Investigation of Elemental Deposition in Lamdong Province (Vietnam) by the Moss Biomonitoring Method and Neutron Activation Analysis

Le Hong Khiem
Institute of Physics
Nguyen Thi Minh Sang
University of DaLat
Son Nguyen An (sonna@dlu.edu.vn)
University of DaLat https://orcid.org/0000-0003-2108-439X
Truong Van Minh
Dongnai University
Tran Tuan Anh
Dalat Nuclear Research Institute
Ho Huu Thang
Reasearch and development centre for radiation technology
Le Dai Nam
Physics Institute

Research Article

Keywords: air pollution, heavy metal, moss biomonitoring, neutron activation analysis, Lamdong

Posted Date: May 19th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1628695/v1

Abstract

The results of an investigation of heavy metal air pollution in Lamdong province (Vietnam) using the moss biomonitoring method are presented in this paper. *Barbula indica* moss samples were collected at 30 different locations in Dalat and Baoloc, two major cities of Lamdong province. The concentrations of 10 heavy metal and metalloid elements, Sc, V, Cr, Mn, Fe, Co, Zn, As, Hf, and Ta in the collected moss samples, were determined by the neutron activation analysis method using the nuclear reactor at the Nuclear Research Institute in Dalat, Vietnam. The results show that the air in Lamdong province may be polluted by Mn and is moderately polluted by Sc, V, Cr, Fe, Co, Zn, As, Hf and Ta. The main sources of heavy metal pollution in the Lamdong atmosphere may be soil dust, traffic emissions, industry, bauxite mining and refining, chemical fertilizers and pesticides, and combustion of coal and oil. By comparing heavy element concentrations in the moss from Lamdong with that of Hanoi, Thainguyen, and several European countries, it is found that heavy metal air pollution in Lamdong is much lower than in Hanoi and Thainguyen and much higher than in the European countries.

Introduction

Air pollution threatens the health of people everywhere in the world. Air pollution exposes people to fine particles in polluted air. These fine particles penetrate deep into the lungs and cardiovascular system, causing strokes, heart disease, lung cancer, chronic obstructive pulmonary disease, and respiratory infections. According to the experts, the main sources of air pollution in Vietnam include the high densities of motorbikes and vehicles in inner city areas, construction work that is not carefully shielded, highly polluting industries such as thermal power, iron and steel, and cement production, the burning of straw by farmers, and the use of coal for cooking by households. According to the report of Greenpeace International on "The status of global air quality in 2018", Vietnam is one of the countries with very high air pollution levels. In Vietnam, air pollution continues to increase at an alarming rate. Air pollution not only affects human health and quality of life directly, but also indirectly affects economic development. It is estimated that about 60,000 Vietnamese people die each year from air pollution. How dangerous is air pollution in Vietnam today? It is still a controversial issue in the scientific community. Although the authorities have implemented many measures to improve the quality of the air, the Vietnamese people are still very worried about air quality.

In order to cope with air pollution, it is necessary to have data on pollution levels over time in all provinces across the country. Automatic air quality monitoring stations have been installed in the largest cities of Vietnam. However, due to high costs, automatic air quality monitoring stations have not yet been installed in small cities, such as those in Lamdong province. To have data on air quality in these provinces, other methods of monitoring are needed.

Around the world, the moss biomonitoring method to study air pollution has been frequently implemented because it is cheap and can be easily carried out over a large area. This method provides the data on airborne chemical elements needed to assess air quality and is very suitable for developing countries like Vietnam. In Vietnam, investigations of air pollution using the moss biomonitoring method have been performed in Hanoi and some other big cities (Nguyen et al. 2010; Doan Phan et al. 2019; Khiem et al. 2020a; Khiem et al. 2020b).

This report presents the results of an investigation of heavy metal air pollution in Lamdong province using the moss biomonitoring method. Samples of *Barbula indica* moss were collected at various locations in the cities of Dalat and Baoloc in Lamdong province in December of 2019. The concentrations of heavy metal elements in the moss samples were determined by the neutron activation analysis method using the nuclear reactor at the Dalat Nuclear Research Institute. The possible sources of heavy metal air pollution are identified by the application of factor analysis.

Materials And Methods

Study area

Lamdong province is located in the South Central Highlands at an average elevation of 800–1000 m above sea level. Lamdong has 12 administrative units including two cities, Dalat and Baoloc. Dalat is the administrative-socio-economic center of Lamdong province. Dalat is a famous tourist city of Vietnam and is located at an altitude of 1500 m above sea level. With many beautiful landscapes, Dalat is known as the city of flowers, the city of love, and the city of fog. Baoloc is located at an altitude of 900 m above sea level and is a rich agricultural land. It is assumed that Lamdong is one of the provinces with the best air quality in Vietnam. The main economic sectors of Lamdong are tourism, high-tech agriculture, processing industry, mineral exploitation, and production of household appliances. The areas studied in this work were total 30 locations, 19 of which were in Dalat and 11 of which were in Baoloc, from November of 2020 to March of 2021 (Fig. 1).

Moss sampling

The most common moss species in Vietnam is *Barbula indica*. Therefore, it was chosen for biomonitoring in our investigation of elemental atmospheric pollution in Lamdong province. *Barbula indica* has been used in several previous investigations in Vietnam (Nguyen et al. 2010; Doan Phan et al. 2019; Khiem et al. 2020a; Khiem et al. 2020b). The collection of the living moss at the field sites under investigation was performed in accordance with the guidelines of UNECE ICP 2015 (ICP 2015). Information about each collected sample was written in the sampling log book, including the time of sampling, the coordinates (longitude and latitude) of the sampling point, and the characteristics of the area around the sampling point. The latter information is helpful in understanding sources of heavy element concentrations in the moss samples. The moss plants were collected carefully using plastic tweezers and kept in sealed plastic bags to avoid contamination. All moss sampling sites were chosen at locations more than 200 meters from highways and more than 50 meters from small roads. The moss plants collected in an area of 2 km × 2 km were combined into one sample.

Moss sample preparation

After the moss samples were transferred to the analytical laboratory at Dalat University, they were first sorted to remove rubbish and non-moss plants. In the second step, the green part of the moss plants was selected. In the third step, the moss plants were washed carefully using double-distilled water. According to Aničić (Aničić et al. 2007) there is only a small difference in concentration between the washed and unwashed moss for the majority of the analyzed elements. These differences are within the analytical error of neutron activation analysis. Finally, the moss samples were dried in an oven at a temperature of 40°C until the sample masses no longer change to ensure that the water in the moss has evaporated. The preparation of the moss samples was always carried out with plastic gloves to avoid contamination. The dry mosses were used to make samples for irradiation in the Dalat nuclear research reactor.

Neutron activation analysis

Neutron activation analysis is recognized as a very effective analytical technique for determining the elemental composition of samples. With high sensitivity and good accuracy, as well as the ability to analyze multiple elements simultaneously, the method has been used widely in many fields of research, such as biology, environmental science, geology, and industry, etc. The Dalat nuclear research reactor, the only one available in Vietnam, has been used to analyze elemental concentrations of geological, biological, and environmental samples since the 1980s. Its power is 500 kW and the thermal neutron flux is about 10^{13} neutrons/cm^2/s.

The neutron activation analysis method based on k_0 standardization is one of the well-known methods for calculating elemental concentrations. The method was first developed in 1974 by De Corte et al. (1987). Since then, the k_0 method has been used by many neutron activation analysis (NAA) laboratories and has been recognized by the Nuclear Analysis Association as a standardized analytical method. The k_0-NAA method has been used in investigations at the Dalat Nuclear Research Institute since the 1980s. By 2002, this method was officially applied through the K_0-DALAT program. The main advantages of the k_0-NAA method are its simplicity and, especially, its ability to make measurements without the use of different multi-element reference materials. The general procedure of neutron activation analysis for biological samples at the Dalat nuclear reactor is described briefly below.

To irradiate the moss samples, two neutron irradiations in the active zone of the reactor were used, namely channel 7 – 1 with a neutron flux of about 4.2×10^{12} neutrons/cm^2/s and the irradiation hole of the rotary rack with a neutron flux of about 3.5×10^{12} neutrons/cm^2/s. The average masses of the dried moss samples for the short and long irradiations were about 60 mg and 160 mg, respectively. The samples were sealed in polyethylene bags for both short and long irradiations.

To measure the gamma spectra of the irradiated moss samples, a gamma multi-channel spectrometer was used. It consists of a HPGe detector with a resolution (full width at half maximum) of 2.0 keV at 1332 keV and a relative efficiency of about 40%. Genie-2K software was used to analyze the gamma spectra and the K_0-Dalat software (Dung et al. 2003; Dung et al. 2016a) was used to determine the elemental concentrations from the obtained count rates.

To maximize the analytical sensitivity of the elements of interest, two modes of sample irradiation were applied: short and long irradiations. Channel 7 – 1 was used for the short irradiation mode with an automatic sample pneumatic system to transfer the sample to the irradiation location in the active zone and back to the detector for gamma-ray measurement. This mode is used to determine the concentration of the short-lived radioactive isotopes, including V, Cl, Mn, I, and Dy. The sample irradiation time was 120 s. To analyze V, a decay time of 600 s and a measuring time of 150 s were used. For other elements, including Cl, Mn, I, and Dy, a decay time of 3600 s and a measuring time of 400 s were used.

For the long-lived radioactive isotopes, the rotary rack was used for irradiation. We divided the long-lived radioactive isotopes into two groups. The first group includes Na, K, Ga, As, Br, La, Sm, and U, while the second group includes Sc, Cr, Fe, Co, Zn, Se, Sb, Sc, Ce, Eu, Tb, Yb, Hf, and Th. The decay and measuring times for the first group of elements were 4–6 d and 1200 s, while the decay and measuring times for the second group of elements were 30 d and 18,000 s.

The moss samples were analyzed using this procedure to determine the elemental concentrations using the Dalat nuclear research reactor and the k_0-NAA method. We focused only on the heavy metal and metalloid elements, including Sc, V, Cr, Mn, Fe, Co, Zn, As, Hf, and Ta.

Quality control

For quality control of our neutron activation analysis, certified reference materials, including SRM-1572 and SRM 1547 from NIST (National Institute of Standards and Technology), the trace elements in hay (powder) IAEA-V-10 (from the International Atomic Energy Agency), and a synthetic multi-element standard material (SMELS Types I, II, and III) were analyzed under the same experimental conditions. Our analysis procedure (Dung et al. 2016b) was used for these materials and the obtained concentrations were compared with the certified values. For all elements, the obtained concentrations were in good agreement (within 7%) with the certified values. The ratios between the measured and certified values for the elements are as follows: Cl (1.04), Sc (1.03), V (0.95), Cr (1.03), Mn(1.01), Fe (0.97), Co (0.94), Cu (1.01), Zn (1.04), As (0.98), Se (1.05), Br (0.96), Sr (1.03), Zr (0.98), Mo (1.03), In (1.05), Sb (0.97), I (1.04), Cs (0.95), La (0.97), Ce (1.01), Pr (1.01), Yb (0.96), Au (0.96) and Th (1.03).

Results And Discussion

Descriptive statistics

Microsoft Excel 2013 was used to calculate descriptive statistics. The descriptive statistics of the concentrations of 10 heavy metal elements, Sc, V, Cr, Mn, Fe, Co, Zn, As, Hf, and Ta, in the moss samples are presented in Table 1. The relative errors of the elemental concentrations for all analyzed elements are less than 15%. Concentrations are given in mg/kg. The coefficient of variation (CV) in percent was calculated as the ratio between the standard deviation and the mean concentration value. The normality of the concentration distributions for the 21 elements was tested using the Shapiro-Wilk test. The probability values (p-value) obtained for the element distributions are given in Table 1. The hypothesis of normality will be rejected (with 95% confidence) if the corresponding p-value is less than 0.05. It can be clearly seen in Table 1 that among the 10 analyzed elements, only three had a normal distribution: V, Fe, and Ta.

Table 1
Descriptive statistics

El.	Min	Max	Mean	Median	STDEV	CV (%)	p-value
Sc	0.08	3.55	1.32	1.23	0.87	66	0.157
V	0.98	18.53	7.75	7.53	4.56	59	0.098
Cr	1.11	19.91	6.93	6.09	4.52	65	0.04
Mn	50	207.4	102.28	89.59	38.46	38	0.018
Fe	284	6542	2503	2213	1615	65	0.052
Co	0.25	3.39	1.46	1.35	0.80	55	0.148
Zn	43	1298	285.47	175.5	282.7	99	< 0.001
As	0.49	17.07	3.93	2.40	4.06	103	< 0.001
Hf	0.04	1.31	0.48	0.37	0.32	66	0.020
Ta	0.02	0.41	0.15	0.14	0.10	66	0.068

The coefficient of variation for the analyzed elements varied from 38 to 103%. The maximum coefficient of variation for the concentrations was obtained for As (103%) and the minimum coefficient of variation was observed for Mn (38%). The concentrations of the 10 heavy metal elements in the moss samples decrease in the following order: Fe > Zn > Mn > V > Cr > As > Co > Sc > Hf > Ta.

The mean elemental concentrations (mg/kg) of the moss samples collected in Lamdong, other cities in Vietnam (Hanoi, Thainguyen), and Europe (Tver, Yaroslav and Tula regions of Russia, Silesia-Kraków and Legnica-Głogów Copper Basin of Poland, Prut river catchment region of Romania, Norway, and Moldova) are presented (Table 2). It should be noted that the same analytical technique (neutron activation analysis) was used to obtain the elemental concentration data for all regions mentioned above.

Table 2
The mean elemental concentrations (mg/kg) in moss obtained in the present work and in other cities in Vietnam and Europe

El.	Lamdong (*Present work*)	Hanoi (*Nguyet et al. 2010*)	Thainguyen (*Nguyet et al. 2010*)	Tver and Yaroslav regions, Russia (Ermakova et al. 2004a)	Tula region, Russia (Ermakova et al. 2004b)	Silesia-Kraków and Legnica-Głogów Copper Basin, Poland (Grodzinska et al. 2003)	Prut river catchment, Romania (Lucaciu et al. 2004)	Norway (Steinnes et al. 2016)	Moldova (Zinicovscaia et al. 2017)
Sc	1.32	1.16	1.3	0.14	0.57	0.19	0.48	0.1	1.1
V	7.75	17.28	53	3.2	8	3.9	7.0	1.6	9.6
Cr	6.93	20.81	16	1.5	5	6.2	5.4	1.1	10.3
Mn	102.28	147.8	153	400	300	145	180	450	132
Fe	2503	4400	4700	550	2200	1226	1900	490	3300
Co	1.46	1.93	1.5	0.41	0.63	0.3	0.57	0.5	1.4
Zn	285.47	457.7	121	34	54	150	40	36	39
As	3.93	3.19	9.9	0.22	0.5	0.43	0.73	0.17	1.2
Hf	0.48	0.68	1.8	0.18	0.82	0.17	0.53	-	-
Ta	0.15	0.22	0.2	0.020	0.078	0.02	0.056	-	-

Comparing the concentrations of the elements in the moss samples from Hanoi and Lamdong, we found that except for Sc and As, the concentrations of the other metal elements, V, Cr, Mn, Fe, Co, Zn, Hf, and Ta, are from 1.32 to 3 times higher in Hanoi than in Lamdong. This is understandable because there are many more sources of pollution in Hanoi than in Lamdong. Hanoi is now considered one of the two most polluted cities, in Vietnam. In the case of Thainguyen, the concentrations of all elements except Zn are higher than in Lamdong. In particular, the concentrations of some elements in the samples of Thainguyen are very high in comparison with those in Lamdong, namely, 6.84 times for V, 3.75 times for Hf, and 2.52 times for As. Thainguyen is also the major center of the country and there are many ore mines, especially iron ore. Therefore, air pollution in this area is expected to be much higher than in Lamdong.

Looking the element concentrations in the moss from European countries listed (Table 2), it is clearly seen that heavy metal air pollution in these European countries, especially Norway, is much lower than in Lamdong, Hanoi, and Thainguyen.

To visualize more clearly the differences in the mean concentrations of 10 metal elements in the mosses of Lamdong, Hanoi, Thainguyen, and European cities, the ratios of the elemental concentrations in the mosses from cities in Vietnam and Europe to those of Lamdong are shown (Fig. 2).

Correlation analysis

The correlation coefficients of the elemental concentrations in the moss samples can give some information about their origin. The Pearson correlation coefficients with significance level $p = 0.05$ are presented in Table 3. Several pairs of elements are strongly correlated, such as Sc and Hf ($r = 0.85$), Sc and Ta ($r = 0.787$), Sc and As ($r = 0.699$), Mn and Co ($r = 0.624$), Fe and As ($r = 0.627$), Fe and Ta ($r = 0.739$), As and Ta ($r = 0.773$), and Hf and Ta ($r = 0.745$). It was found that natural soils having high levels of Co always have the presence of Mn and Fe (Kosiorek & Wyszkowski 2019). It can be confirmed from Table 3 that there are quite strong correlations between Mn and Co (r = 0.624) and Mn and Fe (0.544). It is observed that some elements, including V, Cr, Co, and Zn, are very weakly correlated with other elements (Table 3).

Table 3
Correlation matrix

	Sc	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Zn**	**As**	**Hf**	**Ta**
Sc	1									
V	-0.029	1								
Cr	0.153	0.25	1							
Mn	0.488	0.286	0.309	1						
Fe	0.591	0.321	0.456	0.544	1					
Co	0.393	-0.122	0.323	**0.624**	0.259	1				
Zn	0.095	-0.142	0.116	0.041	0.108	0.294	1			
As	**0.699**	-0.005	0.032	0.452	**0.627**	0.102	0.142	1		
Hf	**0.85**	0.019	0.017	0.297	0.441	0.267	-0.003	0.507	1	
Ta	**0.787**	-0.05	0.189	0.509	**0.739**	0.426	0.133	**0.773**	**0.745**	1

Contamination factor

The contamination factor (CF) is a quantity that can be used to assess the pollution level of an element at the surveyed location. According to Fernandez and Cårballeira (2000), the elemental contamination factor can be evaluated by the following equation:

$$CF_{El} = \frac{C_{El}}{BG_{El}}$$

where C_{El} is the mean concentration of the element of interest in all investigated moss samples in the region under study, and BG_{El} is the background concentration. Since the background concentrations of all elements of interest in Lamdong province are not available, the minimum values of the elemental concentration listed in Table 2 were chosen as background values. Therefore, for the background values of Sc, V, Cr, Fe, Zn, Co, and As, the data of Norway (Steinnes et al. 2016) were used, while for Hf and Ta, the data of Silesia-Kraków and Legnica-Głogów Copper Basin, Poland (Grodzinska et al. 2003) were used. Finally, the mean value of the 3 smallest concentrations of Mn among all moss samples collected in Lamdong province in this work was used as the background value for Mn.

Based on the value of the elemental contamination factor, pollution levels can be divided into 6 categories ranging from C1 to C6, as follows: category C1 (unpolluted) if $CF \leq 1$; category C2 (may be polluted) if $1 < CF \leq 2$: C2; category C3 (polluted at low level) if $2 < CF \leq 3.5$: category C4 (moderately polluted) if $3.5 < CF \leq 8$; category C5 (polluted at high level) if $8 < CF \leq 27$; and C6 (extremely polluted) if $CF > 27$. The calculated values of the elemental contamination factors for Lamdong province are listed in Table 4. It can be seen from this table that the air in Lamdong province might be polluted by Mn (C2), is polluted at a low level by Co and Hf (C3), is moderately polluted by V, Cr, Fe, Zn, and Ta (C4), and is polluted at a high level by Sc and As (C5).

Table 4
Contamination factors

Element	**Sc**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Zn**	**As**	**Hf**	**Ta**
Background	0.1	1.6	1.1	56.37	490	0.5	36	0.17	0.17	0.02
Mean	1.32	7.75	6.93	102.28	2503	1.46	285.47	3.93	0.48	0.15
CF	13.20	4.84	6.30	1.81	5.11	2.92	7.93	23.12	2.82	7.50
Category	C5	C4	C4	C2	C4	C3	C4	C5	C3	C4

Factor analysis

Factor analysis is a very suitable tool to find the sources of elemental air pollution when using the moss biomonitoring technique. This method has been used by previous researchers (Schaug et al. 1990) to analyze the concentrations of elements in moss samples and identify possible sources of pollution. In this work, IBM SPSS software version 20 was used to analyze the concentration data. The results presented in Table 5 include the factor loadings of the elements as well as the eigenvalues, the explained variance, and the cumulative explained variance of the extracted factors.

Table 5
Factor analysis of the elemental concentrations in the moss samples

Element	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6
Sc	0.45	**0.80**	0.24	0.07	-0.03	0.03
V	0.03	-0.02	0.01	0.13	**0.98**	-0.08
Cr	0.07	0.00	0.18	**0.95**	0.12	0.05
Mn	0.44	0.11	**0.81**	0.08	0.28	-0.07
Fe	**0.71**	0.30	0.15	0.43	0.27	0.04
Co	-0.04	0.24	**0.88**	0.21	-0.17	0.21
Zn	0.08	0.00	0.10	0.05	-0.07	**0.99**
As	**0.90**	0.32	0.06	-0.08	-0.03	0.08
Hf	0.21	**0.96**	0.09	-0.03	0.04	-0.03
Ta	**0.66**	**0.61**	0.26	0.14	-0.10	0.05
Eigenvalue	4.395	1.551	1.338	0.882	0.677	0.584
Expl. Variance (%)	43.95	15.51	13.38	8.82	6.77	5.84
Cumulative (%)	43.95	59.46	72.83	81.65	88.42	94.26

Six factors have been extracted that can explain 94.26% of the total variance. The explained variances of Factor-1, Factor-2, Factor-3, Factor-4, Factor-5, and Factor-6 are 43.95%, 15.51%, 13.38%, 8.82%, 6.77%, and 5.84%, respectively. If the value of any factor loading is greater than 0.6, then it is written in bold (Table 5).

Before discussing the factors that have been extracted, it should be emphasized that the Central Highlands, including Lamdong province, has the largest amount of aluminum bauxite in Vietnam. Moreover, Vietnam has been estimated to hold the third largest reserves of bauxite in the world. Currently, there are two large bauxite refineries operating in Lamdong province. Aluminum and ferric oxides are the main components of bauxite (Nechitailov et al. 2008). However, other toxic metals may also contaminate the surrounding environment, depending on the characteristics of the land and the land use activities (Abdullah et al. 2016). Therefore, these refineries are expected to be large atmospheric pollution sources of heavy metal and metalloid elements.

Factor-1 and Factor-2 explain 43.95% and 15.51% of the total variance, respectively. Factor-1 is heavily loaded by the elements As (0.90), Fe (0.71), and Ta (0.66), while Factor-2 is mainly loaded by the elements Hf (0.96), Sc (0.80), and Ta (0.61). All are elements in the Earth's crust, and Fe, especially, is the fourth-most abundant element in the Earth's crust. Therefore, we can conclude at a glance that Factor-1 and Factor-2 reflect contamination with soil dust. The presence of As in Factor-1 can also be explained by the presence of As in the agricultural soil of Lamdong. This province is very famous in Vietnam for growing vegetables, coffee, and flowers. These products are supplied to the whole country, especially the southern region. To grow these products, farmers must use a lot of chemical fertilizer and pesticides with a high concentration of As, so that the soil in Lamdong might be contaminated with As. The elements present in Factor-1 and Factor-2 can also be released from other industries and human activities. As highlighted above, there are two large bauxite refineries in Lamdong, and the presence of these elements in Factor-1 and Factor-2 might be a consequence of bauxite mining activities in Lamdong province. Therefore, it is possible to say that Factor-1 and Factor-2 represent pollution sources from agriculture and the bauxite refining industry.

Factor-3 has high values for Co (0.88) and Mn (0.81), and it accounts for 13.38% of the total variance. The presence of Co and Mn in the air can be caused by both natural and man-made sources. Some of the natural sources that emit Co into the air include weathering and erosion of rocks and soil, forest fires, and evaporation of seawater, etc. Crystalline rock is the strongest natural source of Mn in the air. The other natural sources of Mn in the air are sea spray, forest fires, and vegetation activity (Schroeder et al. 1987; Stokes et al. 1988).

Several man-made sources of cobalt air pollution are reported (ATSDR 2004), namely, coal-fired plants, emissions from vehicles, mining and processing of ores containing Co, utilization of chemical supplies containing cobalt, etc. The main anthropogenic sources of Mn released to the air are industrial emissions (such as ferroalloy production and iron and steel foundries, power plants, and coke ovens), combustion of fossil fuels, and re-entrainment of manganese-containing soils (Lioy 1983; Ruijten et al. 1994).

Factor-4 contains Cr (0.95) only and explains 8.82% of the total variance. Cr rarely occurs in nature (Barałkiewicz & Siepak 1999) so Factor-4 can be related to human activities. It was suggested by Cheng that the combustion of coal and oil is the most important emission source of Cr in China (Cheng et al. 2014). In Lamdong province, coal is still the main fuel used for cooking by many families, and oil is used to pump water from underground wells to irrigate fields of vegetables, flowers, and coffee plants.

Factor-5 is heavily loaded on V (0.98) and explains 6.77% of the total variance. It has been found that combustion of fossil fuels and oil is the major source of V in the atmosphere (Kousehlar & Widom 2019). In Lamdong province, the use of fossil fuels for cooking and people's daily activities is still common. Furthermore, farmers in Lamdong province regularly use diesel-powered engines to irrigate coffee and other industrial crops. These activities may be the main sources of vanadium emission into the atmosphere.

Factor-6 contains only Zn (0.99) and explains 5.84% of the total variance. An investigation of air quality in Asian countries conducted by Hopke et al. (2008) shows that Zn is emitted into the atmosphere by two-stroke vehicles, which are a very popular means of transportation in Asia, including Vietnam. In addition, Zn can be emitted from tire wear (Blok 2005; Longhin et al. 2016). Thus, Factor-6 may be related to two-stroke motor vehicles and tire wear.

Conclusions And Recommendations

Based on the results obtained in this study, several important conclusions can be drawn:

(1) The concentrations of 10 heavy metal elements determined in the moss samples collected in Lamdong province decrease in the order of Fe > Zn > Mn > V > Cr > As > Co > Sc > Hf > Ta.

(2) The concentrations of the analyzed metal elements, V, Cr, Mn, Fe, Co, Zn, Hf, and Ta, are much smaller in Lamdong than in Hanoi and Thainguyen.

(3) By comparing the concentrations of elements in the moss of Lamdong with those from several European countries, it is found that the heavy metal pollution in the air of Lamdong is higher than that of the European countries, especially Norway.

(4) Based on the values of the elemental contamination factor, it can be concluded that the air in Lamdong province might be polluted by Mn, is polluted at a low level by Co and Hf, is moderately polluted by V, Cr, Fe, Zn and Ta, and is polluted at a high level by Sc and As.

(5) Based on the factor analysis results, it is concluded that soil dust, traffic emissions, industry, bauxite mining and refining, chemical fertilizers and pesticides, and combustion of coal and oil are the main possible sources of heavy metals in the Lamdong atmosphere.

Declarations

ACKNOWLEDGEMENTS

This work was supported by the International Centre of Physics at the Institute of Physics (grant ICP.2022.11), the Vietnam Academy of Science and Technology (project VAST07.05/22-23), and Dong Nai Department of Science and Technology’s project, Vietnam. Author Nguyen Thi Minh Sang has received research support from Dalat University, Viet Nam. We would like to thank Steven Carlson for the corrected version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

AUTHOR CONTRIBUTIONS

L. H. Khiem, Nguyen An Son and Le Dai Nam suggested the experiment plan. Nguyen Thi Minh Sang proposed and implemented the experiment. Truong Van Minh, Nguyen Thi Minh Sang, Tran Tuan Anh and Ho Huu Thang compiled the data and prepared the manuscript and completed the manuscript.

References

1. Abdullah NH, Mohamed N, Sulaiman LH, Zakaria TA, Rahim DA (2016) Potential health impacts of bauxite mining in Kuantan. Malaysian J Med Sci 23:1–8
2. Aničić M, Frontasyeva MV, Tomašević M, Popović A (2007) Assessment of atmospheric deposition of heavy metals and other elements in Belgrade using the moss biomonitoring technique and neutron activation analysis. Environ Monit Assess 129(1):207–219
3. ATSDR (2004) Toxicological profile for cobalt. https://www.atsdr.cdc.gov/ToxProfiles/ tp33.pdf
4. Barałkiewicz D, Siepak J (1999) Chromium, nickel and cobalt in environmental samples and existing legal norms. Pol J Environ Stud 8:201–208
5. Blok J (2005) Environmental exposure of road borders to zinc. Sci Total Environ 348(1–3):173–190
6. Cheng H, Zhou T, Li Q, Lu L, Lin C (2014) Anthropogenic chromium emissions in China from 1990 to 2009. PLoS ONE 9:e87753
7. De Corte F, Simonits A, De Wispelaere A, Hoste J (1987) Accuracy and applicability of the k0-standardization method. J Radioanal Nucl Chem 113(1):145–161
8. Doan Phan TT, Trinh TTM, Khiem LH, Frontasyeva MV, Quyet NH (2019) Study of air pollution in Central and Southern Vietnam using moss technique and neutron activation analysis. Asia-Pac J Atmos Sci 55(3):247–253
9. Dung HM, Hien PD (2003) The application and development of k0-standardization method of neutron activation analysis at Dalat research reactor. J Radioanal Nucl Chem 257:643–647
10. Dung HM, Thien TQ, Doanh HV, Sy NT (2016a) Determination of multielement composition of Vietnamese marine sediment and tuna fish by k0-NAA. J Radioanal Nucl Chem 309(1):235–241
11. Dung HM, Thien TQ, Doanh HV, Vu CD, Sy NT (2016b) Quality evaluation of the k0-NAA at the Dalat research reactor. J Radioanal Nucl Chem 309(1):135–143
12. Ermakova EV, Frontasyeva MV, Pavlov SS, Potoreiko EA, Steinnes E, Cheremisina YEN (2004a) Air pollution studies in Central Russia (Tver and Yaroslavl Regions) using the moss biomonitoring technique and neutron activation analysis. J Atmos Chem 49:549–561
13. Ermakova EV, Frontasyeva MV, Steinnes E (2004b) Air pollution studies in Central Russia (Tula Region) using the moss biomonitoring technique, INAA and AAS. J Radioanal Nucl Chem 259:51–58
14. Fernandez JA, Cårballeira A (2000) Evaluation of contamination, by different elements, in terrestrial mosses. Arch Environ Contam Toxicol 40:461–468
15. Grodzinska K, Frontasyeva M, Szarek-Lukaszewska G et al (2003) Trace element contamination in industrial regions of Poland studied by moss monitoring. Environ Monit Assess 87(3):255–270
16. Hopke PK, Cohen DD, Begum BA et al (2008) Urban air quality in the Asian region. Sci Total Environ 404(1):103–112
17. ICP-Vegetation (2015) Heavy metals, nitrogen and POPs in European mosses: 2015 survey -Monitoring manual. https://icpvegetation.ceh.ac.uk/sites/default/files/ Moss % 20protocol %20 manual.pdf
18. Khiem LH, Sera K, Hosokawa T, Quyet NH, Frontasyeva MV, Trinh TTM, My NTB, Nghia NT, Trung TD, Nam LD, Hong KT, Mai NN, Thang DV, Son NA, Thanh TT, Tien DPT (2020a) Assessment of atmospheric deposition of metals in HaNoi using the moss bio–monitoring technique and proton induced X–ray emission. J Radioanal Nucl Chem 324:43–54
19. Khiem LH, Sera K, Hosokawa T, Nam LD, Quyet NH, Frontasyeva M, Trinh TTM, My NTB, Zinicovscaia I, Nghia NT, Trung TD, Hong KT, Mai NN, Thang DV, Son NA, Thanh TT, Sonexay X (2020b) Active moss biomonitoring technique for atmospheric elemental contamination in Hanoi using proton induced X-ray emission. J Radioanal Nucl Chem 325:515–525
20. Kosiorek M, Wyszkowski M (2019) Remediation of cobalt-polluted soil after application of selected substances and using oat (Avena Sativa L.). Environ Sci Pollut Res 26:16762–16780

21. Kousehlar M, Widom E (2019) Sources of metals in atmospheric particulate matter in Tehran, Iran: Tree bark biomonitoring. Appl Geochem 104:71–82
22. Lioy PJ (1983) Air pollution emission profiles of toxic and trace elements from energy related sources: status and needs. Neurotoxicology 4:103–112
23. Longhin E, Gualtieir M, Capasso L et al (2016) Physico-chemical properties and biological effects of diesel and biomass particles. Environ Pollut 215:366–375
24. Lucaciu A, Timofte L, Culicov O et al (2004) Atmospheric deposition of trace elements in Romania studied by the moss biomonitoring technique. J Atmos Chem 49:533–548
25. Nechitailov AP, Suss AG, Zhilina TI, Belanova EA (2008) New method of analyzing bauxites to determine their main components and impurities. Metallurgist 52:625–632
26. Nguyen VH, Frontasyeva MV, Trinh TTM, Bernard N (2010) Atmospheric heavy metal deposition in northern Vietnam: Hanoi and Thainguyen case study using the moss biomonitoring technique, INAA and AAS. Environ Sci Pollut Res 17(5):1045–1052
27. Ruijten MWMM, Sall HJA, Verberk MM, Smink M (1994) Effect of chronic mixed pesticide exposure on peripheral and autonomic nerve function. Arch Environ Health 49:188–195
28. Schaug J, Rambaek JP, Steinnes E, Henry RC (1990) Multivariate analysis of trace element data from moss samples used to monitor atmospheric deposition. Atmos Environ 24A:2625–2631
29. Schroeder WH, Dobson M, Kane DM (1987) Toxic trace elements associated with airborne particulate matter: a review. J Air Pollution Control Association 37:1267–1285
30. Steinnes E, Uggerud HT, Pfaffhuber KA, Berg T (2016) Atmospheric deposition of heavy metals in Norway - National moss survey 2015. NILU Report 28/2016. Norwegian Institute for Air Research
31. Stokes PM, Campbell PGC, Schroeder WH et al (1988) Manganese in the Canadian environment. Ottawa, Ontario, National Research Council of Canada, Associate Committee on Scientific Criteria for Environmental Quality (NRCC No. 26193)
32. Zinicovscaia I, Hramco C, Duliu OG et al (2017) Air pollution study in the Republic of Moldova using moss biomonitoring technique. Bull Environ Contam Toxicol 98:262–269

Figures

Figure 1

Sampling locations in the cities of Dalat and Baoloc in Lamdong province (Inset is a map of Vietnam)

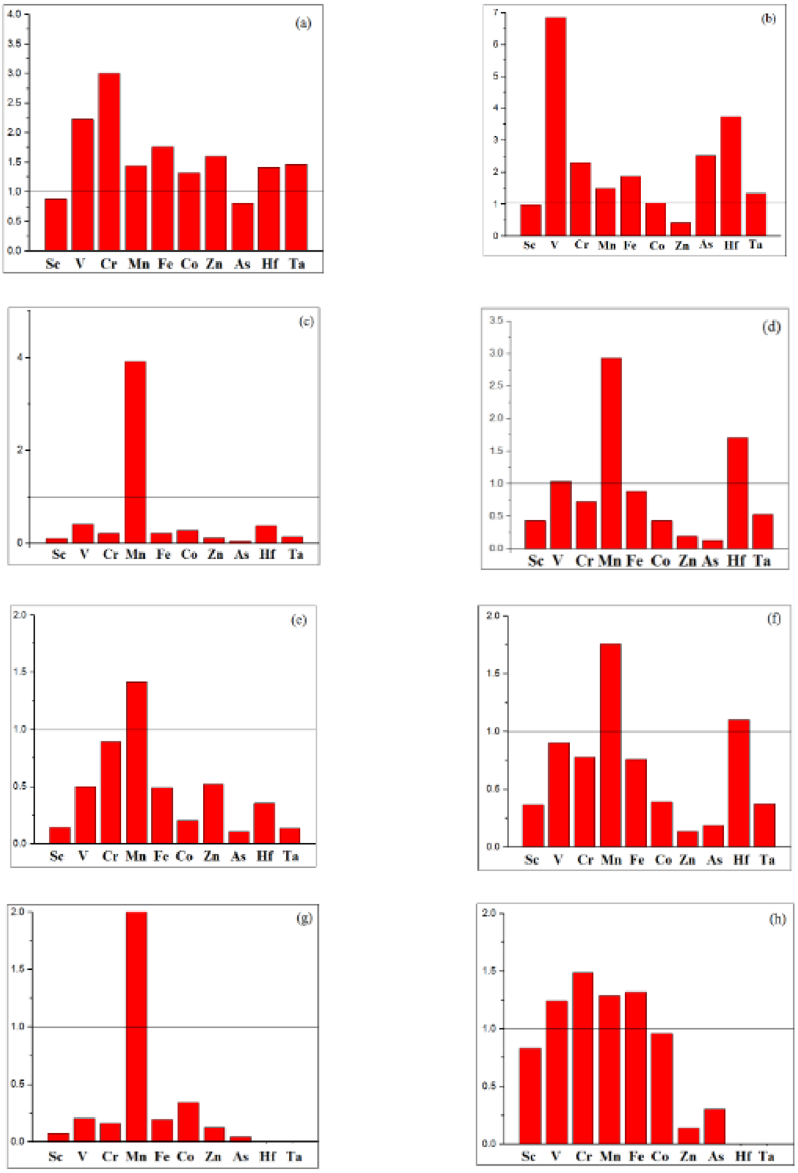

Figure 2

Comparison of the ratios of elemental concentrations from cities in Vietnam and Europe to those of Lamdong. (a)Hanoi/Lamdong, (b) Thainguyen/Lamdong, (c) Tver and Yaroslavregions (Russia)/Lamdong, (d) Tula region (Russia)/Lamdong, (e) Silesia-Kraków and Legnica-Glogów Copper Basin (Poland)/Lamdong, (f) Prut river catchment (Romania)/Lamdong, (g) Norway/Lamdong, (h) Moldova/Lamdong