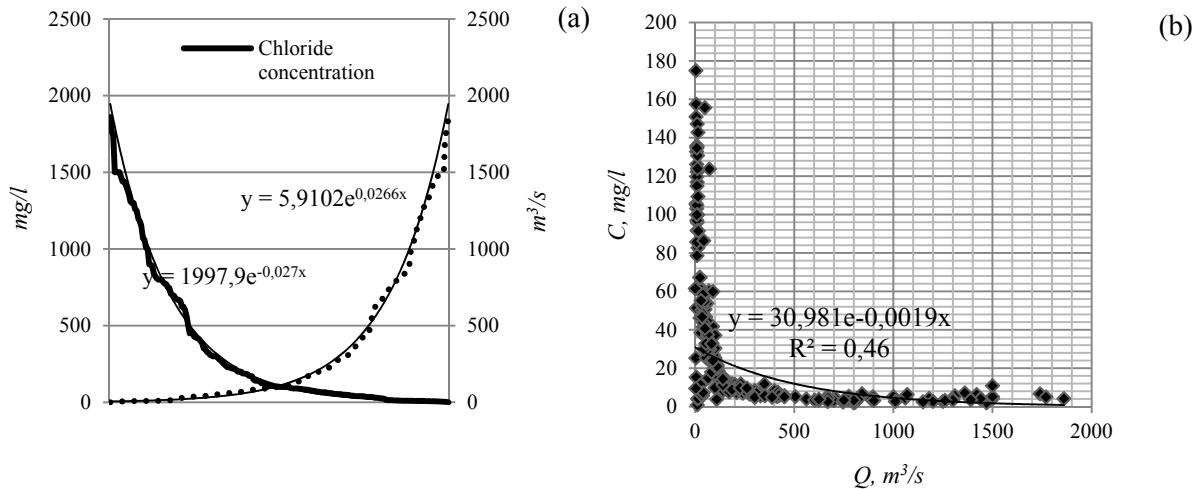


Figure 1. Exponential variability of the chloride ion concentration and water flow on example of the Sula river – Kotkina village (1978 - 2007) (a); the graph of the dependence of the chloride ion concentration on the discharge on example of the Sula river – Kotkina village (1978 - 2007) (b).

The determination the ion concentration C_{winter} when the discharges of deep winter low period are known was realized by constructing the exponential dependence $C = f(Q)$ on the basis of known concentrations and discharges for the all period (figure 1b).

3. Results and discussion

There is the domination of the surface chloride ion runoff formed as a result of elution of ions by thaw and storm water from soil horizons (figure 2)

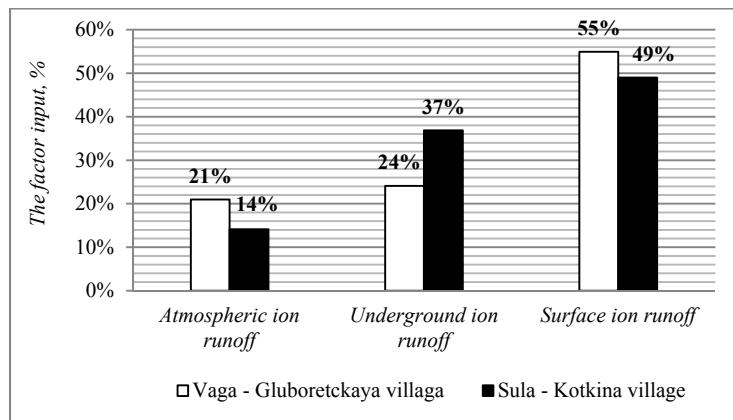


Figure 2. Genetic structure of chloride ion runoff within the basins of the Vaga river and the Sula river (1978-2007).

So, the input of surface chloride ion runoff to chloride ion runoff of the Vaga river is 55% (or 700 kg/km²), and of the Sula river – 49% (or 4253 kg/km²) for the middle long-term period.

The Sula river basin is karst therefore the underground component of chloride ion runoff is high (37% or 2936 kg/km²). Conversely, the atmospheric component of chloride ion runoff is 14% (1121 kg/km²).

Moreover, the underground component of chloride ion runoff of Vaga river basin is 24% (297 kg/km²) because the river basin is composed of aquitard morainic loams (figure 2).

The atmospheric component is almost equal to the underground component of chloride ion runoff and is 21% (266 kg/km^2).

Primarily, the variability of the components of the chloride ion runoff within the karst geosystem is higher. Statistically, the coefficient of variation fluctuates from 38.5% to 55.4% within the Sula river basin (table 1).

Table 1. Coefficient variation (in the numerator) and coefficient k of the linear trend (in the denominator) of time variability of structure of chloride ion runoff

River basin	Components of chloride ion runoff			Ion runoff
	Atmospheric	Underground	Surface	
Sula – Gluboretckaya village	<u>55.4%</u> -40.35	<u>46.9%</u> -6.53	<u>42.5%</u> 42.16	<u>38.5%</u> 28.09
Vaga – Kotkina village	<u>24.7%</u> -33.94	<u>42.9%</u> 3.97	<u>31.4%</u> -131.58	<u>35.1%</u> 16.68

The maximum values are noted for the atmospheric component. Conversely, the minimum values are fixed for the surface component.

The coefficient of variation varies from 24.7% to 42.9% within the Vaga river basin. There is the minimum variability of the atmospheric component of chloride ion runoff, the maximum is observed for underground component.

Primarily, the most fixed increase in the multi-year variability of the components of the chloride ion runoff of the Sula river basin is noted for the surface component (k of the trend line is 42.16) (figure 3, table 1).

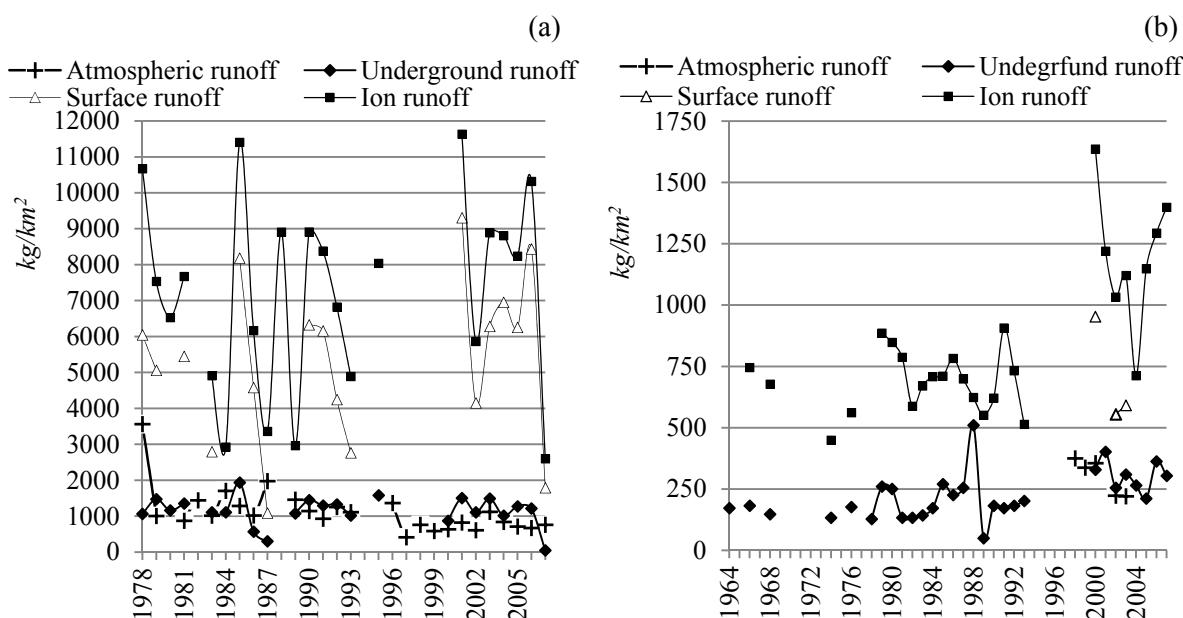


Figure 3. Dynamics of variability of the components of chloride ion runoff of the Sula river (a) and the Vaga river (b)

Conversely, there is significant decrease for the atmospheric component ($k = -40.35$). A small decrease is also fixed for the underground component ($k = -6.53$). This fact is connected with the comparative isolation of groundwater from the external factors. Broadly speaking, in the multi-year aspect the increase is recorded for the total ionic runoff ($k = 28.09$). It indicates a significant influence of the surface component of ion runoff.

Secondly, there is an increase ($k = 16.68$) for the total chloride ion runoff for the Vaga river. There is also a small increase ($k = 3.97$) for the underground component.

The other components are characterized by a significant decrease. So, $k = -33.94$ for the atmospheric component, $k = -131.58$ for the surface component because there is a short observation period.

In time aspect the highest values of variability of the components of the chloride ion runoff are noted for karst geosystems. There is prevalence of the local factors influence because the atmospheric component decreases while ion runoff increases.

Finally, the ion runoff consists of atmospheric, underground and surface components. Surface (soil) component of chloride ion runoff is the main factor of chloride ion runoff formation. In time aspect, there is the maximum variability of values of components of chloride ion runoff for karst river basins.

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