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Environmental Assessment of the Content of Trace Elements in the Components of the Ecosystem of the Vilyuy Region of Yakutia

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Abstract

The article analyzes the content of chemical elements in the main abiotic components of the ecosystem and a group of chemical elements and their compounds that determine the development of microelementosis and affect the health of the population of the Vilyuysky district of Yakutia.

The biomaterial was analyzed on the basis of a combination of two methods of atomic absorption and emission spectrometry with inductively coupled plasma and with the determination of the content of total and mobile forms of trace elements.

During the research, it was concluded that the health of the population is affected by the accumulation of mobile forms of trace elements, which are genetically inherited from the underlying rocks and accumulate in the main abiotic components of the ecosystem. Fe, Al, Si, Ti make up the groundmass and structure of aluminosilicate minerals. Na, K and Li together with Cl are the main components of mineral salts used for food. Ca and Mg are alkaline earth elements that are the main components of the Mesozoic carbonate rocks and are widely distributed throughout the Vilyuy region of Yakutia. (**International Journal of Biomedicine. 2020;10(3):281-286.**)

Key Words: microelementoses • eco-dependent diseases • alases • cryogenic soils

Introduction

The supply of chemical elements from the external environment to the human body, through the food chain, is a system-forming factor of vital activity and homeostasis of the body. At the same time, the influence of the environment on the content of macro- and trace elements in the human organism makes it possible to consider the "elemental portrait" of a person from the standpoint of its eco-dependence.

In the conditions of technogenic transformation of the biosphere, it is important to conduct a comprehensive study of especially dangerous biogeochemical endemic diseases of animals and humans, their genesis, evolution, and the forecast of their manifestation because of natural disasters and anthropogenic factors.[(1)] It is well known today that the imbalance of vital elements and the accumulation of toxic concentrations of chemical elements in the body of animals and humans depend on their genetic basis and local biogeochemical cycles, which are determined by the processes of rock weathering, accumulation and migration in soils and vegetation, as well as anthropogenic factors.

In recent years, biomonitoring population studies of the elemental status of the population have become a promising and relevant trend that is being actively developed around the world.[(2-16)]

Despite the high level of modern research, the biogeochemical panorama of the Republic of Sakha (Yakutia) (RS(Y)) is insufficiently studied, which is primarily due to its vast territory and sparse human population. Some studies of the status of trace elements in children and adults indicate pathological conditions related to an excess, deficiency or imbalance of trace elements in the human organism by the example of the cities of Yakutsk and Mirnyj, as well as small localities in northern and southern Yakutia.[(17-19)] At the same time, the identification of the relationship between the chemical composition of the human environment and the health indicators of the population is occasional.[(20-23)] As a result, there is a lack of reliable information about the prevalence and intensity of many endemic diseases of biogeochemical origin, which include microelementosis.

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The purpose of the research was a geoecological analysis of the state of the main abiotic components of different types of ecosystems in the middle-taiga landscape zone of the territory of the middle course of the Vilyuy river, and identification of marking groups of chemical elements that determine the development of microelementoses and affect the health of residents of the Vilyuy region of Yakutia.

Materials and Methods

The material was collected in the period 2001-2018 within the framework of various thematic works carried out by SRIAE NEFU, MI NEFU, DPMGI SB RAS. To identify what is genetically inherited from the underlying rocks, accumulated in different environments, and enter the human body, the following schemes were developed: soil-bottom sediments – natural waters –hydrobionts (fish) and soil – natural waters – vegetation. The developed schemes were tested during the research of the territory of small settlements in the middle reaches of the Vilyuy river.[20] This territory is the starting point of the food chain, where the flow of mineral components, which are consumed by animals and humans, is formed. The basis of these schemes, which determines the geochemical specifics of the ecosystem as a whole, are the underlying rocks and soils.

Chemical, physical-chemical, and agrochemical and agrophysical properties of soils were determined by standard methods in laboratories ISSA SB RAS, SRIAE NEFU, "Yakutskgeologia" JSC. Generalization and interpretation of the data of chemical and analytical studies was performed in the laboratory of metallogeny DPMGI SB RAS.

The multilevel analysis of the absolute content of trace elements in bioassays and samples of soils, bottom sediments, and surface waters was performed using an atomic absorption spectrometer ICE3500 ThermoFisheScientific (USA) and an emission spectrometer with inductively coupled plasma iCAP 6300 ThermoScientific series for the content of gross and mobile forms of trace elements.

Hair samples were taken from children aged 5 to 8 years in 13 settlements located in the studied territory as the objects of the elemental profile study. Hair sampling was carried out by MI NEFU employees in the period 2001-2015.

For analysis, the hair was cut from several (3-5) sections of the occipital part of the head, closer to the neck; the length of the hair was 2-4cm, and the mass of the total weight (one sample) should be within 100-300mg. The hair was placed in special bags, then in envelopes with identification records.

Before mineralization, the hair samples were processed in acetone (high purity, Khimmed, Russia) 10–15 minutes, then washed three times with deionized water (18 MOm•cm); The deionized water was obtained by an electric distiller with combined membrane set DVS-M/1HA-1(2)-L (Mediana-Filtr, Russia). After that, the samples were kept at a temperature of 60° C until they reached air-dry condition.

Weight portions of samples 0.1g were mineralized in Teflon liners with 2ml H_2O_2+8ml HNO_3 (high purity, Khimmed, Russia) in the system HotBlock for 1 hour at a temperature of 120^0 C until the sample was completely dissolved. The resulting solutions were cooled to 45^0 C and quantitatively transferred to 15 ml polypropylene tubes. The Teflon liners and lids were washed three times with deionized water, and the washout was transferred to the appropriate test tubes. Then 1 ml of In_2O_3 was added to the solutions and brought to a volume of 15 ml of deionized water and thoroughly mixed by shaking in closed test tubes.

The analysis of hair samples was calibrated using monoelement solutions of 0.1mg/dm^3 CuCdN-ICPMS-71A. The quality of the definition was controlled using a reference sample GBW09101 (The Shanghai Institute of Nuclear Research, China). The bioassays were analyzed using atomic absorption spectrometry.[24] The method is based on measuring the content of metals in biological material (hair), after appropriate preparation of samples.

Results and Discussion

The research area is located approximately between 67°30' and 63° north latitude; 113° and 126° east longitude, and covers the basin of the middle course of the Vilyuy river—the western tributary of the Lena river. Currently, the Vilyuy river basin, located in the western part of the Central Yakutian lowland, has become one of the most long-term and large-scale technogenically affected territories of Yakutia.

The general structure of the relief is absolutely dominated by watershed spaces, where soil-forming rocks are represented by horizontal and lenticular interbeds of conglomerates and sand-gravel-pebble rocks of the Early Mesozoic. And they are the lithochemical basis of lacustrine-boggy, Neogene-Quaternary deposits of areas subjected to alas sedimentogenesis.

According to the combination of physical and geographical features and the stage of anthropogenic transformation of landscapes, the territory of the middle Vilyuy river basin can be divided into three types of ecosystems using the principle of space-time analogies: alas, valley-river and taiga (Fig.1).

Fig. 1. The research area and conditional zoning based on ecosystem principle.

The content of trace elements in the underlying rocks is given according to the data of "Yakutskgeologia" JSC. According to B.S. Yagnishev, the comparison of average chemical element contents shows that the transgressive-regressive stages of the Mesozoic sedimentation are characterized by a close trace element composition of rock-forming terrigenous material. Insignificant, in general, variations in average values indicate the constancy of eroded ancient hills and the manifestation of local differences in the terrigenous complex of drained rocks,[25] part of which is associated with variations in the composition of the cementing material, and part with a different ratio of the sand-clay component under the obvious influence of epigenetic processes. Internal differences are expressed in the occurrence of higher concentrations of trace elements in the ancient Early Jurassic differences, where the increased number of elements such as Co, Mo, and Mn is typical, at close values of V, Sn, Li, P and at the same time lower contents of Ti, Ni, Cu, Pb, Zn, and B. Up the geological section there is a noticeable decrease in the amount of V, Cu, Pb, Mo, Li, and Ag. In the same direction there is an increase in the concentrations of Cr and Ti.

The zonal soil type of the entire territory of the Vilyu river basin is permafrost pale-yellow soils; permafrost alluvial and permafrost organic waterlogged soils are intrazonal. In the structure of the soil cover of alas landscapes, pale-yellow typical, gray, or varying degrees of solodization and permafrost pale-yellow transitional soils occupy intra-alas space.[20,26-28] In addition, directly within alases, permafrost alas soil is formed. Therefore, in the structure of the soil cover of alas ecosystems, two equilibrium interdependent and complementary systems are identified, either of which is characterized by a different dominance of elemental soil processes and by the peculiar conditions of soil formation: alases and intra-alas space (Fig.2).

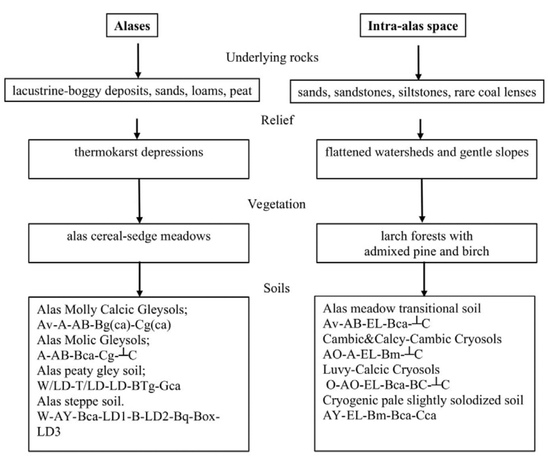


Fig. 2. *The scheme of conditions of soil formation of alas landscapes in the basin of the middle reaches of the Vilyuy river.*

The determination of elements that are genetically inherited from the soil-forming substrate was carried out by calculating the accumulation coefficients (K_1), representing the ratio of the total content of the element in the soil to the content in the soil-forming rock (Table 1), where there are only those elements whose accumulation coefficient K1 values are ≥1; consequently, there is some accumulation of these elements in the soil layer. Manganese and gallium are accumulated most intensively in the soils of the study area, where gallium has a low degree of mobility and manganese has a medium one.[29] Significant accumulation was observed for Pb, Ti, Cr, and B, with medium and slight accumulation for Ni, Zn, V, Co, and Cu. Trends in the accumulation of this spectrum of trace elements can be traced in the soils of the identified types of ecosystems.

Table 1.
Pattern of accumulation of basic trace elements in soils

Element, mg/kg	Terrigenous-continental Early Mesozoic sediments (n=850)	Average contents for soils (n= 214)	Coefficient of accumulation (K_1)	Pattern of accumulation of elements
Ga	0.18±0.02	10.3±2.06	57.2	Intensive, K_1 >10
Mn	64.0±2.66	669.0±133.8	10.4	
Pb	1.00±0.92	9.5±1.9	9.5	Significant, K_1=5-10
Ti	490.0±51.06	4010.0±802.0	8.2	
Cr	3.90±3.49	29.2±5.84	7.5	
B	4.35±3.03	21.8±4.36	5.01	
Ni	3.75±2.43	18.1±3.62	4.8	Medium, K_1= 2-5
Zn	11.5±2.56	40.1±8.02	3.4	
V	9.35±2.07	24.5±4.9	2.6	
Co	2.50±1.20	5.8±1.16	2.3	
Cu	11.6±3.06	21.5±4.3	1.8	Slight, K_1= 1-2

Now there is no doubt that the forming soils inherit the elemental chemical composition of the parent rock as a whole and the already existing distribution of microelements between granulometric fractions. In the soils of permafrost areas of alluvial and alas ecosystems, where in addition to the influence of cryoturbation in the first case, the primary soil-forming rocks are affected by alluvial processes, and in the second case by alas sedimentogenesis. At the same time, it is natural that the soils of each ecosystem differ in their morphological and physico-chemical properties; this difference is reflected in the variations of the trace element spectrum, which, in turn, can be traced in the composition of bottom sediments and natural lake waters, often used by the population as the main sources of water (Table 2). The Table 2 shows elements whose values are higher than the background parameters. Of these, the trace elements whose accumulation is consistently traced in the system are indicated in bold: soil-lake water- bottom sediments. At the same time, there are a number of trace elements that are accumulated to varying degrees in soils, waters and bottom sediments of all types of ecosystems – titanium, manganese and chromium.

It should be noted that the relatively low concentrations in which these elements and their compounds are found in water and bottom sediments, in themselves, do not do much harm to hydrobionts and humans, but they point to water contamination with organic substances of animal (and sometimes vegetable) origin. This group may contain sulfate and phosphate salts as well as chlorides, which are a characteristic sign of recent water pollution by human and animal wastes.

Table 2.

Trace elements in the soil system – surface water – bottom sediments in different types of ecosystems of the Vilyuy region of Yakutia

Ecosystem type	Soils	Lake waters	Bottom sediments
Alas	**Sc**, **Y**, **Mn**, **La**, **B**, **Ti**	**Ti**, **P**, **Y**	**B**, **Mn**, **Y**, Mo, **Ti**, Co, **La,** Pb, **Sc**
Valley river	**B**, Mo, **Nb**, **Sc**	**Ti**, **Sc**, **V**, **Pb**	Li, **Pb**, **Ti**, **V**, Cr, Ni, Cu, Zn, **Nb**, Sn, **B,** Ga
Taiga	Sc, Ti, **Mn**, P, **Cu**, Nb, Pb, **Ni**, V, Zn, **Co**, Sn, **Cr**	**Mn**, **Cr**, **Ni**, B, **Cu**, **Co**	Y, Ag

The research area, as already noted, is sparsely populated. But at the same time, the historical specificity of the local population's current way of life suggests that the geochemical conditions of the environment create a certain background that predisposes people to the development of certain groups of diseases. Statistical processing of the results of medical examinations and data on the incidence of illness in children living within different ecosystems revealed regularities. Children living within the alas ecosystem are characterized by the lowest incidence of illness. The difference in the number of diseases detected, on average, in one child from alas and two children from other ecosystems is statistically significant with a 99% confidence in the conclusion. There are almost no differences in the incidence of illness in children in the taiga and valley-river ecosystems.

Along with the number of diseases detected in the examined children from different ecosystems, the structure of diseases differs (Table 3). The greatest number of diseases in the whole studied area was observed for diseases of the digestive system, which is naturally associated, first of all, with the quality of drinking water and the state of water consumption sources.

Table 3.

Degree of incidence of illness in children on the example of settlements located within different ecosystems on the territory of the Vilyuy region of Yakutia (%)

Ecosystem	Diseases								
	DS	ES	RS	Inf	CVS	MSS	NS	Other diseases	Healthy children
Alas (n=50)	50.6	8.0	18.4	2.3	4.6	3.4	3.4	5.7	3.4
Taiga (n=49)	35.3	19.5	12.8	6.8	6.0	3.0	5.3	11.3	0.0
Balley river (n=35)	31.7	13.5	19.2	1.9	4.8	5.8	11.5	11.5	0.0

Notes: DS – digestive system; ES – endocrine system; RS respiratory system; CCC – cardiovascular system; MSS – musculo-skeletal system; Inf – infectious; HC – nervous system.

Comparison of the structure of diseases using the criterion of contingency shows that the ratio of types of diseases of children living in territories with different geochemical landscapes is significantly different, with a 99% reliability of conclusion. The calculated value of the Pearson criterion χ^2 estimated for the data shown in Table 3 (χ^2=32.0), exceeds the critical value for 1% of the significance level $\chi^2_{1\%}$=32.0

To determine a possible relationship between children's health and the geochemical landscape of the territories where they live, mechanisms of distribution of chemical elements in the hair of children who have undergone a medical examination were studied. Processing of analytical data of the elemental composition of children's hair by factor analysis showed that the overall variability of the content of elements by 79.6% is determined by seven factors. To simplify the structure of the identified factors, their promaxcontaination (oblique-angled) transformation was performed (Table 4). Changing the sign before the coefficient within one column indicates opposite trends in the behavior of elements. So, for example, in factor F1 with an increase in the content of iron, aluminum, silicon and titanium in children's hair, the content of selenium, tin, phosphorus and calcium decreases.

Table 4.

Factor loading coefficients of elements in promaxcontaination factors

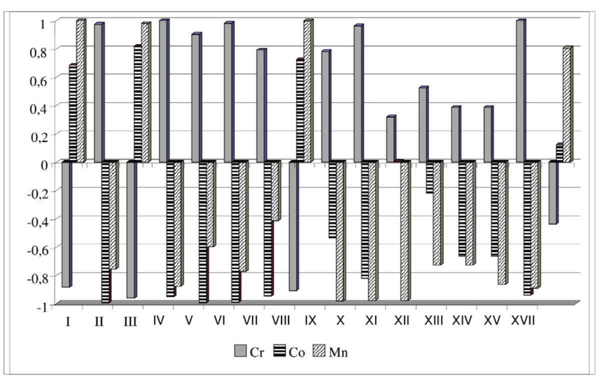
Element	F1	F2	F3	F4	F5	F6	F7
Fe	**0.73**	-0.11	0.02	-0.09	-0.04	0.01	-0.19
Al	**0.71**	-0.03	0.08	0.09	-0.07	0.10	0.11
Si	**0.69**	0.08	-0.18	0.11	0.03	0.21	0.11
Ti	**0.59**	0.00	-0.05	-0.23	0.08	-0.36	0.02
Se	-0.47	-0.14	-0.05	0.00	-0.10	0.32	-0.08
Ni	0.42	0.12	0.11	0.05	-0.33	-0.13	-0.19
Na	0.03	**-0.81**	0.06	-0.01	-0.03	0.02	-0.12
K	-0.05	**-0.79**	-0.06	0.01	-0.14	-0.11	0.07
Li	0.35	**-0.50**	0.00	0.14	0.07	0.17	-0.09
Mg	0.09	-0.02	**0.78**	-0.06	0.05	0.05	0.08
Ca	-0.10	0.00	**0.76**	0.01	-0.02	0.27	-0.02
Mn	0.15	-0.02	0.47	0.47	-0.03	0.03	0.01
Co	0.21	0.06	0.46	0.20	-0.03	-0.12	-0.22
Sn	-0.21	0.09	-0.05	**0.61**	-0.06	-0.03	-0.12
Pb	0.28	-0.13	0.02	**0.59**	0.06	-0.30	0.03
Cd	0.29	-0.09	0.11	**0.58**	0.06	-0.10	0.11
V	-0.07	0.00	0.20	0.04	**-0.74**	0.03	0.12
Cr	0.38	-0.05	-0.12	-0.16	**-0.67**	-0.04	-0.07
As	-0.07	-0.15	-0.15	0.10	**-0.66**	0.03	0.14
Zn	0.08	0.18	0.28	-0.28	0.06	**0.65**	0.09
P	-0.16	-0.16	0.00	-0.23	-0.03	**0.65**	-0.03
Cu	0.12	0.10	0.01	0.14	0.02	0.47	-0.07
Be	-0.03	-0.22	0.10	-0.07	0.16	-0.01	**-0.52**
Hg	0.02	0.20	-0.24	0.19	0.04	0.04	**-0.46**
Total dispersion, %	33.3	16.6	10.8	7.5	5.9	3.0	2.4

Note: elements that significantly determine the structure of the factor are highlighted in bold.

The variability of chemical elements in children's hair by more than 60% is determined by three factors, with a clear geochemical structure. The first factor includes elements (Fe, Al, Si, and Ti) that make up the bulk and structure of aluminosilicate minerals. The second factor combines sodium, potassium and lithium; these elements together with chlorine are the main components of mineral salts used for food. The third factor characterizes the variability of calcium and magnesium content; these two alkaline earth elements are the main components of the Mesozoic carbonate rocks that are widespread throughout the studied area.

In general, the highest concentration coefficients relative to the background parameters of the main components – soil, water, bottom sediments – are recorded in alas ecosystems. The "rich" trace element composition of the environment (high concentrations of a wide range of trace elements relative to background values) has, to a certain extent, a beneficial effect on the overall structure of the incidence of illness in children in alas ecosystems; but with the progressive degradation of the main components caused by pollution of lakes and soils, we can confidently predict the development of ecopathologies. This is evidenced by a fairly high percentage of diseases of the digestive system and respiratory organs.

Diseases of the children's population of the studied area correlate with the content of trace elements in the hair, which is most traceable by variations of Cr, Co, Mn (Fig. 3). There is a high (r= -0.84 - (-0.98)) inverse correlation of chromium with infectious diseases, blood diseases and congenital anomalies. Negative correlation dependence was observed in manganese in most classes of the disease. This indicates that increasing the concentration of these elements in the body of children does not affect the state of health.



I	Infectious diseases	IX	Diseases of the circulation organs
II	Neoplasms	X	Diseases of the respiratory system
III	Blood diseases	XI	Diseases of the digestive system
IV	Diseases of the endocrine system and metabolism	XII	Skin disease
V	Mental disorders	XIII	Diseases of the osteomuscular system
VI	Diseases of the nervous system	XIV	Diseases of the urinary system
VII	Eye disease	XVII	Congenital malformations
VIII	Diseases of the ear		

Fig. 3. *Correlation dependence of the child population disease distribution on Cr, Co and Mn content.*

However, there is a direct correlation, with a very high correlation coefficient (r=0.8-0.97), of cobalt and manganese with infectious diseases, blood diseases and congenital malformations. It is the excess of cobalt and manganese in the body of children of the studied localities that can explain the marked blood diseases and the weakening of the immune system.

The eco-dependent diseases—neoplasms; diseases of the blood, endocrine system and metabolism; and of the nervous system, respiratory organs, skin, and urinary system—have a direct correlation with the content of chromium in the hair of girls. Excess chromium in the body can contribute to the development of neoplasms, cancers and the progression of bronchial asthma.

Thus, we can assume that the picture of eco-dependence in the studied area is determined by chromium; that is, an increase in the concentration of chromium in the body of children leads to an increase in the incidence of illness in children in six classes of diseases.

In our study, we determined the ranking of the risk of environmental-dependent pathology in children of the Vilyuy region. Research on the impact of environmental problems on children's health has shown that this factor increases the risk that eco-dependent diseases will progress in children. Respiratory diseases were ranked first in terms of the risk that eco-dependent diseases will progress; second were diseases of the circulatory system; third, diseases of the digestive system; and fourth, diseases of the eyes and appendages, the osteomuscular system, and the endocrine system.

The supply of chemical elements from the external environment to the internal environment, the human body, through the food chain, is a system-forming factor of vital activity and homeostasis of the body. The influence of the environment on the content of major elements and trace elements in the human body gives reason to consider the "elemental portrait" of a human in general and the children of the studied territory in particular from the standpoint of their eco-dependence.

Competing Interests

The authors declare that they have no competing interests.

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