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Biomonitoring of atmospheric depositions of heavy metals and radionuclides in Irtysh areas of Kazakhstan

This article aims to analyze the data obtained by researching the atmospheric depositions of heavy metals and radionuclides in Irtysh areas of Kazakhstan using the method of moss-biomonitors. This method was applied for the Northeastern and Eastern parts of the Republic of Kazakhstan to assess the environmental situation in these regions. The thirty moss samples were collected in autumn and summer of 2015–2016 growth periods. A total of 42 elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Co, Zn, As, Se, Br, Rb, Sr, Zr, Nb, Mo, Ag, Cd, Sb, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Tm, Hf, Ta, W, Au, Th and U) were determined by the epithermal neutron activation analysis, also 14 elements (Ba, Ca, K, Mg, Na, Sr, Cr, Mn, Ni, Co, Zn, Cd, Cu, Pb) were determined by the atomic emission spectrometry with inductively coupled plasma. Multivariate statistical analysis of the obtained results was used to assess the pollution sources in the studied area (Pavlodar, Ust-Kamenogorsk, and Semey regions).

Keywords: biomonitoring, heavy metals, neutron-activation analysis, atomic-emission spectrometry.

Human impact on the natural environment is immense; its power is comparable to natural geological processes and continues to grow with the rate of technological progress. It is especially significantly in the regions of large industrial centers and large cities.

Protection of environment from anthropogenic impacts involves two main activities: monitoring and control. Monitoring should ensure the organization of continuous monitoring of the environment state.

Growth of industrial production in recent decade causes an increase of human affects both components of the environment and public health. Study of atmospheric deposition of trace elements is one of the most important tasks of the environmental protection and collective efforts of scientists from many countries of the world dedicated to this area more than 40 years. Control of air quality requires primarily multi-elemental analysis of the composition of aerosol particles and determination of the concentrations of elements that are recognized as toxic to living organisms.

In Kazakhstan, due to the current socio-economic development, there are disadvantaged regions by state of the environment, which is a unique urbanistic system saturated with varied companies of very different technological orientation. The presence of large number of enterprises and high levels of radiation in Irtysh area of Kazakhstan determine the urgency of these studies.

The state of the environment and thus the health of the population largely depend on the state of the earth's atmosphere. The atmosphere basically consists of a mixture of natural gases. The particulates pass into the air either from natural sources (soil, rocks, water bodies and living organisms) or as a result of anthropogenic activity (industry, transport, fuel, human waste, etc.). Essentially, atmosphere is an aerosol system, where solid particles are dispersed in a mixture of gases. Among the various types of pollutants, the most hazardous are heavy metals.

The use of mosses as biomonitors of atmospheric depositions of trace elements were introduced in Scandinavian countries and shortly after that, usage of the mosses to assess the atmospheric deposition of metals was well proven in the UN Commission of European air [1]. Mosses have only a rudimentary root system and readily take up elements from the atmosphere. The main advantages of the method are the simplicity of sample collection and the relative ease of analysis compared to precipitation samples conventionally used to assess metal deposition. In addition, the abundance and large geographical distribution of mosses is advantageous and provides for an inexpensive and simple alternative to conventional bulk deposition analysis. Thus, a high density network of sampling sites is easily achieved.

The method of moss biomonitoring of atmospheric depositions of trace elements was applied for the first time in Irtysh area to assess the environmental situation in this region.

Theoretical and experimental obtained data from the studying of air depositions of trace elements, based on the moss biomonitors, will make a significant contribution to the level of ecological safety development of Kazakhstan.

This direction seems to be new and highly topical; being that only some regions of the country were previously studied. Based on the small number of studied territories, we can talk about the need to increase the area of sampling and further work on the entire territory of the Republic of Kazakhstan for studying the state of the atmosphere.

Coordination of the European moss survey is since 2014 led by the Joint Institute for Nuclear Research in Dubna, Russian Federation. Kazakhstan joined to the United Nations Program in 2015.

The research results will be used in the preparation of the «Ecological map of the world – 2018» in the «Kazakhstan» section.

Heavy metals are rare elements (scattered, trace), as performing certain biological functions in the body, which are accumulated in high concentrations in the environment.

The main natural source of heavy metals is magmatic and sedimentary rocks and their forming minerals. Many elements enter into the biosphere from cosmic dust, volcanic gases, etc. The entrance of heavy metals into the environment due to industrial pollution carried out in various ways. The most important of these is the release of the processes associated with high temperatures (metallurgy, roasting, burning of fuel). Despite the great diversity of heavy metal compounds, a set of elements in the gas-dust emissions of the ferrous and non-ferrous metallurgy enterprises are the same type; mainly oxides represent them [2].

Heavy metals and other toxic elements emitted into the atmosphere from the industrial constructions, mostly distributed locally around the emission sources. In a real natural environment, it is usually observe a good correlation of the shape and size of areas of contamination with the configuration of the wind rose.

Around large enterprises, ferrous and nonferrous metallurgy formed strong technogenic anomalies of metals. «Characterized by the presence of the zone of maximum concentrations of heavy metals at a distance of 5 km from the source and the zones of high grade at a distance of 20–25 km. Further, the content of heavy metals decreases to the values of the local background. Local anthropogenic anomalies generate around the enterprises that process raw materials containing heavy metals and other contaminants in the form of impurities. Around major thermal power plants, there are zones of contamination with metals 10–20 km in diameter. Any urban areas are a significant source of heavy metal pollution. High pollution found near freeways, especially lead, zinc, cadmium» [3].

Since many heavy metals tend to accumulate, the negative effects of their impact on the environment can occur slowly. Elevated concentrations of heavy metals in soils, groundwater, leading to stunted growth of trees, agricultural crops and accumulation in the human body can have a detrimental effect on the health of future generations. Hence, there is the need for monitoring atmospheric deposition of pollutant elements [4].

Morphological and physiological properties of mosses along with their wide distribution make these plants very useful bio-indicators to assess the state of the environment. They have a number of advantages over other plants biomonitors (lichens, tree bark, grass, etc.): the absence or severe change in the cuticle, thin and close-set leaves, and poorly developed conducting tissue, it leads to efficient accumulation of materials carried by air, and the little direct uptake from the substrate. Mosses are the most effective at concentrating heavy metals and other trace elements from air and precipitation. Moreover, they do not have a root system and, therefore, the contribution of sources other than atmospheric deposition, in most cases is limited. Sample collection is simple, the analysis of mosses is much simpler than precipitation, the period of exposure can be determined accurately [5].

Methods of biomonitoring were developed in the late 70s of the last century as a way to study atmospheric deposition of heavy metals.

The main types of biomonitoring in the European study are the mosses Hylocomium splendens and Pleurozium schreberi. These species of mosses distributed in a wide interval of temperature zones, and annual growth of them can be easily identified. Typically, the analysis takes a three-year growth of moss.

In research were used well-known and widely used physical and chemical methods of analysis, modern statistical and mathematical methods of calculations.

Neutron activation analysis

Determination of the elemental composition of moss samples was carried out by using instrumental neutron activation analysis (NAA).

Neutron activation analysis — analysis in which the identification and quantitative determination of elements in an irradiated sample is carried out selectively, using the variation of irradiation conditions — (energy of bombarding particles, the exposure time), and consider the nuclear-physical properties of elements and the occurring radionuclides (particularly schema-defined decay of radionuclides, half-life).

NAA of moss samples were carried out at the PFR-2 (pulsed fast reactor) using activation of epithermal neutron along with a full range of neutrons [6, 7].

The application of NAA allows to determine up to 45 elements: Ag, Al, As, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Cs, Dy, Eu, Fe, Hf, Hg, I, In, K, La, Lu, Mg, Mn, Mo, Na, Nd, Ni, Rb, Sb, Sc, Se, Sn, Sm, Sr, Ta, Tb, Th, Ti, V, U, W, Yb, Zn, Zr [2].

Important stages in the analysis are sampling, and sample preparation.

Environmentally important element, lead cannot be identified using the method of neutron activation analysis. Due to low contents of mosses in the samples also hampered the detection of copper and mercury, therefore, to identify these elements, and compare the obtained results, it also was used the method of atomic emission spectrometry with inductively coupled plasma (AES with ICP).

Determination of metals in moss samples by atomic emission spectrometry

Atomic emission spectrometry with inductively coupled plasma is characterized by high sensitivity and ability to detect a range of metals and several nonmetals at concentrations up to 10^{-10} %, i.e. one particle of 10^{12}. The method is based on using inductively coupled plasma as ion source and mass spectrometer for separation and detection. ICP-MS also allows for isotopic analysis of the selected ion.

As the particles of the powdered sample fall in the Central channel of the ICP, it evaporates as the particles are first dissolved therein and disintegrate into atoms. At this temperature, a significant number of the atoms of many chemical elements are ionized, while the atoms lose the least bound electron, moving in a state of the singly charged ion.

Sampling and sample preparation

In compliance with the Moss Manual 2015 (Harmens and Frontasyeva, 2015; http://icpvegetation.ceh.ac.uk/) the three moss species *Hylocomium splendens*, *Pleurozium schreberi*, *Pleurochaete squarrosa* (Fig. 1–3) were collected over the Irtysh area during the period of autumn and summer of 2015–2016. The sampling network with numbered sampling sites is shown in Figures 4–7.

Figure 1. Hylocomium splendens

Figure 2. Pleurozium schreberi

Figure 3. Pleurochaete squarrosa

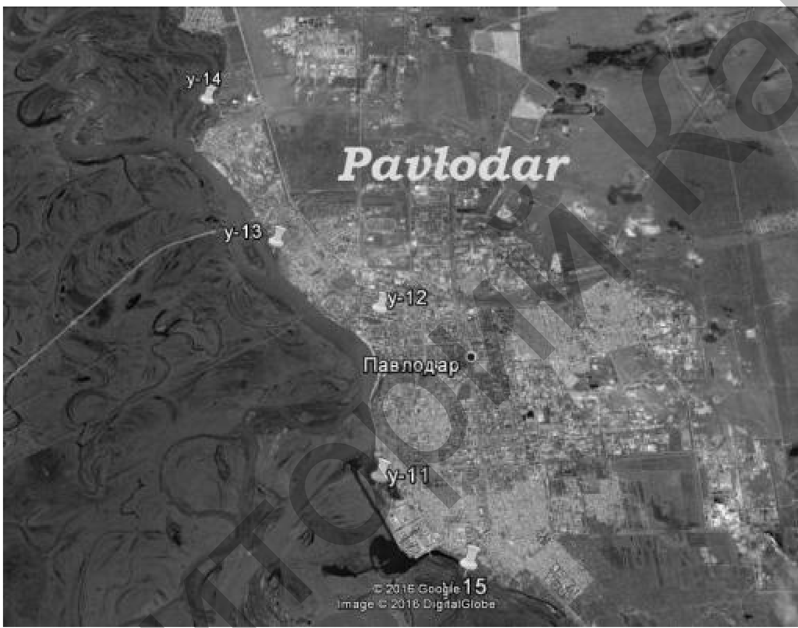

Figure 4. Sampling map (5 samples from Pavlodar)

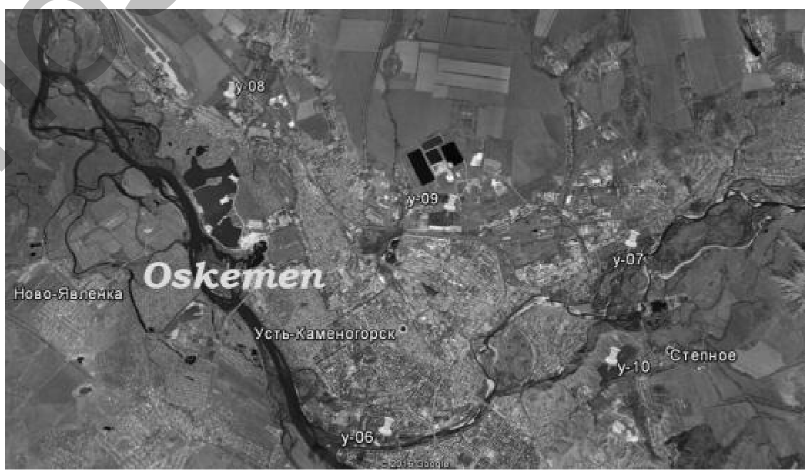

Figure 5. Sampling map (5 samples from Ust-Kamenogorsk)

Figure 6. Sampling map (5 samples from near the river Irtysh)

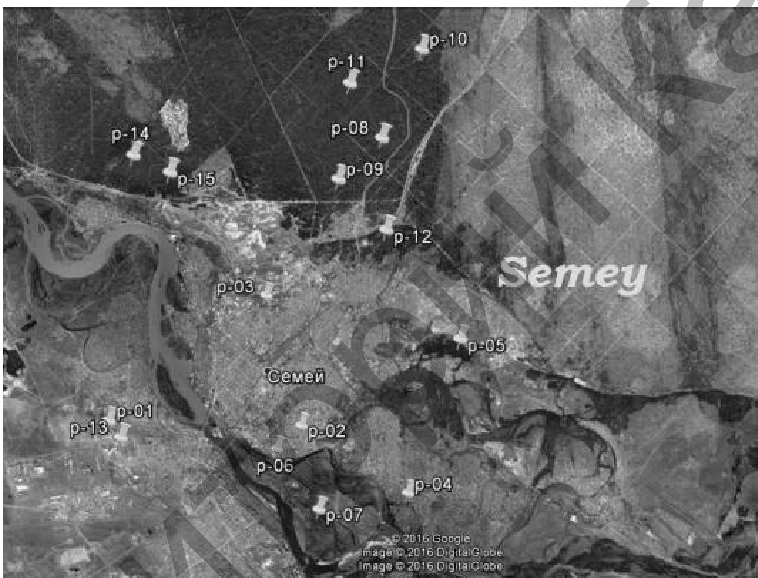

Figure 7. Sampling map (15 samples from Semey)

Samples were collected in forest glades or on open heath to reduce through-fall effects from the forest canopy, and the sampling sites were located at least 300 m from main roads, 100 m from local roads, and 200 m from villages. Collected material was stored in paper bags. A separate set of disposable polyethylene gloves was used for collection of each sample.

In the laboratory the samples were cleaned from extraneous plant material and air-dried to constant weight at 30–40 ºC for 48 hours. The samples were neither washed nor homogenized. Green-brown moss shoots representing the last 3 years' growth were subjected to analysis, as they correspond approximately to the deposition over the last 3 years. Previous experience from the use of NAA in moss biomonitoring has shown that samples of 0.3 g are sufficiently large to be used without homogenization.

The concentrations of 42 elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Co, Zn, As, Se, Br, Rb, Sr, Zr, Nb, Mo, Ag, Cd, Sb, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Tm, Hf, Ta, W, Au, Th, and U) determined by epithermal neutron activation analysis, also 14 elements (Ba, Ca, K, Mg, Na, Sr, Cr, Mn, Ni, Co, Zn, Cd, Cu, Pb) determined by atomic emission spectrometry with inductively coupled plasma in the moss samples are reported. Multivariate statistical analysis of the obtained results was used to assess the pollution sources in the studied area (Pavlodar, Ust-Kamenogorsk, and Semey regions).

The descriptive statistics of the 42 analysed elements in all collected moss samples (n=30) from three different cities are shown in Table 1. All values in Table 1–4 are given in $mg \cdot kg^{-1}$, dry weight. In Table 3 the median values and minimum-maximum ranges for the contents of all elements were compared with the data obtained from Georgia (moss survey in 2014) and the data from Norway considered as a pristine area of Europe.

A comparison of concentrations Kazakhstan-Norway showed the increased values for most of heavy metals (Cd, Sm, Ti, V, As, Mo, Mg, Al, Ca, etc) in the studied samples that apparently are due to the state of the industrial sector of Kazakhstan. The main potential sources of air pollution from the industrial sector of Irtysh area are the Aksu ferroalloy plant, aluminium factory, Kazakhstan electrolysis plant, petrochemical plant in Pavlodar region; Ul'binsk metallurgical plant, titanium-magnesium plant in Ust'-Kamenogorsk region; bus factory, engineering plant, silicate plant in Semey region and etc.; also the production of steel and zinc and etc., coal mining, extraction of natural resources.

Table 1

Comparison of the results of NAA for element content in mosses collected in the autumn of 2015 (all data are given in mg·kg^{-1})

Elements	Region											
	Ust'-Kamenogorsk				Pavlodar				Semey			
	Arithmetic mean	Average median	C(min.)	C(max.)	Arithmetic mean	Average median	C(min.)	C(max.)	Arithmetic mean	Average median	C(min.)	C(max.)
Na	3437.1	3100	2700	3690	2429.2	2400	816	3710	4758	5600	1970	6920
Mg	6248	5900	5760	7170	7106	7550	4910	8220	7250	7790	5470	8480
Al	18260	17800	16500	22000	14356	13900	5380	22300	20420	20800	15300	26500
Cl	140.04	167	36.8	255	312.2	292	45	508	50.26	48.3	42.7	60.9
K	7922	8080	7430	8370	14100	15800	10800	16900	9970	10200	7390	11800
Ca	9328	8790	7790	11700	15290	15100	9550	22800	9666	9820	8020	10700
Sc	4.208	4.09	4.010	4.52	2.924	2.88	1.37	4.1	4.36	4.73	2.56	5.42
Ti	1054.4	970	920	1250	862.6	767	300	1400	1119.8	1170	806	1460
V	25.7	24.7	22.5	30.4	19.258	18.9	7.79	29.5	25.38	24.8	21.2	30.7
Cr	21.06	20.6	19.1	23.5	19.1	20.7	12.6	23.1	20.46	21.1	12.2	26.1
Mn	351.8	219	200	907	376.4	422	228	482	250.4	252	196	313
Fe	7280	7390	5250	9290	6452	6480	3030	8680	7322	7390	5090	9820
Ni	9.968	10.5	8.88	10.8	9.36	8.88	6.87	12.6	9.682	10.8	6.34	12.1
Co	5.610	5.91	4.84	6.4	4.218	4.5	3.07	4.62	6.048	6.74	3.29	7.9
Zn	1.222	1.19	1.05	1.46	404.64	453	87.2	811	1.1226	1.18	0.933	1.27
As	0.130	0.126	0.15	0.17	3.37	3.54	2.51	3.81	0.12658	0.125	0.0909	0.163
Se	0.269	0.293	0.25	0.31	0.3824	0.391	0.275	0.511	0.2502	0.251	0.119	0.351
Br	3.388	4	3	4	5.124	4.64	4.08	7.52	3.286	3.54	2.28	4
Rb	28.32	28.6	26.3	30.1	22.72	23.5	12.1	29.9	33.5	38	19.1	42.3
Sr	53.46	54.7	48.1	57.5	167.22	187	88.1	238	59.98	63.9	39.1	80.1
Zr	69.36	73.3	34.9	94.5	36.6	13.5	10.7	78.4	67.38	54.3	35.3	117
Nb	1.286	1.38	0.73	1.8	4.68	5.02	1.52	7.32	1.075	0.892	0.583	2.14
Mo	0.08	0.08	0.074	0.09	0.8224	0.748	0.369	1.4	0.07438	0.068	0.0639	0.0954
Ag	0.002	0.0	0.002	0.003	0.2738	0.263	0.155	0.436	0.001696	0.00166	0.0014	0.00208
Sb	0.155	0.150	0.134	0.167	1.0604	1.155	0.604	1.77	0.1514	0.15	0.11	0.184
Cd	0.019	0.019	0.0155	0.027	0.0055	0.0055	0.0055	0.0055	0.014226	0.013	0.00973	0.0234
I	2.318	2.37	1.55	3.06	2.846	2.71	1.99	3.64	2.076	2.05	1.83	2.45
Ba	201.4	196	195	222	174.4	174	154	193	236.6	258	149	305
Cs	1.52	1.6	1.34	1.64	1.0922	1.09	0.543	1.5	1.5006	1.59	0.983	1.8
La	8.692	8.8	5.59	12.7	8.754	6.94	2.38	15.4	9.988	10.9	5.98	14.9
Ce	20.02	20.6	12.3	29.5	19.536	15	4.68	34.8	22.5	24.4	13.5	35.2
Nd	8.428	7.37	5.48	12.5	9.698	8.52	3.51	15.5	9.456	11.1	4.63	13.6
Sm	2.59	2.47	1.88	3.28	1.8544	1.37	0.502	3.34	2.722	2.74	1.45	3.95
Eu	0.31	0.35	0.285	0.35	0.2832	0.254	0.202	0.439	0.4074	0.427	0.194	0.591
Tb	0.2632	0.262	0.197	0.377	0.23742	0.178	0.0741	0.411	0.2812	0.311	0.163	0.406
Tm	0.15058	0.147	0.0549	0.257	0.10514	0.0794	0.033	0.179	0.16412	0.144	0.0756	0.297
Yb	0.9264	0.97	0.673	1.35	0.7324	0.659	0.262	1.38	0.9346	0.874	0.529	1.46
Hf	2.474	2.58	1.37	3.41	1.8382	1.7	0.601	3.03	2.27	1.88	1.35	3.99
Ta	0.2204	0.24	0.143	0.281	0.21022	0.212	0.0941	0.319	0.2352	0.29	0.135	0.305
W	0.00504	0.00249	0.00214	0.0159	0.6102	0.593	0.416	0.847	0.008342	0.00286	0.00208	0.0264
Au	0.004404	0.00338	0.00179	0.00772	0.009564	0.00833	0.00681	0.0137	0.0055	0.00589	0.0012	0.0076
Hg	0.07308	0.0923	0.0271	0.0978	0.0436	0.0376	0.0206	0.097	0.06686	0.0791	0.0264	0.0996
Th	3.252	3.59	1.44	5.8	3.2456	2.2	0.768	6.03	3.132	2.63	1.53	6.01
U	0.7882	0.773	0.38	1.34	0.7024	0.602	0.201	1.17	0.7282	0.65	0.419	1.19

Table 2

The results of analysis of moss survey, which were collected in the summer of 2016 (all data are given in mg·kg^{-1})

Elements	Arithmetic mean	Average median	C(min.)	C(max.)	Elements	Arithmetic mean	Average median	C(min.)	C(max.)
Na	2344.69	1540	312	6890	Cd	0.35	0.228	0.12	0.786
Mg	3554.23	2830	918	8370	In	0.26	0.317	0.0528	0.493
Al	10181.53	7400	2240	26000	Sb	0.34	0.23	0.128	0.788
Si	34935.38	25400	5290	116000	I	1.18	1.01	0.305	2.56
Cl	115.30	102	50.2	238	Ba	108.89	81.4	22.5	258
K	6090	5420	1450	10900	Cs	0.81	0.595	0.391	1.5
Ca	5415.38	5510	1100	8670	La	4.37	2.42	0.922	11.7
Sc	2.40	1.35	0.75	6.64	Ce	9.04	5.18	1.93	23.7
Ti	511.92	358	111	1260	Nd	3.96	2.15	0.969	10
V	13.30	8.37	3.74	34.4	Sm	0.82	0.469	0.169	2.11
Cr	16.44	9.62	5.79	49.4	Eu	0.27	0.193	0.0809	0.693
Mn	155.76	117	30.8	349	Gd	0.48	0.283	0.106	1.22
Fe	4098.46	2530	1190	9580	Tb	0.13	0.0823	0.0373	0.353
Ni	6.63	4.1	1.68	19	Dy	0.71	0.451	0.221	1.9
Co	3.50	1.84	0.873	11.5	Tm	0.075	0.0557	0.0276	0.192
Zn	54.63	57.4	26.2	84.3	Yb	0.51	0.312	0.131	1.37
Se	0.30	0.344	0.152	0.409	Lu	0.073	0.0553	0.00782	0.246
As	2.22	1.67	0.823	4.89	Hf	0.617	0.308	0.102	1.53
Br	2.93	2.83	1.39	4.46	Ta	0.112	0.0725	0.0265	0.315
Rb	16.22	11.2	6.64	34.4	W	0.311	0.204	0.0831	0.689
Sr	62.80	47.5	14.8	150	Au	0.0055	0.00415	0.0026	0.00969
Zr	22.22	10.1	4.56	55.7	Hg	0.42	0.402	0.295	0.576
Mo	0.35	0.223	0.0857	0.858	Th	0.975	0.554	0.253	2.44
U	0.29	0.175	0.0568	0.756					

Table 3

Comparison of the median values and ranges of element content in moss from Kazakhstan between data of the moss survey Norway, Georgia and Kazakhstan (2014–2015) (all data are given in mg·kg^{-1})

Kazakhstan moss survey 2016–2017			Kazakhstan moss survey 2014–15 (Nazarova. et al. 2015)		Georgia moss survey 2014 (Shetekauri. et al. 2015)		Norway moss survey (Shetekauri. et al. 2015)	
№ of sample	n=30		n=23		n=16		n=100	
Element	Median	Range C(min.)-C(max.)	Median	Range C(min.)-C(max.)	Median	Range C(min.)-C(max.)	Median	Range C(min.)-C(max.)
^{24}Na	2929	312–6920	2000	424–17100	721	268–1990	nd	nd
^{27}Mg	5329	918–8480	6060	1710–24800	4410	2720–11600	1730	940–2370
^{28}Al	14197	2240–26500	9510	33.8–35100	5195	2450–20800	200	67–820
^{38}Cl	143	36.8–508	180	95.5–1270	225	140–465	nd	nd
^{42}K	8540	1450–16900	10800	3820–23200	5875	3080–9040	nd	nd
^{49}Ca	8636	1100–22800	12500	2340–24000	11800	7140–15300	2820	1680–5490
^{51}Ti	779	111–1460	603	99–3920	547	216–2070	23.5	12.4–66.4
^{52}V	18.7	3.74–34.4	13	1.7–56.7	11.8	6.2–54.0	0.92	0.39–5.1
^{56}Mn	247	30.8–907	178	70.5–1260	158	70–592	256	22–750
^{76}As	1.68	0.0909–4.89	1.92	0.80–8.1	0.88	0.33–2.87	0.093	0.020–0.505
^{82}Br	3.46	1.39–7.52	4.67	2.3–31.3	4.545	2.3–9.8	4.5	1.4–20.3
^{99}Mo	0.34	0.0639–1.4	0.69	0.21–2.03	0.35	0.24–0.77	0.135	0.065–0.70
^{115}Cd	0.17	0.0055–0.7865	0.75	0.02–2.74	0.25	0.12–0.56	0.058	0.025–0.171
^{140}La	6.9	0.922–15.4	6.4	1.35–37.3	59.28	18.8–138	17.1	5.6–50.5
^{153}Sm	1.66	0.169–3.95	1.05	0.198–7.09	2.13	0.92–6.28	0.189	045–2.56
^{187}W	0.25	0.00208–0.847	0.44	0.12–1.42	0.43	0.035–0.945	0.33	0.05–1.34
^{198}Au	0.00584	0.0012–0.0137	0.00145	0.00023–0.00441	0.13	0.06–0.27	0.127	0.009–1.23

The average concentrations of elements are given in Table 4 to compare two different methods: NAA and AES with ICP, and was found a correlation coefficient, which is 0,7784.

Table 4

The average concentrations of elements, determined by two different methods

Elements	Ba	Ca	Cd	Co	Cr	K	Mg	Mn	Na	Ni	Sr	Zn
C(average), mcg/kg by NAA	170	8909	0.3	4.9	19.9	8762	5716	247	3178	9.1	86.6	146.2
C(average), mcg/kg by AES	114	12720	2.0	5.4	33.7	5316	2971	473	1868	172.3	76.6	225.1

The performed preliminary investigation shows that the moss biomonitoring of atmospheric deposition of heavy metals is an efficient technique to study the environmental situation in the Kazakhstan. The experience of this study can be successfully used in the other regions of the Kazakhstan. Also, there will be maps of the spatial distribution of elements and radionuclides in the study area, based on the statistical analysis of the data created with the use of maps of the distribution of elements, will assess potential sources of pollutants into the environment.

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Қазақстан Республикасының Ертіс өңіріндегі ауыр металдар мен радионуклидтердің ауадан түсулерінің биомониторингі

Мақалада мүк-биомониторлар талдауы негізінде Қазақстанның Ертіс өңіріндегі ауыр металдар мен радионуклидтердің атмосфералық түсулерін зерттеу барысында алынған мәліметтер талқыланған. Бұл әдіс Қазақстан Республикасының Солтүстік-Шығыс және Солтүстік аймақтарының экологиялық жағдайын бағалау мақсатында қолданылды. 30 мүк үлгілері 2015–2016 жж. өсу кезеңінің күз және жаз мезгілдерінде жиналған. Жалпы, 42 элемент (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Co, Zn, As, Se, Br, Rb, Sr, Zr, Nb, Mo, Ag, Cd, Sb, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Tm, Hf, Ta, W, Au, Th және U) эпижылулық нейтрон-белсенділік талдау әдісімен, сонымен қатар 14 элемент (Ba, Ca, K, Mg, Na, Sr, Cr, Mn, Ni, Co, Zn, Cd, Cu, Pb) индуктивті байланысқан плазмалы атом-эмиссиялық спектрометрия әдісімен анықталды. Алынған нәтижелердің көпфункционалды статистикалық талдауы зерттелген территориядағы (Павлодар, Өскемен және Семей аймақтары) ластану көздерін бағалау мақсатында қолданылды.

Кілт сөздер: биомониторинг, ауыр металдар, нейтрон-белсенділік талдау, атом-эмиссиялық спектрометрия.

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Биомониторинг воздушных выпадений тяжелых металлов и радионуклидов в Прииртышье Республики Казахстан

В статье проанализированы данные, которые были получены при изучении атмосферных выпадений тяжёлых металлов и радионуклидов в Прииртышье на основе анализа мхов-биомониторов. Данный метод был применён для оценки экологической ситуации в Северо-восточных и Восточных регионах Республики Казахстан. 30 образцов мхов были собраны осенью и летом 2015–2016 гг. растительного периода. В целом, 42 элемента (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Co, Zn, As, Se, Br, Rb, Sr, Zr, Nb, Mo, Ag, Cd, Sb, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Tm, Hf, Ta, W, Au, Th и U) были определены с помощью эпитеплового нейтронно-активационного анализа, а также 14 (Ba, Ca, K, Mg, Na, Sr, Cr, Mn, Ni, Co, Zn, Cd, Cu, Pb) — с помощью атомно-эмиссионной спектрометрии с индуктивно-связанной плазмой. Многофункциональный статистический анализ полученных результатов был использован для оценки источников загрязнения на исследованной территории (регионы Павлодара, Усть-Каменогорска и Семея).

Ключевые слова: биомониторинг, тяжелые металлы, нейтронно-активационный анализ, атомно-эмиссионная спектрометрия.