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RESEARCH

Mosses as bioindicators of air pollution with potentially toxic elements in the Burabay State National Natural Park, Kazakhstan

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Abstract The Burabay State National Natural Park is a national park of the great natural and historical values located in the north of Kazakhstan, which has been exposed in recent years to significant anthropogenic impact. The moss biomonitoring was performed in the Borovoye resort community, an important tourist destination in the national park, to identify the level of air pollution. Mosses collected at 29 locations were subjected to neutron activation analysis to determine 36 elements and additionally to ICP-OES to detect the level of Cu and Pb. Factor analysis was applied to check if there are any associations between identified elements and to link them with possible emission sources. According to contamination factor and pollution load indices the investigated area belongs to three classes of pollution: unpolluted, suspected and moderate. Potential ecological risk index calculated for selected elements revealed harmless risk to human health. The level of element obtained in Burabay State National Natural Park was compared with the data available for other national parks.

Keywords State National Nature Park "Burabay" · Pollution · Biomonitoring · Recreational zones · Neutron activation analysis

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Introduction

Atmospheric pollution significantly affects the quality of the environment and is the primary cause of respiratory, cardiovascular and other types of diseases (Cui et al., 2022). The constant growth of the industrial and agricultural sectors results in the release of a wide variety of pollutants, including chemical elements into environment. Potentially toxic elements (PTEs) due to their stability and cumulative capacity pose a danger to humans and ecosystems (Ding et al., 2022; Mitra et al., 2022). Among the important sources of PTE emissions can be listed mining, industry, transport, energy sector, waste incineration plants and agriculture (Haddaway et al., 2022; Pachana et al., 2010; Rashid et al., 2023).

In recent years, biomonitoring methods, separately or together with chemical analysis, have increasingly been used to assess air pollution in many countries. Bioindicators, such as pine needles, mosses and lichens, have been used to assess the level of air pollution with heavy metals, ozone, radionuclides and persistent organic pollutants (Chaligava et al., 2021; Chaudhuri & Roy, 2023; Lazo et al., 2022; Q. Wu et al., 2014).

The morphological and physiological properties of mosses, along with their wide distribution, make these plants very practical bioindicators for assessing the state of the environment on large territories. They have several advantages over other biomonitors, such as the absence or strong change of the cuticle, high leaf permeability to ions of chemical elements and high surface-to-volume ratio (Kosior et al., 2020). Mosses effectively concentrate pollutants from air and precipitations. The lack of a well-developed root system ensures element accumulation mainly from atmospheric depositions (Chaudhuri & Roy, 2023; Szczepaniak & Biziuk, 2003; Vergel et al., 2022).

Pollutants emitted by different industrial activities not only affect the quality of the nearby territories, but can also be transported on the large distances exerting a negative impact on recreational areas, including national parks. Previously mosses were applied in several studies to assess the quality of air in national parks (Bykowszczenko et al., 2006; Grodzińska et al., 1990; Kosior et al., 2020; Petrinec et al., 2022).

The aim of the present study was to assess the level of air contamination with PTEs on the territory of the Burabay State National Natural Park located in the Akmola region of Kazakhstan applying moss biomonitoring technique. Even though the park is an area protected by the state, it experiences stress due to high tourist influx and infrastructure functioning. In addition, in the Akmola region, deposits of gold, uranium, titanium, iron, manganese, molybdenum and industrial diamond are explored, and minerals processing industry are actively developed. The main objectives of the study included (i) determination of the content of PTEs in moss samples using two analytical techniques, (ii) application of statistical tool to group elements with similar emission sources and (iii) assessment of level of studied area pollution.

Materials and methods

Studied area

The northern region of Kazakhstan, specifically the Burabay district of the Akmola region, is home to the Burabay State National Natural Park, which was established in compliance with the Government of the Republic of Kazakhstan's Decree of August 12, 2000. The nature park has the status of an environmental and scientific institution that is part of the system of specially protected natural areas of republican significance and is under the jurisdiction of the Administration of the President of the Republic of Kazakhstan (Decree of the Government of the Republic of Kazakhstan 2017). The main activities seen within the nature park are environmental, scientific, eco-educational, recreational and related to tourism (Akiyanova et al., 2019). The national park is an environmental state institution that is part of the system of specially protected natural areas of republican significance and is under the jurisdiction of the Administration of the President of the Republic of Kazakhstan.

The national park spans 129,299 ha in total, with 73,000 permanent residents living within its boundaries (Akiyanova et al., 2019). The climate of the Burabay district is sharply continental, but with moderately cold winters (the average temperature in the park in January is − 16 °C) and warm summers (the average temperature in July is + 19 °C). Burabay is referred to as "pearl of Kazakhstan" and "Kazakh Switzerland". Six lakes dotting the steppe landscape are part of the Burabay National Natural Park, with Lake Borovoe drawing the greatest number of visitors (Barinova et al., 2022).

Chernozems are present in the western and central parts of the territory of the Burabay region. For elevated plains, characteristic ordinary and carbonate chernozems are found, while for slopes of hills is found close occurrence of bedrock skeletal soils. Southern chernozems are widespread in the northern and eastern parts of the region. The soil-forming rocks are Quaternary deposits, represented mainly by eluvial-deluvial crushed loams, underlained by crushed stones (less commonly dense rocks), and locally by loess-like loams (Baisholanov, 2017).

Kenashy, Arshaly, Kalshaakty and Zholbold are the most important rivers in the park (Nurtazina, 2021). The visiting card of the park is Mount Kokshetau

(Sinyukha) height of 947 m. Lake Borovoe is not the only site most visited by tourists; there are also several balneological resorts on it. According to scientific reports increased anthropogenic pressure on the lake is seriously affecting the water quality. On the lake's eastern edge is located village Burabay (former name Borovoye), which is home to a large number of guest houses and balneological resorts (Barinova et al., 2022).

Although tourism and agriculture are considered the main economic activities in Burabay district on the territory of the district are operated several industrial enterprises: limited liability company "Kaisar-B"—exploration and development of mineral deposits; limited liability company "Raigorodok"—use of subsurface resources, gold mining; branch of the national railway company—Borovoye rail welding enterprise"; limited liability company "Borovoe locomotive-wagon depot"—repair of locomotives and passenger carriages; limited liability company "Rauan—Burabay"—repair and maintenance of railway rolling stock; limited liability company "Wagon-repair depot "Burabay"—provision of agricultural enterprises by rail transport; limited liability company "Shchuchinsky KMZ"—boiler production; limited liability company "Carpenter shop"—production of wooden products; limited liability company "Provisor"—pharmaceuticals production.

Sampling and chemical analysis

In July 2019, 29 *Hylocomium splendens* samples were collected in the Burabay State National Natural Park, mainly near Burabay resort community (Fig. 1, Table S1). The moss species *Hylocomium splendens* is pleurocarpus moss growing in wefts or mats that obtains moisture and nutrients mainly from precipitation. Branched shoots with numerous leaves densely stacked to the stem make a roughly moss surface enabling efficient entrapment of particles (Aničić Urošević et al., 2020).

The manual developed by the ICP Vegetation Program (Frontasyeva & Harmens, 2015) was followed in the sampling and preparation for analysis.

The elemental content of the collected moss samples was determined using two analytical methods. Neutron activation analysis at the REGATA facility of the IBR 2 reactor in Dubna, Russia, was used to determine the main part of elements. More information about samples irradiation and quality control of the measurements (Table S2) can be seen in our previously published papers (Zinicovscaia et al., 2019, 2020).

Complementary to neutron activation analysis, the content of Cu and Pb was measured in the same moss specimens by using inductively coupled plasma atomic emission spectrometer (ICP-OES) ICPE-9000 (Shimadzu, Japan). For analysis, 0.5 g of moss sample was mixed with 7 mL of HNO_3 and 2 mL of H_2O_2 (both concentrated of analytical grade). Sample digestion was performed in the microwave system MASTER (MDS-10, China), under pressure 1.2 MPa for 35 min. After digestion obtained solutions were filtered through 0.45-μm filter paper and made up to the volume of 50 mL with bi-distilled water. Next solutions were analyzed using ICP-OES. Reference material NIST 1570a (Spinach leaves) was used to ensure the quality of the obtained results. The difference between experimental and certified values for Cu was 4% and for Pb 5%.

Statistical analysis

Excel (Microsoft, Redmond, Washington, DC, USA) was used to process the data. A factor analysis was performed using STATISTICA 13.0 to find correlation between chemical elements. The Box-Cox transformation was applied since factor analysis is sensitive to non-normally distributed data. Maps displaying the spatial distributions of the elements were created using the ArcGIS program (Esri, Redlands, CA, USA).

Data evaluation

The contamination factor (CF) is defined as the ratio between the content of an element in the sample and its background value (Fernández & Carballeira, 2001):

$$CF = \frac{C_m}{C_b} \tag{1}$$

where C_m is the content of a selected element and C_b is the background concentration for the same element.

Contamination degrees can be categorized as following: CF < 1—no contamination; 1–2—suspected; 2–3.5—slight; 3.5–8—moderate; 8–27—severe and > 27—extreme (Fernández & Carballeira, 2001).

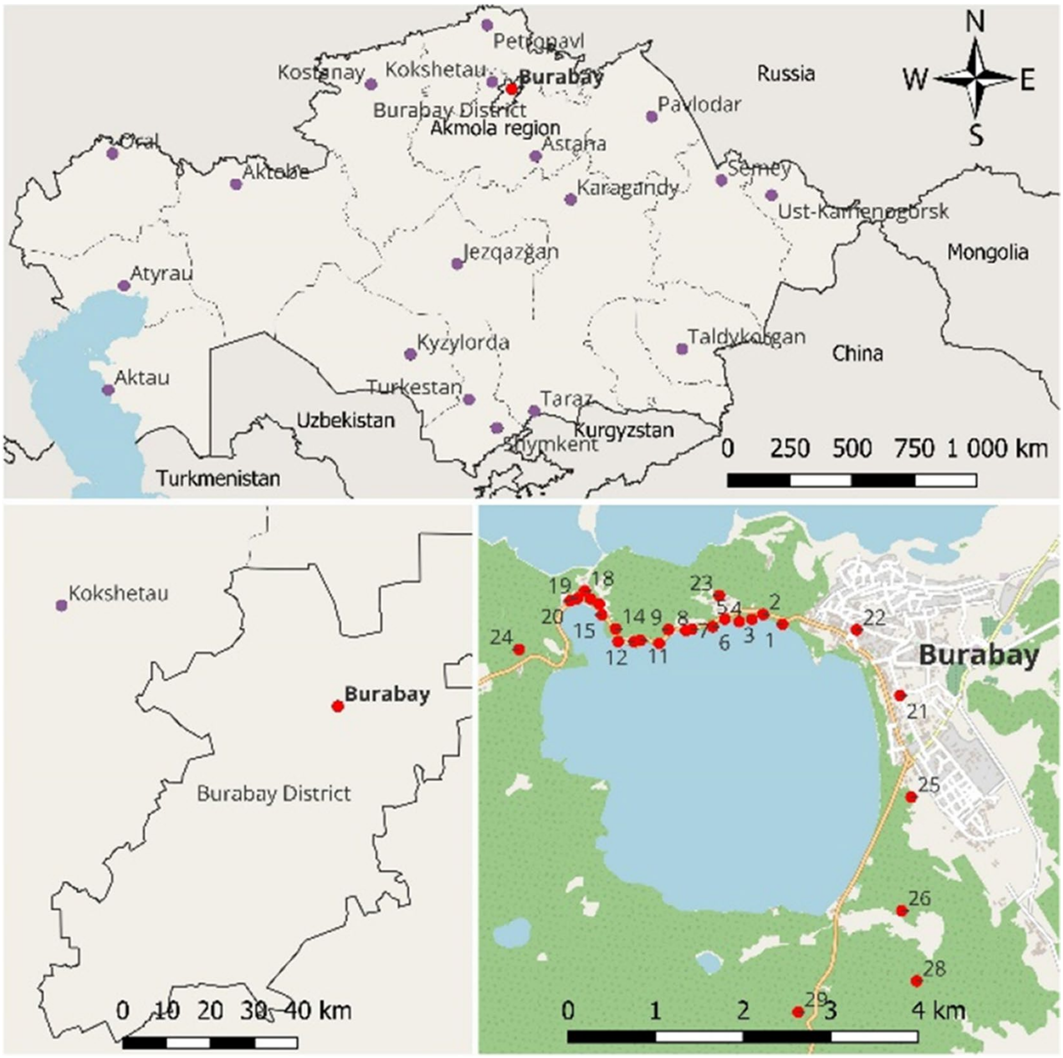

Fig. 1 Moss sampling map in the Burabay State National Natural Park in the Akmola region, Kazakhstan

The PLI represents the n^{th}-order geometric mean of the entire set of CF values (Tomlinson et al., 1980):

$$\mathrm{PLI} = \sqrt[n]{\prod_{i=1}^{n} C_{F,i}} \quad (2)$$

where n is the total number of elements.

The PLI data are classified in several groups: $PLI < 1$—unpolluted, $1 < PLI < 2$—unpolluted to moderately polluted, $2 < PLI < 3$—moderately polluted, $3 < PLI < 4$—moderately to highly polluted, $4 < PLI < 5$—highly polluted and $PLI < 5$—very highly polluted (Wu et al., 2018).

Ecological risk index (RI) is used to measure the ecological risk of a given element in moss according to the toxicity of metals and response of the environment:

$$RI = \sum PER_f^i \quad (3)$$

$$PER_f^i = C_f^i \times T_f^i \quad (4)$$

where PER_f^i is the potential ecological risk index of each element, C_f^i is the contamination factor and T_f^i is the "toxic-response" coefficient for the given single metal. The toxic response factors are 2 for Cr, 6 for

Ni, 5 for Cu, 10 for As, 30 for Cd, 1 for Zn and 5 for Pb (Hakanson, 1980). The ecological risk according to its severity is classified into four groups: RI < 150—low ecological risk; 150 ≤ RI < 300—moderate ecological risk; 300 ≤ RI < 600—considerable ecological risk; RI ≥ 600 – very high ecological risk (Hakanson, 1980).

The enrichment factor *(EF)* is calculated according to the following Eq. (5):

$$EF = \frac{M_x Sc_b}{M_b Sc_x} \tag{5}$$

where M_x and Sc_x are the element and Sc concentration in experimental sample, while M_b and Sc_b are their background concentrations. Upper continental crust values were used as reference values (Rudnick & Gao, 2003).

An *EF* value lower than 1.5 suggests that elements may originate from natural sources, while an *EF* value greater than 1.5 suggests that elements originate from anthropogenic activity (Liu et al., 2015).

Results and discussion

Basic statistics

The basic statistics for 38 elements (minimum, maximum, median, mean, standard deviation (SD) and coefficient of variation (CV)) determined in moss samples appying two analytical techniques is presented in Table 1.

The values of the coefficient of variation calculated for determined elements ranged from 24 to 170%, indicating a large range of variation. The highest variations were obtained for Sm, Th, U, La, Au and Ce 122%, 125%, 131%, 147%, 154% and 170%, respectively. It is considered that a large range of variation points at a significant difference in the content of elements throughout the study region (Stafilov et al., 2020) as well as presence of outliers or extremally high values determined by geological conditions or anthropogenic activity (Tepanosyan et al., 2022). As it was previously shown in biomonitoring studies performed in Albania (Allajbeu et al., 2016) and Serbia (Aničić Urošević et al., 2020) the accumulation of rare earth elements in mosses can be associated with the wind-blowing metal-enriched soils. Particular ratios of rare earth elements can be used to understand their origin. According to Olmez and Gordon (1985), the La/Sm ratio less than 4.9 indicates

Table 1 Basic statistic for 38 elements determined in moss samples collected in the Burabay State National Natural Park, Kazakhstan, (in mg/kg dry weight)

Element	Range	Median	Mean ± SD	CV, %
Na	260–2790	625	730 ± 560	76
Mg	1100–6310	2150	2615 ± 1270	48
Al	1410–15,800	3010	4030 ± 2990	74
Cl	45.6–269	119	130 ± 56	43
K	3040–9470	6290	6470 ± 1540	24
Ca	1620–11,000	4730	5510 ± 2410	44
Sc	0.29–3.81	0.7	1.1 ± 0.08	73
Ti	61.7–832	205	260 ± 17-	66
V	2.63–25.1	5.9	7.4 ± 5.0	68
Cr	3.19–17.9	7.4	8.6 ± 3.7	43
Mn	44.3–444	198	215 ± 100	47
Fe	884–10,000	2030	2720 ± 1950	72
Co	0.48–3.91	1.1	1.4 ± 0.9	62
Ni	1.8–8.81	3.4	4.0 ± 1.8	45
Zn	28.3–101	44	50 ± 18	34
As	0.88–5.42	2.5	2.8 ± 1.2	43
Se	0.17–0.4	0.27	0.28 ± 0.07	23
Br	2.44–12.8	4.1	4.7 ± 2.2	47
Rb	4.76–26.2	9.2	10 ± 4.0	44
Sr	14.9–53.8	24	30 ± 11	41
Zr	4.02–29.5	8.2	11 ± 7.9	69
Sb	0.14–0.72	0.25	0.3 ± 0.1	46
Cs	0.22–1.85	0.4	0.5 ± 0.3	63
Ba	12.5–84.4	35	40 ± 20	51
La	0.78–31.8	2.04	4.0 ± 6.0	147
Ce	1.54–69.3	3.8	7.5 ± 12.7	170
Nd	0.38–14.4	1.7	2.6 ± 2.9	110
Sm	0.1–3.07	0.3	0.48 ± 0.59	122
Eu	0.03–0.34	0.09	0.11 ± 0.07	63
Tb	0.02–0.48	0.04	0.07 ± 0.09	122
Hf	0.08–1.76	0.2	0.34 ± 0.32	94
Ta	0.02–0.41	0.05	0.07 ± 0.07	106
W	0.004–1.59	0.3	0.5 ± 0.47	93.4
Au	0.0002–0.02	0.001	0.003 ± 0.005	154
Th	0.23–7.27	0.6	1.07 ± 1.33	125
U	0.08–2.1	0.19	0.36 ± 0.48	131
Cu	1.66–15.3	4.8	5.6 ± 3.4	60
Pb	2.31–43.46	7.5	9.6 ± 9.7	100

elements geogenic origin; higher values may be indicative for emissions from petroleum products and motor-vehicle emissions. In the present research the values of La/Sm ratio ranged from 5.1 to 12.1, pointing to anthropogenic origin of mentioned elements.

When comparing the median and mean values of the elements' concentration a skewness in the data distribution was observed. The highest difference between mean and median values was obtained for Au (three times), La (two times) and Ce (two times). For U, W, Tb, Th, Sm and Nd the mean to median ratio was higher than 1.5, while for Hf, Sc, Ta, Zr, Fe, Al, Co, Pb, Ti, V, Eu, Mg, Sr, Cs, Ni, Na, Zn, Cu, Cr, Ca, Sb, Ba, Br, As, Cl, Mn and Rb it lied between 1.0 and 1.5. The ratio lower than 1.0 was obtained for Se and K. In a biomonitoring study performed in several Polish National Parks the most significant difference between the mean and median values of the concentrations was obtained for Sc, while for Hf, Co, Fe, Na, V, Cs, Al, Mg and Cr it was higher than 1.5 (Kosior et al., 2020).

Factor analysis

Factor analysis, widely applied in biomonitoring studies, was used to see the relationships between determined elements and identify emission source. Four main factors that represent 85% of the total variance were revealed, and the matrix of rotated factor loadings is presented in Table 2.

Factor 1 (45% of variance) includes elements: Na, Mg, Al, Sc, Ti, V, Cr, Fe, Co, Ni, Rb, Sb, W, Th and U, which most probably have geogenic origin (soil and dust particles) (Chaligava et al., 2021; Sorrentino et al., 2021). Since in the Akmola region the climate is dry with little precipitation, soil erosion can affect moss contamination with mineral particles (Akiyanova et al., 2019; Baisholanov, 2017). Similar results were reported for the Republic of Moldova (Zinicovscaia et al., 2022) and Northern Greece (Betsou et al., 2021). Weathering of granites and minerals containing Al, Fe, Mg, Cr, Mn, Ni, V, Cu and W, mining and gravel roads can be regarded as alternative source of element accumulation in moss. In general, the elements included in Factor 1 had a relatively uniform distribution throughout the study area. The maximum factor scores were obtained at sites 10, 13, 17 and 29.

Table 2 Matrix of rotated factor loadings. Varimax normalized

Element	Factor 1	Factor 2	Factor 3	Factor 4
Na	**0.92**	0.26	0.20	0.10
Mg	**0.83**	0.38	0.12	0.22
Al	**0.96**	0.20	0.09	0.09
K	0.16	0.08	**0.77**	0.45
Ca	0.29	**0.66**	−0.08	0.51
Sc	**0.89**	0.36	0.18	0.01
Ti	**0.90**	0.28	0.08	0.12
V	**0.92**	0.28	0.12	0.10
Cr	**0.64**	**0.66**	0.21	−0.12
Mn	0.05	0.22	**0.82**	−0.04
Fe	**0.90**	0.35	0.22	0.01
Co	**0.81**	0.50	0.18	0.09
Ni	**0.73**	0.50	0.24	0.11
Zn	0.46	**0.61**	0.50	0.22
As	0.45	**0.71**	0.33	−0.24
Se	0.21	0.10	**0.67**	−0.37
Br	0.38	**0.63**	0.21	−0.09
Rb	**0.76**	0.16	0.52	0.00
Sr	0.55	**0.63**	0.07	0.36
Zr	0.17	**0.90**	0.14	−0.05
Sb	**0.83**	0.40	0.18	−0.08
W	**0.63**	0.48	0.03	0.36
Th	**0.94**	0.00	0.14	0.08
U	**0.76**	0.33	−0.05	0.01
Cu	0.45	0.08	0.19	**0.76**
Pb	−0.09	−0.09	−0.10	**0.75**
Prp.Totl	0.45	0.20	0.11	0.09
Expl.Var	11.67	5.11	2.82	2.24

$p < 0.05$, significance of bold entries

Factor 2 accounts for 20% of the total variance and is linked with high loadings of Ca, Cr, Zn, As, Br, Sr and Zr. The main source of Ca, Br, Sr and Zr can be considered soil erosion, road dust, mining and construction activities, including road maintenance and repair (Wang & Zhang, 2018; Wei & Yang, 2010). Akmola region is a large mining region in the Republic of Kazakhstan, with 23% of republican gold reserves, 5.5% of uranium, 3.1% of titanium, 3% of iron, 1.7% of manganese, 1.2% of molybdenum and 100% of industrial diamond reserves. The region has 51 deposits of ore minerals. Of these, 32 are gold mining sites, 14 are uranium deposits, four are iron ore deposits, one titanium deposit and one zirconium deposit (Department of Entrepreneurship and Industry of Akmola region., 2024, Official Information Source of the Prime minister of the Republic of Kazakhstan., 2024). Thus, mining and processing of the ores are the main source of Zr emissions. In the Burabay district there operates the limited liability partnership "Kaysar-B", which activity includes operation of gravel and sand pits in the as well as production of ready-mixed concrete. Dust formed during production can contain Cr and Zn (Silva et al., 2021).

Arsenic in the studied region can be emitted during operation of diesel engines (Talebi & Abedi, 2005), while tire abrasion and diesel soot are important source of Zn (Adamiec et al., 2016). The main anthropogenic sources of Cr entering the environment are fuel combustion, ferrous metallurgy and the metalworking industry (Saha et al., 2022). High content of Cr is usually characteristics for road dust from a heavily used roads (Murakami et al., 2007). The maximum factor scores were identified for sampling sites 5, 8, 13, 16 and 17.

Factor 3 (11% of the total variance) contains high loadings of K, Mn and Se. These elements can be associated with the physicochemical characteristics of the moss. An important source of the K can be agricultural activity (use of potassium fertilizers) (Yeszhanov et al., 2023). Coal combustion, oil refining, fossil fuel and insecticide production are important sources of Se (Ullah et al., 2023). Since Se is present in ores including copper, nickel and lead mining can contribute to its emissions in Akmola region. Mn is an essential element for moss, and, therefore, moss has a high capacity to regulate the levels of this element, unlike those of other contaminants (Kosior et al., 2020). The maximum factor scores were identified at sites 5, 11, 14, 15 and 29.

Factor 4 (9% of explained variance) is represented by Cu and Pb. Lead is an important component of bearing alloys (Skorbiłowicz & Skorbiłowicz, 2019) and in case of studied region an important source of its emission can be considered mining activity (Obukhov et al., 2023). Copper is involved in a number of biochemical processes in plants. However, its concentrations in the environment are currently increasing, mainly due to anthropogenic impact. Copper contamination can originate from friction materials used in the braking system (Skorbiłowicz & Skorbiłowicz, 2019). The maximum factor scores were identified at sites 1, 22 and 28.

Ecological indices of environment contamination

The contamination factor (CF) and pollution load index (PLI) values are shown in Table 3. The background concentrations of elements in mosses were calculated using the "Iterative 2σ-technique" method (Matschullat et al., 2000). The investigated areas can be divided into two pollution categories based on average CF values (Table 3): no contamination and suspected contamination. Nonetheless, CF values at a few sampling locations varied from 3.5 to 8, indicating a moderate level of contamination. Thus, high CF values for W (4.03–6.87), Fe (5.59), Cu (3.58), Pb (6.5–7.62), Co (4.4), V (4.64), Al (5.43) and U (3.56–13) were obtained near the village of Borovoe. The Burabay State National Natural Park can be characterized as unpolluted based on the PLI values.

A low potential environmental risk was indicated by the average PER values for Cr (2.47 ± 1.08), Cu (6.6 ± 3.98), Zn (1.19 ± 0.41), As (11.71 ± 5.02), Pb (8.16 ± 8.48) and Ni (7.65 ± 3.49) below 40. RI values ranged from 17.05 to 68.64 (Fig. 2), with an average value (37.79 ± 14.54) indicating a low environmental risk. The highest RI values were obtained

Table 3 Mean values of the pollution load index (PLI) and contamination factor (CF) as well as the background values for selected elements in moss samples collected in the Burabay State National Natural Park

Element	Background, mg/kg	CF	SD	Element	Background	CF	SD
Al	2910	1.39	1.03	Ni	3.15	1.27	0.58
As	2.39	1.17	0.5	Pb	5.7	1.69	1.7
W	0.23	2.15	2.02	Sb	0.22	1.29	0.59
Co	0.89	1.59	0.99	Zn	43.5	1.19	0.41
Cr	6.97	1.24	0.54	U	0.16	2.25	2.96
Fe	1790	1.52	1.09	V	5.41	1.37	0.93
Cu	4.27	1.32	0.8	PLI = 1.35 ± 0.7			

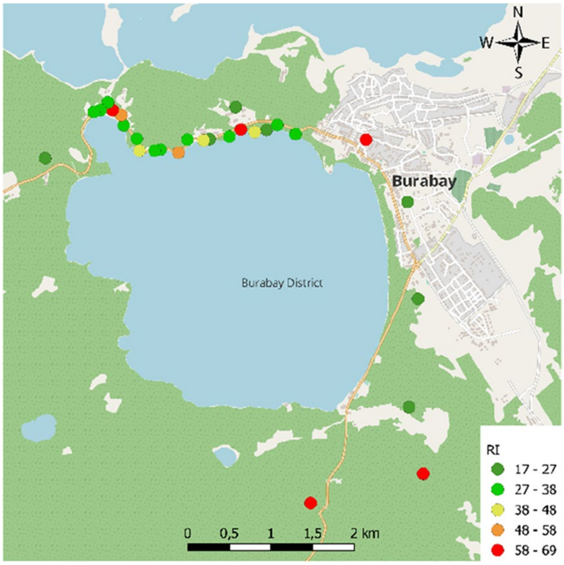

Fig. 2 The spatial distribution maps build for ecological risk index in moss samples collected in the Burabay State National Natural Park

near the village Burabay, indicating the negative impact of human (touristic) activities on air quality.

The maps of spatial distribution created for Cr, Ni, Co, Zn, V, Fe, As and Sb are shown in Fig. 3. The Zn content in the majority of moss samples matched the background values. Maximum content (> 80 mg/kg) was determined at sites 5 and 17. The same pattern was observed for V; its content in the main part of the sampling sites was on the level of background. Background exceedance was observed at site 29 (> 8 mg/kg) and at sites 5, 10, 17 (> 6 mg/kg). EFs for Zn ranged from 4.1 to 30 and for V from 0.6 to 1.6. Thus, V is entirely from natural processes, whereas Zn can be of anthropogenic origin. Zinc is widely taken as a tracer of tyre wear (Beddows et al., 2023).

According to the calculated CF values (Table 3), Sb contamination can be considered suspected. The relatively uniform distribution of Sb in the study area indicates its anthropogenic origin. The EF values in the range of 5.4–18 support this fact. The maximum values (in the range of 0.35 mg/kg) were determined at sampling sites 5, 8, 10, 13, 16, 17 and 29, located close to roads. Antimony is added to friction material as a lubricant and comprises up to 5% of brake linings, mostly in the form of stibnite (Földi et al., 2018).

Iron is considered the main element of terrigenous origin. In general, Fe levels were consistent with background values throughout the area, with the exception of sites 5, 10, 13, 17 and 29, where Fe levels exceeded 4000 mg/kg. The EFs for Fe varied between 0.1 and 1.1 confirming its geogenic origin. The content of Ni was relatively low throughout the study area, except sites 5, 10, 17 and 29, where its content was higher than 6 mg/kg. The EFs for Ni were in the range of 0.7–1.9 and can be considered element of geological origin. The same pattern was observed for Co (EFs 0.5–1.5); its content exceeds background value only at sampling site 29. The content of As in moss samples was 4 times higher than the background level, except sites 1, 2, 23 and 28. The EF values for As were in the range of 3.2–16 that points at its anthropogenic origin. Considerable amount of arsenic is emitted during operation diesel engines (Talebi & Abedi, 2005). According to the calculated CF values (Table 3), contamination of environment with Cr can be considered suspected. The maximum Cr content (> 15 mg/kg) was determined at sampling sites 5 and 29. The relatively uniform distribution of Cr in the study area and EFs in the range of 0.6–2.5 indicate its mainly geogenic origin. In general, the high level of elements was determined at sampling sites 5, 10, 17 and 29 located near village Burabay, indicating that their sources are mainly resuspension of soil participles, road dust and vehicles.

Comparison with the literature data

The mean concentrations of the elements determined in the present study were compared with values reported for Burabay State National Natural Park and national parks in other countries (Table 4).

Bukabayeva et al. (2023) measured the level of Pb, Cr, Cd, As, Ga, V and Cs epiphytic and epigeal lichens collected near the roads in the Burabay National Park. The mean values of the elements were lower than in the present study. Scots pine was selected as a bioindicator of air pollution in the Burabay National Park by Yelkenova et al. (2023). The content of elements in pine needles, expect Mn, was lower than in *Hylocomium splendens* samples. It should be mentioned that in previously performed studies authors covered a very limited area in the national park. The concentration of elements in analyzed moss samples agreed reasonably well with the

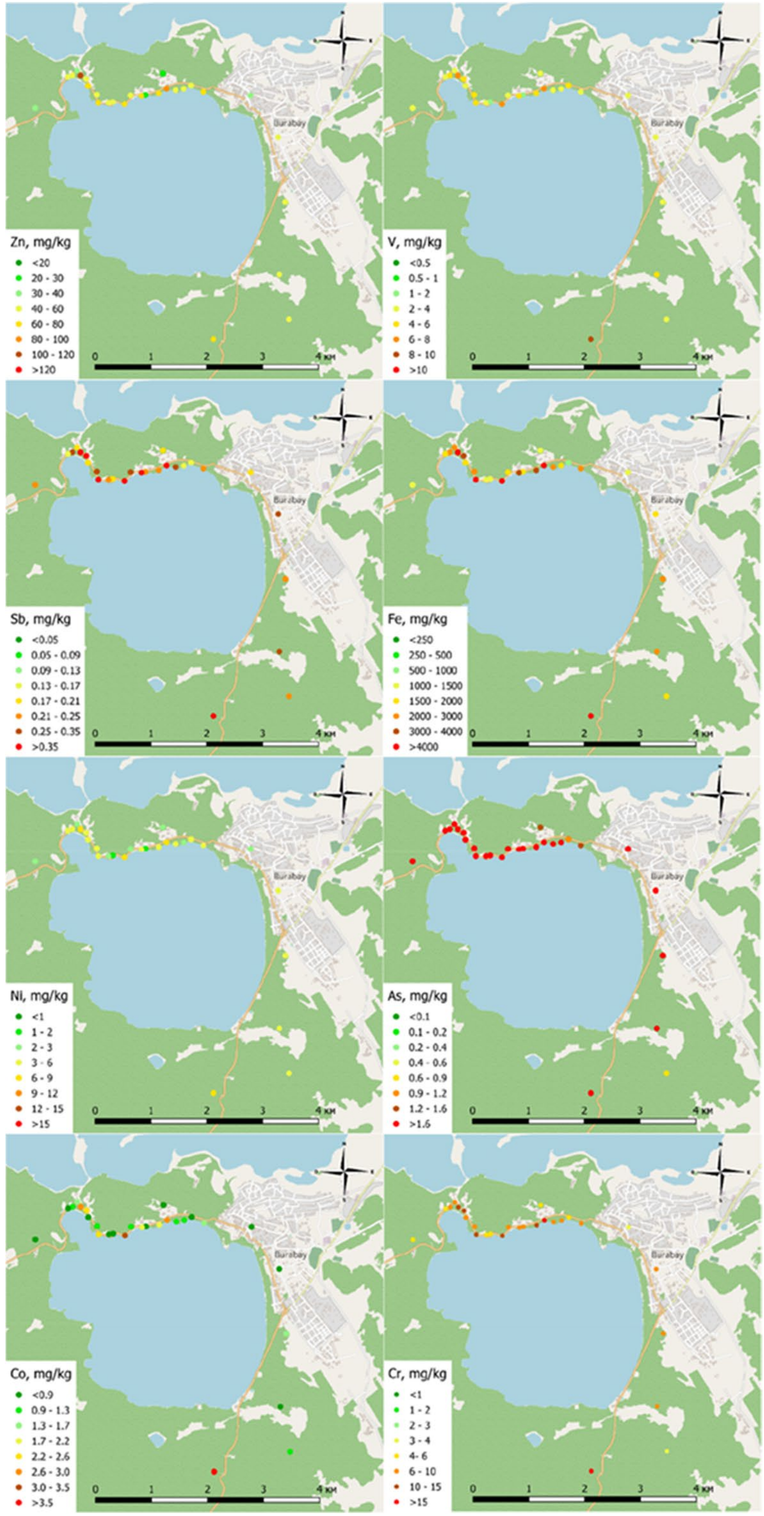

Fig. 3 The spatial distribution maps build for Cr, Ni, Co, Zn, V, Fe, As and Sb levels determined in moss samples collected in the Burabay State National Natural Park

Table 4 Comparison of the obtained mean values with the literature data reported for national parks, in mg/kg dry weight

Reference	Species	Element							
		Cu	Pb	Zn	Mn	Cr	Co	As	Cs
Present study	*Hylocomium splendens*	5.64	9.64	51.8	215.7	8.61	1.41	2.8	0.5
Lichens (Bukabayeva et al., 2023)	*Cladonia alpestris* (L.) *Rabenh*	4.4	6.11	32.9	65.5	6.19	0.56	2.19	0.26
Pine needles (Yelkenova et al., 2023)	*Pinus sylvestris* L	2.2	0.68	36.4	285	1	0.07	0.0015	0.017
Mountainous parks, Poland (Kosior et al., 2020)	*Pleurozium schreberi*	8.8	10.7	54	207	4.2	0.5	0.4	0.5
Lowland parks, Poland (Kosior et al., 2020)	*Pleurozium schreberi*	6.4	4.9	40	406	1.6	0.2	0.2	0.3
Słowiński National Park (Bykowszczenko et al., 2006)	*Pleurozium schreberi*	-	-	38	-	0.8	-	-	-
Buzuluksky Bor, Russia (Bogdanova et al., 2022)	*Pleurozium schreberi*	9.83	-	38.5	345	5.32	0.5	0.63	-

moss biomonitoring data reported for mountainous parks in Poland, but was higher than values obtained for lowland parks (Kosior et al., 2020). The mean content of Zn in the presented study was comparable with its level in Słowiński National Park (Poland), while level of Cr was significantly higher (Bykowszczenko et al., 2006). In "Buzuluksky Bor" in Russia mean content of Cu and Mn was higher than values obtained in the present study, while levels of other elements were comparable or lower. High levels of Co and Cr in *Hylocomium splendens* can be explained by its higher bioconcentration capacity as well as morphological differences or differences in specific surface area (Carballeira et al., 2008). Higher accumulation of elements in *Hylocomium splendens* in comparison with other moss and lichens species was shown in Carballeira et al. (2008) and Coskun et al. (2009).

Conclusions

Monitoring of the ecological situation in national parks is of critical importance in order to maintain their unique biodiversity. Moss biomonitoring, at this stage not very common in Kazakhstan, was applied to assess the level of air pollution in Burabay National Park. The content of 38 elements determined in 29 moss samples using two analytical techniques varied in a wide range, and the highest concentration of elements was determined near village Burabay, the famous tourist destination. According to factor analysis main sources of elements emission in the park can be considered soil erosion, weathering of granites and minerals, mining, ore processing, agricultural practice and vehicles. The level of environment pollution changed from unpolluted to moderate polluted with low potential ecological risk for human health. The high CF values were obtained for W, Fe, Cu, Pb, Co, V, Al and U mainly near the village of Burabay. Comparison of the obtained results with the data reported for national parks in other countries showed high uptake of Co and Cr in moss samples, which can be explained by high bioaccumulation capacity and morphological features of *Hylocomium splendens*. According to EF values Zn, As and Sb may originate from anthropogenic sources, while V, Fe, Ni, Co and Cr are more likely of geogenic origin.

Despite the fact that the Burabay National Park is protected by the state the anthropogenic pressure on it is constantly growing. A high level of tourism development as well as active industrial activity in the region poses a serious threat to the park's ecosystems. Application of the moss biomonitoring technique is a cheap and effective approach to control the quality of the air in the park. The data can be used by national authorities to prevent deterioration of the environmental situation.

Author contribution Makhabbat Nurkassimova- moss samples collection, ICP-OES analysis, manuscript draft preparation and final revision; Nuriya Omarova—samples collection, ICP-OES analysis, manuscript final revision; Inga Zinicovscaia – performing of neutron activation analysis, manuscript draft preparation and final revision; Nikita Yushin- performing of neutron activation analysis, mapping, manuscript final revision; Omari Chaligava- statistical analysis, manuscript final revision. All authors agree with the final version of the manuscript.

Data availability Experimental data will be made available on the request.

Declarations

Ethics approval All authors have read, understood and have complied as applicable with the statement on "Ethical responsibilities of Authors".

Competing interests The authors declare no conflict of interests.

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