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Sodium Balance Structure within the Elementary Geosystems (by the Example of Basin of the Elva River in the Komi Republic)

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ABSTRACT

The evaluation of the sodium ionic balance by the example of the little-developed area of the Elva River basin in the Russian Federation has been performed in the present research. It has been established that the main role in the element circulation belongs to the lithogenic base due to prevalence of the freely-soluble rocks composing the basin. The contribution of the atmospheric precipitations to the ion delivery and removal within the catchment area is insignificant and makes about 20% which is related to remoteness of the area from the large industrial centers and areas of the seas. It has been discovered that the plant industry plays a small part in the sodium circulation. In general, the anthropogenic transformation of the sodium circulation is primarily associated with the animal industry facilities due to the cattle-feeding with NaCl.

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INTRODUCTION

As of today intensification of the anthropogenic activities has caused biogeochemical disbalance of many elements. Thus, sodium as an element featuring high migration capacity does not stay in the intermediate media and is accumulated in the terminal basins determining the open circulation of the element. As a consequence, sodium is used as one of the main indicators of the environmental status. Being an active water migrant, it is able to enter into many links of the biogeochemical circulation as well as to be easily removed from the terrain. That is why studying the ways of migration of the specified element in the environmental conditions and as the result evaluation of the aggregated sodium balance within the elementary geosystems still remains relevant [1-4]. It is worth mentioning the attempt of evaluating the elements balance within the basin geosystems by the example of nitrogen [5-8] performed on the basis of the "Method of calculating the biogenic substances removal and assessment of the future headwater septic condition" developed by the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus [9].

In the present research the emphasis is made on input and output removal the central link of which is the river basin itself. Within the calculations the data on the ecosystem spatial structure determining the ion redistribution within the basin were used.

The objective of this work is the assessment of sodium balance components within the basin of the Elva River for the years 2000-2007.

In order to achieve the objective stated the following task complex was solved:

- 1) Estimation of the annual values of the sodium ion delivery with the atmospheric precipitations, mineral fertilizers applied to the agricultural areas, from the settlement waste pits and results of the livestock breeding complexes performance.
- 2) Estimation of the annual values of the ion removal due to the surface and groundwater runoff and due to the sodium removal through agricultural yield as well as through deposition of the element in the forest, moor vegetation and peat.
- 3) Evaluation of the sodium balance within the catchment area.

The basis of this research consists of information on the hydrological-hydrochemical station located at the basin of the Vychedga River (Elva River – Meschura village) as well as observation data from the background meteorological station Ust-Vym located in immediate proximity (data collected during 2000-2007). Besides, the materials of the "Reports on the environmental status and protection in the Komi Republic in the years 2000-2007" [10] as well as the data of the State Statistics Committee of the Komi Republic have been used [11].

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Methodology:

The evaluation of the sodium ion balance was performed on the basis of extraction of the input and output components in respect of the particular geosystem. In general terms the sodium balance equation within the water catchment area represents the difference between the input and output items:

$$B = B_{\text{input}} - C_{\text{output}}, \quad (1)$$

The input item consists of the following components:

$$B_{\text{input}} = B_{\text{rock}} + B_{\text{atm}} + B_{\text{fert}} + B_{\text{human}} + B_{\text{anim}}, \quad (2)$$

where: B_{rock} – number of the sodium ions of lithogenous origin delivered during the year, t;

B_{atm} – number of the sodium ions delivered to the catchment area together with the atmospheric precipitations per year, t;

B_{fert} – number of the sodium ions delivered to the agricultural areas within the catchment basin together with mineral fertilizers, t;

B_{human} – number of the sodium ions formed within the residential areas (waste pits), t;

B_{anim} – number of the sodium ions formed within the livestock breeding complexes, t.

The output item of the balance indicating removal of the analyzed ions from the terrain and delivery to the rivers consists of the following components:

$$C_{\text{output}} = C_{\text{ionic runoff}} + C_{\text{ID underground}} + C_{\text{crop}}, \quad (3)$$

where: $C_{\text{ionic runoff}}$ – number of the sodium ions removed by the surface flow from the basin area, t;

$C_{\text{ID underground}}$ – number of the sodium ions removed for the underground flow from the basin area, t;

C_{crop} – removal of the sodium ions together with the agricultural yield, t.

The amount of sodium falling on the catchment area together with the atmospheric precipitations was determined with respect to each month as the amount of precipitations multiplied by the sodium ion concentration:

$$M = \frac{S_i \cdot C_i}{10^3}, \quad (4)$$

where M – sodium ion precipitations module, t/km²;

S_i – amount of precipitations, mm;

C_i – concentration of the sodium ions in precipitations, mg/l.

The annual values of the sodium precipitations were calculated as the total amount of the monthly precipitations.

The amount of the fertilizers introduced (equivalent to sodium) was determined according to the land balance sheet account form based on the data from the State Statistics Committee of the Komi Republic for the years 2000-2007 and was calculated according to the formula (5). By doing so it was taken into consideration that sodium enters into the soils with the potassium and nitrogen fertilizers.

$$F = \frac{(k_1 \cdot a_{K_2 O} \cdot M \cdot b \cdot S) + (k_2 \cdot a_N \cdot M \cdot b \cdot S)}{10^3}, \quad (5)$$

where F – number of the sodium ions delivered to the water catchment with the mineral fertilizers, t;

k_1 – coefficient indicating the delivery of sodium with potassium fertilizers [12];

k_2 – coefficient indicating delivery of sodium with nitrogen fertilizers [12];

$a_{K_2 O}$ – potassium fertilizers share in the mineral fertilizers composition;

a_N – nitrogen fertilizers share in the mineral fertilizers composition;

M – amount of mineral fertilizers introduced into the fields, kg/ha;

b – share of the agricultural field area treated with the mineral fertilizers in the present year;

S – agricultural fields area within the water catchment, ha.

It should be mentioned that according to the "Procedure for the removal estimation..." [9] we have taken into account the mineral fertilizers entered into the soil during the present year and besides that those remaining in the geosystem after application in the previous year.

The value of the sodium ion removal by the river flow was calculated according to the formula:

$$W_{\text{ID}} = \frac{\sum_{i=1}^n (Q_i \cdot C_i)}{\sum_{i=1}^n Q_i} W_{\text{water}} \cdot 10^3, \quad (6)$$

where C_i and Q_i – ion concentration (mg/l) and water consumption (m³/sec) as of the sampling date;

W_{water} – liquid flow volume per year (km³);

n – number of samples per year.

The annual liquid flow (W_{water}) was calculated as the total amount of the daily water volumes within the specified river station during all the hydrological seasons of the year [13-15].

The assessment of the lithogenous component in the ion balance ($W_{\text{ID underground}}$) was performed on the basis of the values of ion concentration in the river water during the winter runoff flow period and was calculated according to the formula (7) [16, 17]:

$$W_{\text{ID underground}} = k C_{\text{mean water}} W_{\text{water}} \cdot 10^3, \quad (7)$$

where $W_{\text{ID underground}}$ – underground (lithogenous) component of the ion runoff from the basin area, t;

$C_{\text{mean water}}$ – concentration of the sodium ions in the river water during the winter runoff low period, mg/l;

k – share of the underground component in the annual liquid flow (for the basin of the Vychegda River $k = 0.27$ [18]).

W_{water} – annual liquid flow within the specified river station, km³.

Ionic runoff by the surface flow ($W_{\text{ionic runoff}}$) is calculated according to the following formula (8):

$$W_{\text{ionic runoff}} = W_{\text{ID}} - W_{\text{ID underground}}, \quad (8)$$

The value of the sodium removal with the vegetative weight of the agricultural crops (B_y , kg/year) was determined according to the formula (9):

$$B_y = \sum_{j=1}^n C_j \cdot Y_j, \quad (9)$$

where C_j – sodium content in the j -th crop, kg/centner;

Y_j – capacity of the j -th crop, centner;

F_j – area occupied by the j -th crop, ha;

n – number of the crops.

Within the investigated area the podzolic soils are mostly common, some kinds of boggy and water-logged soils are also to be found. The main cultures cultivated here are represented by potatoes and field vegetables (white cabbage, carrot, beetroot) in respect of which the values of the sodium removal make 0.028 and 0.055 kg/centner of the main products, respectively [19].

Deposition of ions by flora and bog peat reflects the removal of the element from the circulation and equals to the annual true biomass buildup. The value of the ion deposition by the forest and marsh ecosystems was determined on the basis of the methodology for evaluation of dynamics and biological cycle in plant communities developed by L. E. Rodin, N. P. Remezov and N. I. Bazilevich [20]. Thus, by estimation of the sodium deposition in the forest biomass the figures of the ion consumption by different species of woods as well as information on the composition of the forest and bog plant communities have been used.

The difference between the amount of the element formed within the catchment area as well as delivered with the atmospheric precipitations and removed from the specified area represents the indicator indicating peculiarities of its balance.

Main part:

Following the calculations performed there has been discovered the non-uniformity of the sodium ion balance structure as well as its temporal variability which is caused primarily by exposure to the natural factors within the basin under review.

In respect of the spatial aspect the areas prevailing within the basin are covered with the forest- and wetlands occupying 98% of the area in total (2635 km²). Only 2% of the basin area fall at the natural-anthropogenic and anthropogenic complexes, namely – agricultural lands and populated areas occupy 32 and 21.5 km², respectively. Thus, the conditions within the catchment of the Elva River are the most favorable ones for the natural dynamics of such active water migrants as sodium cations.

As it was noted before the body components of the sodium balance are the input item consisting of the lithogenous income, atmospheric precipitations and supply of the element with mineral fertilizers and excrements as well as the output component which in its turn consists of the surface-groundwater (surface) and underground runoff and crops yield. The annual ionic deposition by the plant communities within the catchment area represents the number of ions removed from the circulation within the basin.

In terms of the natural component of the ionic balance the leading positions belong to the lithogenous delivery of ions. In respect of the average long-term aspect their contribution makes 670 kg/km² or 48.62% (Fig. 1).

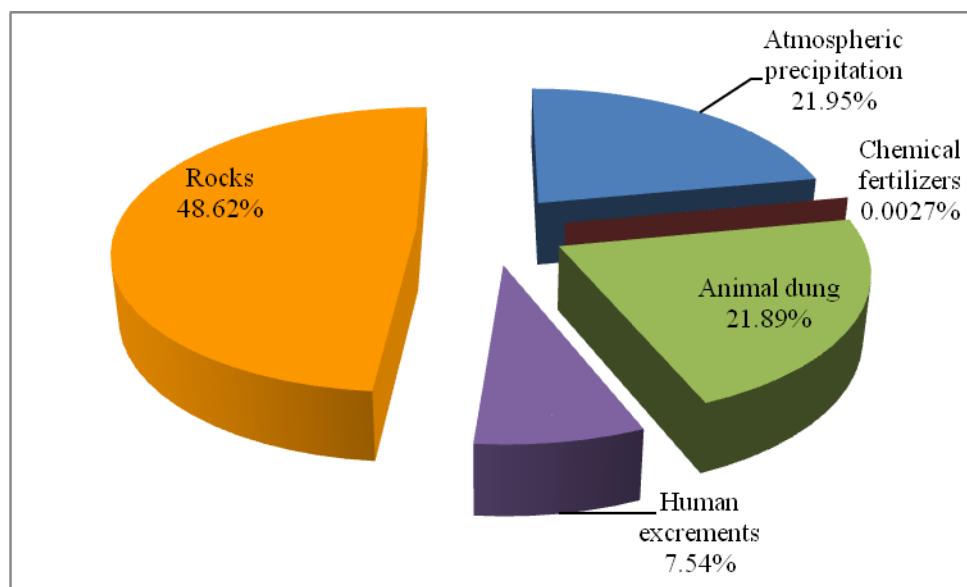


Fig. 1: Structure of the input item of the sodium ionic balance of the Elva River (for the years 2000 – 2007).

The next in order of importance is delivery of the ions to the water catchment with the atmospheric precipitations. Thus, for the average period of 2000-2007 about 302 kg/km^2 of sodium ions were delivered with the atmospheric precipitations which is equivalent to 21.95% of the natural component of the ionic balance (Fig. 1). Such insignificant contribution is due to the area location at considerable distance from the main sources of delivery of the analyzed element to the atmosphere – the areas of the seas and industrial hubs [21, 22]. Thus, the distance to the nearest seaside makes about 450 km while the major portion of the sea aerosols falls within the first 10 km [23]. Besides, the Ust-Vym meteorological station belongs to the “cleanest” in the region under consideration and is the background one.

As the result of operation of the livestock-breeding complexes there is delivery of about 300.9 kg/km^2 of the investigated element which takes place due to the daily introduction of the additional source of sodium – NaCl – into the livestock’s diet. Thus, from 10 to 100 g of the above-mentioned salt may fall per head of livestock per day depending on the animal specimen [24]. Because of the livestock reduction the sodium delivery to the catchment shranked by half - from 454.9 kg/km^2 (in 2000) to 243.8 kg/km^2 (as of the end of the period under review) (Table 1).

Table 1: Structure of the sodium ionic balance within the basin of the Elva River in 2000 – 2007, kg/km^2

Years	Input of balance					Output of balance		
	Atmospheric precipitation	Chemical fertilizers	Cesspool	Livestock farms	Rocks	Ionic runoff	Underground ionic drain	Crop yields
2000	188	-	-	454.9	628.6	769.3	628.6	0.539
2001	366	-	105.1	-	482.6	-	482.6	-
2002	163	0.099	105.1	356.5	682.5	690.5	682.5	0.731
2003	222	-	106.0	297.1	576.5	729.2	576.5	0.779
2004	269	0.042	105.0	271.9	765.5	670.9	765.5	0.516
2005	385	0.006	103.0	254.1	705.0	598.7	705.0	0.474
2006	395	0.012	101.3	228.1	663.6	1235.1	663.6	0.429
2007	427	0.026	99.7	243.8	842.5	949.2	842.5	0.427
The mean	302	0.037	103.6	300.9	668.4	806.1	668.4	0.556

It should be noted that the delivery of ions together with the atmospheric precipitations in terms of time features multi-directionality while the livestock number maintains the tendency to reduction during the investigated period (Table 1).

Sodium delivery from the waste pits of the populated areas makes 103.6 kg/km^2 or 7.5% of the natural component (Table 1, Fig. 1).

As it was noted before, the farmland occupies 1.2% of the basin area which actually determines the insignificant contribution to the natural balance component. Thus, according to the estimates for the period under review, only 0.037 kg/km^2 of sodium are introduced together with the mineral fertilizers (Table 1).

The structure of the output component of the balance is not uniform. In respect of the average long-term aspect (2000 – 2007) the prevalence of the sodium removal with the surface flow due to weathering of the soil-earth cover was observed [25]. In this case the about 806.1 kg/km^2 of sodium are removed annually which makes 54.7% of the output balance component.

Such high rates of the ionic runoff are primarily related to the flushing water regime specific to the investigated middle-taiga subzone predetermining, in its turn, the active sodium ion removal from the entire water catchment area. Besides, due to the longitudinal positioning of the river valley against the geologic structures constituting the Timan Ridge the sustainable groundwater feed of the river is to be observed. That conditions free drainage of the lithogenous section of the basin and as a result active ion removal by the underground runoff due to leaching out.

According to the estimates, only 0.556 kg/km^2 of sodium (0.04%) are removed from the element circulation within the basin together with the crops yield 0.556 kg/km^2 натрия (0.04%) (Table 1).

Besides, due to the annual true biomass buildup about 32.8 kg/km^2 of sodium are deposited within the plant communities the 29 kg/km^2 of which fall at the forestry, 3.8 kg/km^2 – at wetlands.

In general, the active ion removal observed at the water catchment area takes place to their high migration capacity as well as flushing water regime of the investigated region near the southern offshoot of the Timan Ridge with the developed karst.

Findings:

Thus, it can be summarized the following:

- 1) about 1.9 million kg/year of sodium ions are delivered to the water catchment area during the period under review the main sources thereof are rock formations, atmospheric precipitations, mineral fertilizers and excrements formed within the populated areas and livestock-breeding complexes;
- 2) the atmospheric precipitation contribution to the natural component makes about 22% which is associated with the remoteness of the investigated area from the main environmental sources of sodium (the areas of the seas, industrial hubs with the developed paper and paperboard industry, etc.);
- 3) ion delivery to the water catchment area is to the amount of 30% determined by the anthropogenic impact as the result of the sodium delivery from the waste pits of the populated areas as well as the result of operation of the livestock breeding complexes and application of mineral fertilizers;
- 4) the output component is primarily related to the surface runoff integrating the flow of ions of the atmospheric and soil-and-earth origin when about 806.1 kg/km^2 of ions are removed annually while the underground runoff makes around 668.4 kg/km^2 ;
- 5) the contribution to the element input and output as the result of operation of the agricultural facilities is insignificant, thus, about 0.037 kg/km^2 of sodium per year are introduced with mineral fertilizers while 0.556 are removed during harvesting;
- 6) sodium deposition by the plant communities occupying around 98% of the basin area makes 32.8 kg/km^2 which is determined by the selective and insignificant absorption of the analyzed ion by biota.

Thus, the soil-lithogenous component is the main source of the sodium ions within the investigated basin due to prevalence of the karsting rocks and insignificant anthropogenic use of the water catchment area.

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