Handbook of Research on Emerging Developments and Environmental Impacts of Ecological Chemistry

Gheorghe Duca
Academy of Sciences of Moldova, Moldova

Ashok Vaseashta
International Clean Water Institute, USA & New Jersey City University, USA & Academy of Sciences of Moldova, Moldova

A volume in the Advances in Environmental Engineering and Green Technologies (AEEGT) Book Series

Chapter 24
Moss Biomonitoring in Former Sovet Union Countries:
A Review

Inga Zinicovscaia
Joint Institute for Nuclear Research, Russia & Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Romania & The Institute of Chemistry, Moldova

Nikita Yushin
Joint Institute for Nuclear Research, Russia

Konstantin Vegel
Joint Institute for Nuclear Research, Russia

Dmitrii Grozdov
Joint Institute for Nuclear Research, Russia

ABSTRACT

Air pollution is a worldwide environmental and health issue. Among environmental pollutants, heavy metals are the most dangerous due to their persistence and bioaccumulation in food chain. Assessment of heavy metal deposition using moss biomonitors is a cheap and effective technique, which was successfully applied in different European counties. The present work revises application of passive biomonitoring in former Soviet Union countries: Belarus, Estonia, Georgia, Kazakhstan, Latvia, Moldova, Russia, and Ukraine. The air pollution sources in each country were identified. The mean concentration of elements considered as environmental pollutants were compared in order to detect the most polluted countries on the post-Soviet space.

DOI: 10.4018/978-1-7998-1241-8.ch024

INTRODUCTION

Air pollution is a major problem in recent decades, which has a significant toxicological impact on human health and the environment (Ghorani-Azam et al., 2016). Various chemicals are emitted into the air from both natural and anthropogenic sources. The natural sources of air pollution include volcanic eruptions, geothermal sources and emissions from land and water, forest fires, sea salt in a coastal area, biological material and radiological decomposition (Pénard-Morand & Annesi-Maesano 2004). It is noteworthy that natural air pollution did not pose a serious problem as it is part of natural environment equilibrium, whereas the anthropogenic pollution sources present a major challenge for the world today. The increase of the pollution level is directly linked to the population growth which is associated with the growing demands in energy and consumer goods. The anthropogenic chemical pollution has no borders and is independent. The pollutants being released into the atmosphere will have an impact over the global environment (Popescu & Ionel 2010). Traditionally, the anthropogenic sources are divided into two groups - stationary and mobile sources (Pénard-Morand&Annesi-Maesano2004). The most important groups of anthropogenic air pollution sources are industrial activity, mining, transport and agricultural systems (Popescu & Ionel 2010; Aksu 2015; Zinicovscaia et al., 2017)

The long-term air pollution causes millions of deaths each year. In addition, it is associated with the number of immediate, medium-term and long-term human health problems such as the respiratory infections and inflammations, cardiovascular dysfunctions, and cancer (Ghorani-Azam et al., 2016; Olmo et al., 2011).

In the most countries, the various regulatory instruments are combined into a coordinated control programme. However, in practice, the air pollution monitoring is a complex problem, which requires identification of emissions sources, evaluation of analytical methods, risk assessment, control of critical emissions and integration of economic aspects (Wolterbeek 2002). In many countries the particular attention is given to determination of gaseous air pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x: NO, NO_2), carbon dioxide (CO_2) and ozone (O_3), etc. At the same time, the serious threat for the environment and human health represent the heavy metals, due to their toxicity, non-degradable nature and ability to be build up in organisms and move up in the food chain.

Dispersion modeling and field measurements of the emissions are used to learn about air pollutants. However, these techniques are characterized by low sensitivity, high costs and require long-term sampling at large numbers of sampling sites (Wolterbeek 2002). The moss biomonitoring technique, introduced in Scandinavian countries around 1970 (Ruhling & Tyler 1971), has proven to be suitable, cheap and efficient technique for the assessment of atmospheric deposition of heavy metals. In 1989/1990 the first moss survey at the European scale was conducted and since then the number of participating countries has greatly expanded (Harmens et al. 2013). Today, the moss biomonitoring studies in the European countries are mainly performed in the framework of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops International Cooperative Programme, (UNECE ICP Vegetation) (Harmens et al., 2008; 2009; 2013). Estonia, Lithuania and Latvia take an active part in the European moss survey, while similar information about the Newly Independent States (NIS) is not so well highlighted. The present chapter is the first attempt to collect and present data on moss biomonitoring study in NIS countries. A short description of countries is given as well.

MOSS BIOMONITORING IN FORMER SOVIET UNION COUNTRIES

Following the collapse of the Soviet Union, 15 new independent countries (Republic of Armenia, Republic of Azerbaijan, Republic of Belarus, Republic of Estonia, Republic of Georgia, Republic of Kazakhstan, Kyrgyz Republic, Republic of Latvia, Republic of Lithuania, Republic of Moldova, Russian Federation, Republic of Tajikistan, Republic of Turkmenistan, Ukraine, Republic of Uzbekistan) came into existence. Three of them, Republic of Estonia, Republic of Lithuania and Republic of Latvia, joined UNECE ICP Vegetation programme in 1989, while the Republic of Kazakhstan, Republic of Moldova, Republic of Georgia, Republic of Armenia, Republic of Azerbaijan and Republic of Tajikistan in 2015. In Russian Federation and Ukraine moss surveys were carried out periodically and mainly in polluted regions. On Fig. 1 are highlighted countries for which information about moss biomonitoring studies (article papers, conference papers, atlases) is available.

Figure 1.

Republic of Estonia

Located on the eastern coast of the Baltic Sea, Republic of Estonia (Estonia) is the northern most and also the smallest country in the Baltic region, in terms of both population (1.32 million) and area (45,339 km^2). Estonia's neighbors are Russia to the East, Latvia to the South, Sweden to the West and Finland to the North. Almost half of the Estonia's land is covered by forests (approx. 51%). Estonia's biodiversity is formed due to the differences in the climatic conditions. The local climatic differences are attributed to the neighboring Baltic Sea, which warms up the coastal zone in winter and later has a cooling effect, especially in spring. As a result, the summers are moderately warm and the winters are moderately cold (Kallis et al., 2017).

As it was previously mentioned, Estonia joined the UNECE ICP Vegetation programme of the European Nordic countries in 1989 and national moss study is being carried out in Estonia every five years (1989/90; 1995/96; 2000/01; 2005/06, 2010/11) (Liiv & Kaasik 2004). During 1989-2005, the significant decrease in Cd (by 48%), Cr (by 92%), Fe (by 70%), Ni (by 92%), Pb (by 80%) and V (by 76%) concentrations in Estonia's moss was observed, while the concentrations of Cu and Zn do not exhibit a marked shift. The decrease in the concentrations of Cr, Fe, Ni, Pb and V in Estonian mosses was related to the decrease of emissions of solid particles from the Eesti Power Plant and the cement factory of Kunda Nordic Tsement AS, all of them being located in North-Eastern part of the country. The Pb emission has decreased by 80% due to the introduction of unleaded fuel in Estonia (Kösta & Liiv 2011).

The main air pollutants in Estonia originate from the oil shale-based power engineering and chemical industry, as well as from the building materials industry, the north-eastern part of the country (NE Estonia) is considered particularly polluted (Liiv & Kaasik 2004). For example, in 2002, about 97% of air pollution, 86% of total waste and 23% of water pollution in Estonia came from the power industry, which uses the oil shale as the main input for production process (Raukas 2004). Thus, in 1992, 1997, 2002, and 2007 the moss samples were collected around two large oil shale fired thermal power stations and a cement factory in the North-Eastern part of the country. According to obtained results, Cr, Fe, Ni, Pb and V concentrations in moss samples collected from oil shale fired power plants and the cement factory, were diminished remarkably in NE Estonia between 1992–2008. The changes in Cd, Cu, and Zn concentrations in mosses were smaller (Liiv & Kaasik 2004; Kaasik & Liiv 2007; Kösta & Liiv 2011).

Emissions of heavy metals from thermal power plants in NE Estonia have been fallen remarkably since 1989 due to implementation of environmentally friendly technologies. At the same time, due to the increasing of the vehicles number, the emissions from road transport have become dominating, especially in towns. Although the waiver of leaded gasoline has caused a decline in lead pollution, the emissions from diesel fuel and wear-off tires and machine parts remain a significant sources of air pollution (Kaasik & Liiv 2007).

Republic of Lithuania

Republic of Lithuania (Lithuania) is situated on the Eastern shore of the Baltic Sea. The territory of the Lithuania covers 65 302 km^2. It borders Latvia on the North, Belarus on the Eeast and South, Poland and Russia on the Southwest. Lithuania is the country of lowlands with the highest hills reaching up to 300 m. The agricultural land covers about 52.4% of the total land area. The climate in Lithuania varies from marine to continental with the average temperatures on the coast – 2.5 °C in January and 16 °C in July (Lithuania's seventh National Communication, 2017).

In Lithuania, 133 moss samples were collected in 1995, 138 samples in 2000 and 146 samples in 2005. *Hylocomium splendens* and *Pleurozium schreberi* are the most widespread moss species. There are three major metal pollution sources in Lithuania: two thermal power stations located in Elektrenai and Mazeikiai and a cement factory located in Naujoji Akmene (Ceburnis et al., 2002). During three moss surveys the concentration of As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, V and Zn in the analyzed moss samples were determined using atomic absorption spectrometry in order to separate the background and anthropogenic contributions to heavy metal concentrations in moss. The decrease of As, Cr, Ni, Pb, V and Zn content was observed in the Lithuanian mosses during the years 1995–2005, though the concentration of Cu and Hg increased. The decrease in metal concentration can be associated with the decreased of combustion of oil fuel (Šakalys et al., 1999; Šakalys et al., 2009).

Five moss species, namely *Pylocomium splendens*, *Pleurozium schreberi*, *Eurhynchium angustirete*, *Sphagnum* and *Rhytidiadelphus* were used to trace the atmospheric heavy metal depositions, during August–September 1993. Relatively high concentrations of Pb, Ni, Cu, Cr, Cd, Fe were determined near the factory of building materials Naujoji Akmene. The high V concentrations were determined near the Elektrenai and Alytus thermal power stations, indicating that the release of V into the atmosphere is mainly due to the oil refineries and fuels burning (Ceburnis et al., 1997).

Blagnyte & Paliulis (2011) investigated the pollution with heavy metals in mosses along the high intensive traffic in Geležinis Vilkas street, the main rapid traffic street in the city of Vilnius. The moss samples were taken at a different distance (5-45 meters) from the Geležinis Vilkas street. The study results showed that the metals content in all the moss samples tend to decrease with the distance from the Geležinis Vilkas street, the highest metals content being determined in the mosses collected at the distance from 5 to 15 meters from the street. The heavy metals accumulations in the moss samples changed in the following order: Zn > Cu >Pb> Cr, Ni.

The methodological work was carried out by Ceburnis et al. (1999) in order to determine the main sources contributing to heavy metal content in the mosses in Lithuania. The uptake efficiencies of mosses were calculated for Cd, Cr, Cu, Fe, Mn, Ni, V and Zn. It was observed that for Cr, Ni, and Fe the major factor is soil dust influence, so the use of moss to study these elements in atmospheric heavy metal surveys is therefore of limited value, except for the vicinity of local pollution sources. The "Vegetation factor" was dominating for Mn and also significant for Zn, while V is an anthropogenic element.

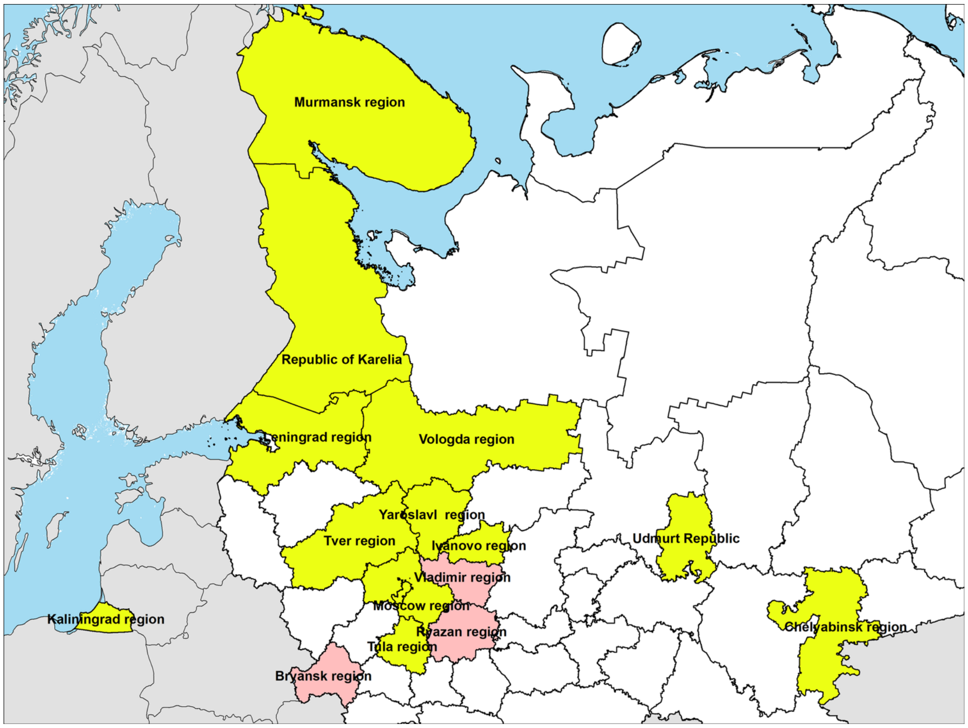
Republic of Latvia

Republic of Latvia (Latvia) is situated on the edge of the Eastern European Plain near the Baltic Sea. The territory covers an area of 64573 km^2in total. It is bordered by Estonia to the North, Lithuania to the South, Russia to the East, and Belarus to the Southeast, and shares a maritime border with Sweden to the West. Latvia is a typical lowland country and its terrain is characterized by flat, low areas and hilly elevations. The air temperature in Latvia has a seasonal nature – February being the coldest month with average air temperature -3.7^{0}C and July being the warmest with +17.4^{0}C (Ratniece et al., 2017)

In Latvia the biomonitoring of atmospheric heavy metal distributions in the framework of UNECE ICP Vegetation programme has been conducted in five national moss surveys: in 1990, using *Hylocomium splendens* collected in 81 plots; and in 1995, 2000, 2005 and 2015, using *Pleurozium schreberi* in 101 plots (Tabors et al., 2017). During the first moss survey conducted in 1990 many industries and thermal power plants were still operating in Latvia, however by the year 2000 the loads from the stationary sources have been decreased by 60% (Nikodemus et al., 2004). The concentrations of seven elements (Cd, Cr, Cu, Pb, Ni, V, Zn) were determined in moss samples. Comparing the result of moss surveys performed between 1990 and 2000 the decrease in Cr, Cd, Ni, Pb and Cu content in moss was noted. The decrease in Pb content was mainly associated with the improved vehicle quality and the waiving of leaded gasoline use. In 2000, the main air pollution sites in Latvia were considered Liepaja, Olaine, Riga, Daugavpils and Broceni (Nikodemus et al., 2004).

In the moss survey conducted in 2015/16 the sampling sites had close locations to those in 1990/91. In Latvia the overall concentrations of heavy metals in mosses in the period from 1990 to 2015 have

Figure 2.



been declined for lead (by 89%), vanadium (by 85%), chromium (by 78%), iron (by 71%), cadmium (by 69%) and nickel (by 66%), followed by zinc (by 21%) and copper (by 14%). In 2000/01, 2005/06 and 2015/16 surveys, the concentrations of Cu and Pb have not decreased significantly. The main sources of heavy metals in Latvia are considered to be transport, thermal power plant, metallurgical industry, pharmaceutical companies, and transboundary transport of pollutants from Poland, Germany and Lithuania (Taborset al., 2017; Nikodemus et al., 2004).

Brumelis et al. (1999) collected moss *Hylocomium splendens* in 43 forests around the metal smelter "Liepajas metalurgs" in order to estimate the distribution of deposition of Zn, Pb and Cu. The results obtained have showed the high concentrations of Zn (>200 μg/g), and elevated concentrations of Pb (38.3 μg/g) and Cu (18.3 μg/g), the metal smelter was identified as the main pollution source in the region.

Russian Federation

Russian Federation (Russia) is the world's largest country (17,098,242 km^2), covering more than 11% of Earth's land areas. Russia is bordered by 14 countries: Azerbaijan, Belarus, China, Estonia, Finland, Georgia, Kazakhstan, North Korea, Latvia, Lithuania, Mongolia, Norway, Poland, and Ukraine. Furthermore, it shares maritime borders with Japan, Sweden, Turkey and the United States. The climate in Russia ranges from steppes in the South through humid continental in much of European Russia; subarctic in Siberia to tundra climate in the polar North; the winters vary from cool along the Black Sea coast to frigid in Siberia; summers vary from warm in the steppes to cool along the Arctic coast (Russia, 2020).

In Russia, the moss survey was performed only in a limited number of regions that can be explained by the big territory and extreme climatic conditions. The regions of Russia, which participated in moss surveys are presented in Fig. 2. In some regions such as Moscow, Tula, Tver region, the biomonitoring studies were conducted for several times, while in the other regions - only once.

Moscow region, one of the most densely populated and industrialized zone in the country, was involved in the two moss survey 2005/06 and 2015/16. Air pollution in Moscow region in both surveys was mainly associated with oil combustion, metallurgy industry and mechanical plants, solid waste disposal, thermal power plants, transport, steel, aerospace, and electronics industry, metallurgical plants, machinery companies, plants for the nuclear fuel production, chemicals, pharmaceutical, fertilizers and pesticides production (Vergel et al., 2009, Vergel et al., 2019). Comparison of the results of performed surveys revealed significant differences for Cl, Ca, K, Co, As, Mo, and Hf between two surveys.

The Tula region is one of the most developed industrial and farming region in Russia. At the same time is considered one of the most polluted region in the Central Russia, more than 450 enterprises are operating within the region. During the first biomonitoring study, summer-autumn of 1998-2000, 83 moss samples were collected throughout the region. The high content of As, Th and U determined in the analyzed moss, was related to the coal mining and refining and coal combustion plants, located in the East of the Tula and in the West of the Tula region. The other anthropogenic sources are ferrovanadium industry (Fe, V), production of chlorine and organic compounds (Cl, I), other industries and general urban activities (Co, Ni, Ba, Cs, Mn, Zn, Cu, Pb,Mo, W) (Ermakova et al., 2004a). Biomonitoring study performed in 2014 showed the decrease of Mn, Zn, and V content due to the reduction of the productive capacity of the "Vanadium-Tula" metallurgical enterprise. An increase of Fe (by 30%), Cr and Co (by 40-43%), As and Cd (by 37%), Sr and Sm (by 22%) was resulted from the ferrous metallurgy enterprises, metal processing and defense industries, ore processing, transport and agricultural activities (Gorelova et al., 2016).

Kaliningrad region participated in three moss surveys moss in 1995/96, 2000/01 and 2005/06. According to the data obtained, the main air pollution sources in Kaliningrad region are engineering, metalworking, fuel and energy complex, agriculture and oil production, transport, peat fires. The transboundary transport is considered an important source of Cr, Cd, Cu and Ag (Korolyova 2010).

During the years 2001-2002, the moss samples were collected in Tver and Yaroslavl regions. These regions have similar geographical and climatic conditions, but for historical reasons Yaroslavl region is more economically developed. Based on the results obtained, the coal combustion, building materials production, industrial activity around Yaroslavl, manufacturing industry in Kashin and steel industry in Cherepovets, the thermal power plant in Konakovo and oil-refinery plant in Yaroslavl were defined as the main pollution sources in the studied regions (Ermakova et al., 2004b). Biomonitoring studies performed in Tver region in 2004 have confirmed that the main pollution sources in the region remain to be the thermal power plant in the town of Konakovo, as well as the factories of the fuel-energy complex allocated in the nearby towns of Kashin and Kalyazin. At the same time, it should be mentioned that the Tver region is considered as a background territory for the Russian Federation (metal concentrations are lower than in other studied regions) (Vergel et al., 2007).

The moss biomonitoring was applied in North-Western region of Russia with the aim to document the environmental impact of the Russian nickel industry near Nikel, Zapoljarnij and Monchegorsk on different compartments of the ecosystem. The high content of Ni, Cr, Fe, Mg, and S was determined in the moss species collected near the nickel roaster in Zapoljarnij, while the high conten of Ag, Ba, Bi, Cd, and Na was associated with the nickel refinery in Monchegorsk. The main source of Al, Ba, Ca, K, La, Na, P, Rb, Sr and Y was considered to be the large open cast apatite mine in Kirovsk near Apatity (Reimann et al., 1999). The comparison of the accumulation of heavy metals (Ni, Cu) by two dominant moss species *Pleurozium schreberi* and *Hylocomium splendens* collected in the Lapland State Biosphere Reserve located in the impact area of atmospheric emissions from the Severonickel Smelter Combine (Monchegorsk, Murmansk Region, Russia) during 1991 and 2011 was performed by (Barkan and Lyanguzova 2018). In 1991 in the Lapland Reserve, the average nickel concentration was 12 times over its background level and copper content was 23 times over, while in 2011 the content ofNi and Cu was only 4 times higher the background concentrations. Decrease in the Ni and Cu content in mainly associated with the reduction in atmospheric emissions by the Severonickel Combine.

The region of the South Ural Mountains is ranked as the most severely polluted region in Russia and probably is among the most polluted areas in the world (Frontasyeva 2000). This region includes several industrial cities such as Karabash, Chelyabinsk, Ozersk and many others, where the clustering of heavy industry has produced the extremely high levels of air and water pollution. In addition, the substantial emissions of radioactive substances have occurred in the Ural region as the result of the full-scale activities of the radiochemical "Mayak" Production Association (Cherchintsevet al., 1999; Frontasyeva et al., 2004). In 1998 the samples of mosses *Hylocomium splendens* and *Pleurozium schreberi* were collected in Chelyabinsk. The high concentrations of Cu, Zn, As, Ag, Sb and Cd are related to the emissions from Karabash copper smelter. High Ni, Co, Cr, and As concentrations were determined near the Ufalei town, where Ni and Co production plant is located (Frontasyeva et al., 2004). At the same period, the moss samples were collected near Magnitogorsk, the "City of Steel". The values determined for Sb (12-29 ppm) were comparable with the previously reported ones for mosses, and have clearly indicated the strong pollution with this element in the Magnitogorsk region. The high concentrations of Cr, Zn, As, Se, Ag, Cd, Sb and Au have indicated that these elements represent a regional pollution problem. (Frontasyeva et al., 2000).

During the summer-autumn of 2005/06, the moss samples of *Hylocomium splendens* and *Pleurozium schreberi* have been collected in the Southern part of the Udmurt Republic at 79 sites. According to neutron activation analysis data and factor analysis, the results of the main anthropogenic sources of heavy metals are: oil refining, steel and lightindustries, mining and building material industry, chemical weapon destruction plant, pesticide and fertilizer storages (Pankratova et al., 2007).

In the Leningrad region the moss biomonitoring was performed in the area surrounding the Tikhvin town, showing that the main source of Cr, Fe, Ni and V is the ferroalloy plant located in Tikhvin (Vergel et al., 2014). In the Ivanovo region, the monitoring of the air quality performed in 2010 has showed an increased concentrations of heavy metals (V, Fe, Co, Zn) in the town of Rodniki and arsenic in its vicinities (Dunaev et al., 2018).

Ukraine

Ukraine is located in the Central and Eastern Europe and covers 5.7% of the entire territory of Europe. Ukraine is bordered by Belarus, Russia, Moldova, Romania, Hungary, Slovakia, and Poland. The most of the Ukraine's territory is located in the South-West of the East-European Plain and only 5% of the territory is mountainous. The continental climate of the country is greatly affected by the proximity to the Black Sea. The average winter temperature varies from -8 ° to -12 ° C, while the average summer temperature is from +18 ° to 25 ° C (The Sixth National Communication of Ukraine on climate change, 2012).

In Ukraine the moss biomonitoring studies were performed in Polissia zone: Rivne, Zhytomyr, Kyiv and Chernigiv regions. During the spring-summer 1995, a set of 79 moss samples was collected and concentrations of 10 elements (As, Cd, Cr, Cu, Hg, Fe, Ni, Pb, V and Zn) were determined. It was found that the high concentration of Cu as well as Cr, Pb and Zn in the west zone of studied area can be related to copper sandstone. The high zinc content was also determined near the chemical factories in Chernigiv and Belaya Tserkov. High concentration of V around the thermal centrals is due to the burning of the crude oil. The central anomalies in Cr and Fe are related to the engine factories in Kiyv and Brovari. The main source of As can be considered tanning and home chemical making, while Cd and Pb may originate from the old machinery disposed after Chernobil accident (Hervada-Sala et al., 2003).

In 1998 and 1999 the moss samples were collected in Zakarpattia and Chernivtsi regions. The element concentrations in the moss from Zakarpattia were lower than those from Chernivtsi. The distinct air pollution sources were not identified (Blum et al., 2002). The moss biomonitoring studies were also performed in Kiev and Zhitomir Regions. The concentration of 23 elements were determined by ICP-MS in mosses *Pleurozium schreberi* and *Brachythecium oedipodium*. As the main air pollution sources titan ore mining and processing in Zhitomir region and transboundary transfer of pollutants from Belarus were mentioned (Shabatura et al., 2018).

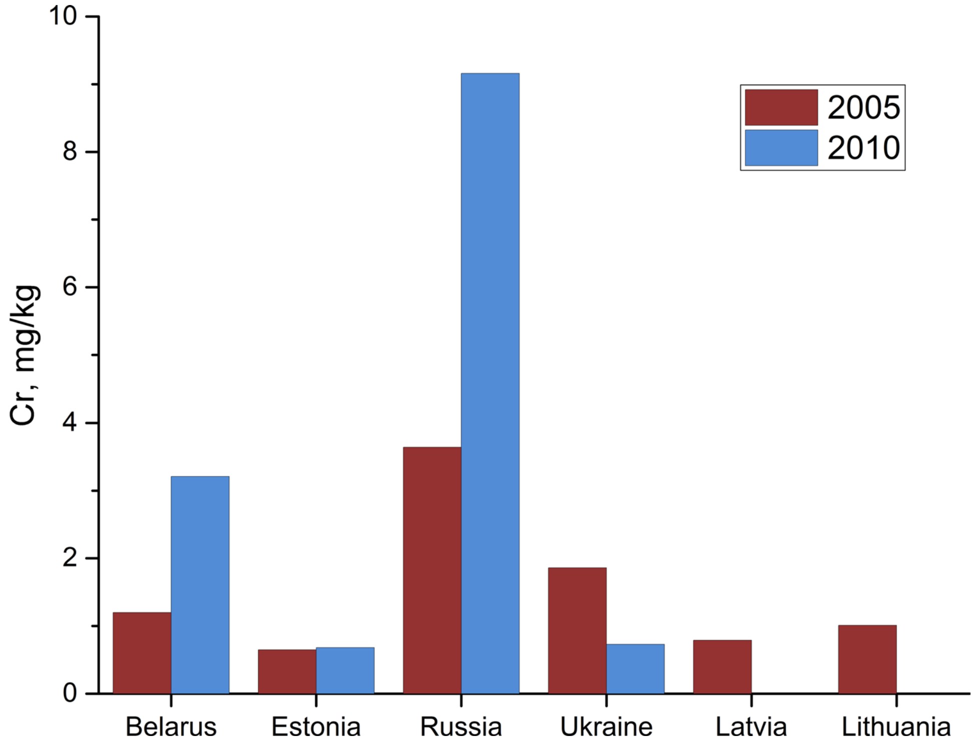
Republic of Belarus

Republic of Belarus (Belarus) occupies the area of 207,600 km^2. The longest distance from West to East is 650 km, from North to South 560 km. The terrain of Belarus is predominantly plain with hills: the average elevation is 160 m above the sea level; the highest elevation is 345 m. Its neighbors are Russia, Latvia, Lithuania, Poland, Ukraine (Aleksiayenak et al., 2010). The South-Eastern part of the country was severely contaminated with fallout from the 1986 accident at the Chernobyl nuclear power plant, situated in Ukraine only 11 km from the Belarus border. About 70% of the total radioactive fallout occurred on Belarus territory (Aleksiayenak et al., 2013).

The moss samples were collected in Belarus during 2005-2008 in Minsk, Gomel, Grodno and Vitebsk regions. The activity of ^{137}Cs and ^{210}Pbactivity was measured in collected moss samples. The maximum activities of ^{137}Cs were observed in the Gomel Region near the town Mazyr (6827 Bq/kg) and the minimum activity in Vitebsk region (4.83 Bq/kg). The “hot spots” near the towns Borisow and Yuratsishki were noticed. The concentrations of ^{210}Pb in moss samples collected over the territory of Belarus varied between 141 and 575 Bq/kg, with a median value of 312 Bq/kg. The low median value of ^{210}Pb obtained for Belarus mosses (312 Bq/kg) is presumably connected with a generally lower uranium abundance in soils in Belarus (Aleksiayenak et al., 2013; Aleksiayenak et al., 2010)

Besides the radionuclides, the concentrations of 36 elements were determined in 156 moss samples collected in the above mentioned regions in the period 2005-2008. The high concentrations of Mg, Co, Se, Mo, Cd, W, Pb, which can be associated with engineering industry were determined near Minsk, Molodechno and Zhodino. The main source of Co, Pb, Fe, Sb, Br, Cr, Cu, Zn, and Sb can be considered metallurgical industry (Aleksiayenak et al., 2015). The results obtained were published in the European atlas of heavy metal atmospheric deposition in 2005/06 and 2010/11.

Figure 3.



Republic of Moldova

Republic of Moldova (Moldova) is a landlocked country, located in the North-Western Balkans, covering the area of 33,846 km^2. Moldova borders with Ukraine and Romania. The relief of Moldova is represented by hills as well as plains, with uplands mostly in the central part of the country. The climate of Moldova is moderately continental, characterized by the relatively mild winters with little snow, long warm summers, and low humidity. The Republic of Moldova has the unique land resources characterized by the predominant black earth soils (~75 per cent) with high productivity potential. Moldova's rich soil and temperate continental climate have made the country one of the most productive agricultural regions in Southeast Europe since ancient times, and a major supplier of agricultural products (Third National Communication of the Republic of Moldova, 2013).

The first attempt to perform the biomonitoring study in Moldova was done by Romanian scientists in 2001 but covered only a limited area, mostly along the Prut river (Cucu-Man 2006). The concentrations of V, Cr, Fe, Ni, As, Br, La, Ce, Th, U were determined in moss samples using ICP-MS technique. In 2015 neutron activation analysis and atomic absorption spectrometry were used by Zinicovscaia et al. (2017) to determine 41elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Zr, Cd, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Tm, Yb, Hf, Ta, W, Pb, Th, and U) in 33 analysed moss samples. High concentrations of Fe, Cr, As, V and U determined around Chisinau and Balti indicate the influence of the industrial sources, while Pb, Sb and Zn are mainly associated with transport.

The calculated values of Geo-accumulation Index I_{geo} and contamination factor C_F points towards the moderate to moderately severely polluted state for the entire territory, with higher values for U in Chisinau.

The comparison of elements determined in the samples from Moldova collected in 2001 and 2015 (Fig. 3) showed the increase of V, Cr, Ni, Cu and Pb contents within 14 years. This increase can be explained by the use of different analytical techniques as well as the economic revival.

Republic of Georgia

Republic of Georgia (Georgia), is a country of Transcaucasia located at the Eastern end of the Black Sea on the Southern flanks of the main crest of the Greater Caucasus Mountains. The country lies between the latitudes 41° and 44° N, and longitudes 40° and 47° E, with an area of 67,900 km^2. It is bounded on the North and Northeast by Russia, on the East and Southeast by Azerbaijan, on the South by Armenia and Turkey, and on the West by the Black Sea. The capital of Georgia is Tbilisi (Suny et al., 2019).

The Western Georgia's landscape ranges from the low-land marsh-forests, swamps, and temperate rainforests to eternal snows and glaciers, while the Eastern part of the country even contains a small segment of semi-arid plains. The general landscape of the Eastern Georgia comprises the numerous valleys and gorges separated by mountains. The main part of the Western Georgia lies within the Northern periphery of the humid subtropical zone, while the Eastern Georgia has a transitional climate - from humid subtropical to continental. More than a third of the country is covered by forests and brush (Georgia, 2019).

Georgian industries and agricultural sector provide the considerable anthropogenic impact on the environment of the Caucasus. Georgia is characterized by high-level anthropogenic pollution in some districts, namely Lower Svaneti, Kutaisi, Zestafoni, and others (Shetekauri et al., 2018).

In 2014 for the first time sixteen *Hylocomium splendens*, *Pleurozium schreberi* and *Hypnum cupressiforme* moss samples were collected in Georgia. The samples were collected along the altitudinal gradients in the range of altitudes from 600 m to 2665 m. The concentrations of 25 elements Na, Mg, Al, Cl, K, Ca, Ti, V, Mn, Fe, Zn, As, Br, Rb, Mo, Cd, I, Sb, Ba, La, Sm, W, Au, and U were determined by neutron activation analysis. According to the data obtained, the mining industry, in particular the metallurgical plants and arsenic containing wastes are the main sources of air pollution. The authors have also observed a remarkable increase in concentrations of all elements with the altitude rising, especially for the light and heavy crust elements. The most obvious explanation of this phenomenon is that the content of mineral soil particles trapped by the moss is increasing with altitude due to the gradually disappearing vegetation cover and appearance of the barren areas from which soil particles may be released by wind erosion and physically captured on the moss surface (Shetekauri et al., 2015).

In 2015, 36 moss samples were collected in different regions of Georgia (Meskheti, Khevsureti, Stepantsminda in Dariali gorge, near the Georgian Military Road, Svaneti, Imereti, Rikoti Pass, Kutaisi). The main environmental pollution sources in sampled regions can be considered transport, mining of manganese, metallurgy, machinery, human waste, and burials of old industrial wastes. The results obtained have shown that the Northwest region of Georgia is characterized by the high pollution level and the majority of metallurgical and mining industry enterprises – like the machine-building factory in Kutaisi, Zestaponi Ferroalloy Plant, and old arsenic mining constructed before 1990 (Ailama, Koruldashi) – the Chiatura mine complex and others are located there (Shetekauri et al., 2018).

The comparison of the moss studies performed in 2014 and 2015 shows that the median concentrations of most elements have been decreased in 2015, which may be attributed to the larger number of samples taken from points with different levels of contamination.

Republic of Kazakhstan

Republic of Kazakhstan (Kazakhstan) is the ninth largest country in the world, covering more than 2.7 million km^2 and accounting for 1.8% of the world's land. It is also the largest landlocked country in the world. Kazakhstan shares borders with Russia, China, Kyrgyzstan, Uzbekistan, and Turkmenistan (Kazakhstan, 2019). The landscape of Kazakhstan is diverse. The Northern forest-steppe urns into steppe, half-deserts and deserts in the South. Kazakhstan is mineral rich country, there are nearly 160 oil and gas deposits including one of the largest world deposits, Tenghiz. In Kazakhstan there are world's largest reserves of chromium, vanadium, bismuth and fluorine. Since Kazakhstan has a vast territory, weather can vary substantially in different parts of the country. In winter the temperature may go down to -45°C and in summer up to +45°C (General information about Kazahkstan, 2019)

Kazakhstan is a rapidly growing economy. The enterprises involved in the extraction and processing of coal, oil, gas, non-ferrous and ferrous metals play a leading role in the national economy. These industries have an adverse effect on the environment. The combination of large coal and energy sectors results in high levels of air pollution (Kenessariyev et al., 2013).

As some other NIS countries, Kazahkstan joint the UNECE ICP Vegetation Programme in 2015. Seventy-eight moss samples were collected in summer and autumn 2015, and thirty-five moss samples in summer 2016. A total of 46 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 in the collected moss samples. As main sources of air pollution in Kazahkstan were defined the metallurgy, mining, engineering and chemical industry (Omarova et al., 2018).

Comparison of the Data Presented in European Atlas of Heavy Metal Atmospheric Deposition

The moss surveys are conducted in European countries every five years and data reported by European countries are presented in the "Spatial and temporal trends in heavy metal accumulation in mosses in Europe (1990-2005)" (Harmens et al., 2008) and "Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe" (Harmens et al., 2013). On Fig.3 the comparison of the data from two abovementioned atlases reported by Estonia, Latvia, Lithuania, Belarus, Russia and Ukraine are presented. Since the main part of the NIS countries have only joined the ICP Vegetation Program in 2015, the data for them are not available yet. For comparison values reported for Cr, Fe, Ni, V and Zn were chosen. For Cr maximum values in 2005/06 and 2010/11 moss surveys were reported for Russia. For Fe, Ni, V and Zn maximum value in 2005/06 was reported for Russia, while in 2010/11 for Ukraine. The significant increase of some elements concentrations in Russia and Ukraine in 2010/11 moss survey can be explained by the involvement of different regions in the studies. In the moss survey 2005/06 Russia presented the results for the North-East of Moscow region, Tula, Tver, Udmurt Republic and Ukraine for Volyn and Sumy region. In the 2010/11 moss survey Russia reported data for Ivanovo, Kostromskaya, Tikhvin-Leningradskaya regions, while Ukraine presented data for Donetsk, the most polluted region in the Ukraine.

CONCLUSION

The air pollution is among the top problems faced by the world today. It can be reduced or avoided based on the permanent monitoring of air quality. The conventional techniques of air quality monitoring are often expensive and inefficient. The moss biomonitoring technique could be addressed as a cheap and useful tool for the pollutants estimating in the air. The moss biomonitoring has been actively applied in Estonia, Latvia and Lithuania, while the main part of the NIS countries have only joined the ICP Vegetation program in 2015. Since many pollution sources were identified on the territory of the countries discussed, it is necessary to perform the moss biomonitoring studies more frequently involving more regions.

The new moss survey was announced for 2020/2021. It is very important for national authorities to support scientific groups involved in biomonitoring studies. Assessment of air pollution is important for both citizen and national authorities since it helps to determine the current level of environmental contamination by heavy metals, to depict the major emission sources and source regions, and to estimate the contribution of atmospheric pathway to the contamination of terrestrial and aquatic environment. Collection of new samples and comparison of obtained results with the previous surveys will provide a view on the environmental situation in the participation countries, will enable the identification of a new sources of air pollution as well as will evaluate the contribution of already known pollution sources.

REFERENCES

Aksu, A. (2015). Sources of metal pollution in the urban atmosphere. (A case study: Tuzla, Istabul). *Journal of Environmental Health Science & Engineering*, *13*(1), 79. doi:10.118640201-015-0224-9 PMID:26587239

Aleksiayenak, Yu., Frontasyeva, M., Florek, M., Sykora, I., Holy, K., Masarik, J., ... Ramatlhape, K. (2013). Distributions of ^{137}Cs and ^{210}Pb in moss collected from Belarus and Slovakia. *Journal of Environmental Radioactivity*, *117*, 19–24. doi:10.1016/j.jenvrad.2012.01.018 PMID:22326019

Aleksiayenak, Yu., Frontasyeva, M., Ostrovnaya, T., & Okina, O. (2015). Moss biomonitoring technique, NAA and AAS in air pollution studies in Belarus. *Problems of Regional Ecology*, 126-134. (in Russian)

Aleksiayenak, Yu., Frontasyeva, M., Steinnes, E., Florek, M., Faanhof, A., & Ramatlhape, K. (2010). Atmospheric deposition of radionuclides in Belarus: 20 years after Chernobyl. *Proceedings of the XVII International Seminar on Interaction of Neutrons with Nuclei (Neutron Spectroscopy, Nuclear Structure, Related Topics).*

Barkan, V., & Lyanguzova, I. (2018). Concentration of Heavy Metals in Dominant Moss Species as an Indicator of Aerial Technogenic Load. *Russian Journal of Ecology*, *49*(2), 128–134. doi:10.1134/S1067413618020030

Blagnyte, R., & Paliulis, D. (2011, May). *Determination of heavy metals in mosses (pylaisia polyantha) along the high – intensive traffic flow in geležinisvilkas street (Vilnius, Lithuania).* Paper presented at the conference The 8th International Environmental Engineering Conference, Vilnius, Lithuania.

Blum, O., Culicov, O., & Frontasyeva, M. (2002). *Heavy metal deposition in Ukrainian Carpathians (Zakarpattia and Chernivtsi regions): the regional biomonitoring*. Paper presented at the conference: Urban Air Pollution, Bioindication and Environmental Awareness. EuroBionet, Stuttgart, Germany.

Brumelis, G., Brown, D., Nikodemus, O., & Tjarve, D. (1999). The monitoring and risk assessment of Zn deposition around a metal smelter in Latvia. *Environmental Monitoring and Assessment*, *58*(2), 201–212. doi:10.1023/A:1006085220366

Ceburnis, D., Ruhling, A., & Kvietkus, K. (1997). Extended study of atmospheric heavy metal deposition in Lithuania based on moss analysis. *Environmental Monitoring and Assessment*, *47*(2), 135–152. doi:10.1023/A:1005779101732

Ceburnis, D., Steinnes, E., & Kvietkus, K. (1999). Estimation of metal uptake efficiencies from precipitation in mosses in Lithuania. *Chemosphere*, *38*(2), 445–455. doi:10.1016/S0045-6535(98)00183-0 PMID:10901666

Cherchintsev, V., Frontasyeva, M., Lyapunov, S., & Smirnov, L. (1999). *Biomonitoring air pollution in Chelyabinsk region (Ural Mountains, Russia) through trace-elements andradionuclides: temporal and spatial trends*. Paper presented at the meeting of the International Atomic Energy Agency, Section of Nutritional and Health-Related Environmental Studies, Vienna, Austria.

Cucu-Man, S. (2006). *Studiul depunerilor atmosferice de metale grele pe teritoriul Moldovei cu ajutorul biomonitorilor* (PhD Thesis). University of Iasi, Romania. (in Romanian)

Dunaev, A., Rumyantsev, I., Agapova, I., Grinevich, V., Vergel, K., & Gundorina, S. (2018). Physical and chemical and biological monitoring in Central Russia: investigation of quality of atmospheric air and soil in territory of Rodniki town. *Izvestiya vysshikh uchebnykh zavedenii khimiya khimicheskaya tekhnologiya, 61*(8), 97-104.

Ermakova, E., Frontasyeva, M., Pavlov, S., Povtoreiko, E., Steinnes, E., & Cheremisina, Ye. (2004a). Air Pollution Studies in Central Russia (Tver and Yaroslavl Regions) Using the Moss Biomonitoring Technique and Neutron Activation Analysis. *Journal of Atmospheric Chemistry*, *49*(1-3), 549–561. doi:10.100710874-004-1265-0

Ermakova, E., Frontasyeva, M., & Steinnes, E. (2004b). Air pollution studies in Central Russia (Tula Region) using the moss biomonitoring technique, INAA and AAS. *Journal of Radioanalytical and Nuclear Chemistry*, *259*(1), 51–58. doi:10.1023/B:JRNC.0000015805.22707.a1

Frontasyeva, M., Smirnov, L., Steinnes, E., Lyapunov, S., & Cherchintsev, V. (2004). Heavy metal atmospheric deposition study in the South Ural Mountains. *Journal of Radioanalytical and Nuclear Chemistry*, *259*(1), 19–26. doi:10.1023/B:JRNC.0000015800.41525.28

Frontasyeva, M., Steinnes, E., Lyapunov, S., Cherchintsev, V., & Smirnov, L. (2000). Biomonitoring of Heavy Metal Deposition in the South Ural Region: Some Preliminary Results Obtained by Nuclear and Related Techniques. *Journal of Radioanalytical and Nuclear Chemistry*, *245*(2), 415–420. doi:10.1023/A:1006799513736

General information about Kazahkstan. (n.d.). Retrieved from https://www.britishcouncil.kz/sites/default/files/general_information_about_kazakhstan.pdf

Georgia. (2019). Retrieved from https://ro.wikipedia.org/wiki/Georgia

Ghorani-Azam, A., Riahi-Zanjani, B., & Balali-Mood, M. (2016). Effects of air pollution on human health and practical measures for prevention in Iran. *Journal of Research in Medical Sciences*, *21*(1), 65. doi:10.4103/1735-1995.189646 PMID:27904610

Gorelova, S., Babicheva, D., Frontasyeva, M., Vergel, K., & Volkova, E. (2016). Atmospheric Deposition of Trace Elements in Central Russia: Tula Region Case Study. Comparison of Different Moss Species for Biomonitoring. *International Journal of Environmental Science,* 220-229.

Harmens, H., Mills, G., & Hayes, F. (2009). *Air pollution and vegetation: ICP Vegetation annual report 2008/2009 NERC/Centre for Ecology & Hydrology, Bangor, UK.* Retrieved from http://www.unfccc.int/resource/docs/natc/mdanc3.pdf

Harmens, H., & Norris, D. (2008). *Spatial and temporal trends in heavy metal accumulation in mosses in Europe (1990-2005)*. Bangor, UK: Centre for Ecology & Hydrology. Retrieved from http://nora.nerc.ac.uk/8672/2/HarmensN008672CP.pdf

Harmens, H., Norris, D., & Mills, G. (2013). *Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe.* Bangor, UK: NERC/Centre for Ecology & Hydrology. Retrieved from http://nora.nerc.ac.uk/502676/1/N502676CR.pdf

Hervada-Sala, C., Jarauta-Bragulat, E., Tyutyunnik, Yu., & Blum, O. (2003). *Indirect geostatistical methods to assess environmental pollution by heavy metals. case study: Ukraine.* Paper presented at the Annual Conference of the International Association for Mathematic Geology, Portsmouth, UK.

Informational bulletin "About the state of natural resources on the environment of the Moscow region in 2015". (2016). The Ministry of Ecology and Natural Resources Use of the Moscow Region. Krasnogorsk. (in Russian)

Kaasik, M., & Liiv, S. (2007). Spatial and temporal variability of trace metals in mosses in Estonia. *Forestry Studies: Metsanduslikud Uurimused*, *46*, 35–44.

Kallis, A., Sims, A., Tammik, A., Roose, A., Türkson, C.-T., Kupri, H.-L., . . . Jurtom, T. (2017). *Estonia's Seventh National Communication Under the United Nations Framework Convention on Climate Change*. Tallinn: Ministry of the Environment.

Kazahkstan. (2019). Retrieved from https://en.wikipedia.org/wiki/Kazakhstan

Kenessariyev, U., Golub, A., Brod, M., Dosmukhametov, A., Amrin, M., Erzhanova, A., & Kenessary, D. (2013). Human Health Cost of Air Pollution in Kazakhstan. *Journal of Environmental Protection*, *4*(08), 869–876. doi:10.4236/jep.2013.48101

Korolyova, Yu. (2010) The bioindication of heavy metal precipitation in the Kaliningrad region. *Bulletin of Kant Russian State University, 7,* 39-44.

Kösta, H., & Liiv, S. (n.d.). *Spatial and temporal trends of heavy metal accumulation in mosses in Estonia*. Paper presented at the 8th International Conference on Ecosystems and Sustainable Development, Alicante, Spain. 10.2495/ECO110121

Liiv, S., & Kaasik, M. (2004). Trace metals in mosses in the Estonian oil shale processing region. *Journal of Atmospheric Chemistry*, *49*(1-3), 563–578. doi:10.100710874-004-1266-z

Lithuania's seventh National Communication. (2017). Ministry of Environment of the Republic of Lithuania. Retrieved from https://unfccc.int/files/national_reports/national_communications_and_biennial_reports/application/pdf/142035_lithuania-nc7-1-7th_national_communication.pdf

Nikodemus, O., Brumelis, G., Tabors, G., Lapin¸, L., & Pope, S. (2004). Monitoring of Air Pollution in Latvia Between 1990 and 2000 Using Moss. *Journal of Atmospheric Chemistry*, *49*(1-3), 521–531. doi:10.100710874-004-1263-2

Olmo, N., Saldiva, P., Braga, A., Lin, Ch., Santos, U., & Pereira, L. (2011). A review of low-level air pollution and adverse effects on human health: Implications for epidemiological studies and public policy. *Clinics*, *66*(4), 681–690. doi:10.1590/S1807-59322011000400025 PMID:21655765

Omarova, N., Nurgalieva, D., Nurkasimova, M., Frontasyeva, M., Morzhukhina, S., & Kabdulkarimova, K. (2018). Environmental monitoring in the Republic of Kazakhstan on the content of heavy metals and radionuclides. *International Electronic journal. Sustainable Development Science and Practice, 1*(3), 20-29.

Pankratova, Yu., Frontasyeva, M., Berdnikov, A., Pavlov, S., Granja, C., Leroy, C., & Stekl, I. (2007). Air Pollution Studies in the Republic of Udmurtia, Russian Federation, using Moss Biomonitoring and INAA. *Nuclear Physics Methods and Accelerators in Biology and Medicine*, *958*, 236–237. doi:10.1063/1.2825794

Pénard-Morand, C., & Annesi-Maesano, I. (2004). Air pollution: From sources of emissions to health effects. *Breathe*, *1*(2), 109–119. doi:10.1183/18106838.0102.108

Popescu, F., & Ionel, I. (2010). *Anthropogenic Air Pollution Sources*. Retrieved from https://www.intechopen.com/books/air-quality/anthropogenic-air-pollution-sources

Ratniece, V., Rubene, L., Cakars, I., Siņics, L., Griķe, I., Gaidis, K., . . . Gancone, A. (2017). *Latvia's seventh National Communication and Third Biennial Report under the United Nations Framework Convention on Climate Change.* Retrieved from https://unfccc.int/files/national_reports/national_communications_and_biennial_reports/application/pdf/9308541_latvia-br3-nc7-1-latvia_nc7_29122017.pdf

Raukas, A. (2004). Opening a new decade. *Oil Shale, A Scientific-Technical Journal, 21*(1), 1-2.

Reimann, C., Halleraker, J., Kashulina, G., & Bogatyrev, I. (1999). Comparison of plant and precipitation chemistry in catchments with different levels of pollution in Kola Peninsula, Russia. *The Science of the Total Environment*, *243/244*, 169–191. doi:10.1016/S0048-9697(99)00390-3

Ruhling, A., & Tyler, G. (1971). Regional differences in the deposition of heavy metals over Scandinavia. *Journal of Applied Ecology*, *8*(2), 497–507. doi:10.2307/2402886

Russia. (2019). Retrieved from https://en.wikipedia.org/wiki/Russia

Russia. (2020). Retrieved from https://en.wikipedia.org/wiki/Russia

Šakalys, J., Kvietkus, K., Sucharová, J., Suchara, I., & Valiulis, D. (2009). Changes in total concentrations and assessed background concentrations of heavy metals in moss in Lithuania and the Czech Republic between 1995 and 2005. *Chemosphere*, *76*(1), 91–97. doi:10.1016/j.chemosphere.2009.02.009 PMID:19269004

Shabatura, A., Blum, O., & Tyutyunnik, Yu. (2018). Regional atmogeochemical fields based on briogeochemical indication data in the central part of northern Ukraine. *Biosphere, 10*(1).

Shetekauri, S., Chaligava, O., Shetekauri, T., Kvlividze, A., Kalabegishvili, T., Kirkesali, E., ... Tselmovich, V. (2018). Biomonitoring Air Pollution Using Moss in Georgia. *Polish Journal of Environmental Studies*, *27*(5), 2259–2266. doi:10.15244/pjoes/73798

Shetekauri, S., Shetekauri, T., Kvlividze, A., Chaligava, O., Kalabegishvili, T., Kirkesali, E., ... Chepurchenko, O. (2015). Preliminary results of atmospheric deposition of major and trace elements in the greater and lesser Caucasus mountains studied by the moss technique and neutron activation analysis. *Annals of Botany*, *5*, 89–95.

Suny, R. G., Howe, G. M., Djibladze, M. L., & Marshall Lang, D. (2010). *Georgia*. Retrieved from https://www.britannica.com/place/Georgia

Tabors, G., Nikodemus, O., Dobkeviča, L., Kļaviņa, L., Ajanoviča, A., Viligurs, K., & Krūz, I. (2017). Assessment of atmospheric pollution with heavy metals and nitrogen using *Pleurozium schreberi* mosses as bioindicator in Latvia: Spatial and temporal aspects. *Environmental and Experimental Biology*, *15*, 143–150.

The Sixth National Communication of Ukraine on climate change. (2012). Ministry of Ecology and Natural Resources of Ukraine. Retrieved from http://www.seia.gov.ua/seia/doccatalog/document?id=638134

Third National Communication of the Republic of Moldova. Under the United Nations Framework Convention on Climate Change. (2013). Chisinau: Imprint Plus SRL.

Vergel, K., Frontasyeva, M., Kamanina, I., & Pavlov, S. (2009). Biomonitoring atmosphernukh vupadenii tyazeluh metallov na severo-vostoke Moskovskoi oblasti s pomosh'yu metoda mhov-biomonitorov. *Ecology of urbanized areas III*, 88-95. (in Russian)

Vergel, K., Frontasyeva, M., Pavlov, S., & Povtoreyko, E. (2007). Air Pollution Studies in Tver Region of Russia using Moss-Biomonitoring with Nuclear Analytical Methods. In *Proceedings of AIP Conference*, (vol. 958, p. 240). 10.1063/1.2825797

Vergel, K., Goryainova, Z., Vikhrova, I., & Frontasyeva, M. (2014). Moss Biomonitoring and Employment of the GIS Technology within the Framework of the Assessment of Air Pollution by Industrial Enterprises in the Tikhvin District of the Leningrad Region. Ecology of Urbanized Areas, 2, 92-101.

Vergel, K., Zinicovscaia, I., Yushin, N., & Frontasyeva, M. (2019). Heavy metal atmospheric deposition study in Moscow region, Russia. *Bulletin of Environmental Contamination and Toxicology*, *103*(3), 435–440. doi:10.100700128-019-02672-4 PMID:31267137

Wolterbeek, H. (2002). Biomonitoring of trace element air pollution: Principles, possibilities and perspectives. *Environmental Pollution*, *120*(1), 11–21. doi:10.1016/S0269-7491(02)00124-0 PMID:12199457

Zinicovscaia, I., Hramco, C., Duliu, O., Vergel, K., Culicov, O., Frontasyeva, M., & Duca, G. (2018). Air pollution study in the Republic of Moldova using moss biomonitoring technique. *Bulletin of Environmental Contamination and Toxicology*, *98*(2), 262–269. doi:10.100700128-016-1989-y PMID:27889805

ADDITIONAL READING

Aničić Urošević, M., Vuković, G., & Tomašević, M. (Eds.). (2016). *Biomonitoring of Air Pollution Using Mosses and Lichens, A Passive and Active Approach, State of the Art Research and Perspectives*. Nova Science Publishers.

Di Palma, A. (2016). *Mosses for monitoring air pollution: towards the standardization of moss-bag technique and the set-up of a new biomaterial* (Ph. D. dissertation). Naples, Italy

Fernández, J. A., Aboal, J. R., Real, C., & Carballeira, A. (2007). A new moss biomonitoring method for detecting sources of small scale pollution. *Atmospheric Environment*, *41*(10), 2098–2110. doi:10.1016/j.atmosenv.2006.10.072

Fernández, J. A., Boquete, M. T., Carballeira, A., & Aboal, J. R. (2015). A critical review of protocols for moss biomonitoring of atmospheric deposition: Sampling and sample preparation. *The Science of the Total Environment*, *517*, 132–150. doi:10.1016/j.scitotenv.2015.02.050 PMID:25725198

Frontasyeva, M., Nazarov, M., & Steinnes, E. (1994). Moss as monitor of heavy metal deposition: Comparison of different multi-element analytical techniques. *Journal of Radioanalytical and Nuclear Chemistry*, *181*(2), 363–371. doi:10.1007/BF02037642

Harmens, H., Norris, D. A., Koerber, G. R., Buse, A., Steinnes, E., & Rühling, A. (2008). Temporal trends (1990 - 2000) in the concentration of cadmium, lead and mercury in mosses across Europe. *Environmental Pollution*, *151*(2), 368–376. doi:10.1016/j.envpol.2007.06.043 PMID:17669565

Stankovic, J., Sabovljevic, A., & Sabovljevic, M. S. (2018). Bryophytes and heavy metals: A review. *Acta Botanica Croatica*, *77*(2), 109–118. doi:10.2478/botcro-2018-0014

Zechmeister, H. G., Riss, A., & Hanus-Illnar, A.Biomonitoring of Atmospheric Heavy Metal Deposition by Mosses in the Vicinity of Industrial Sites. (2004, November). Biomonitoring of Atmospheric Heavy Metal Deposition by Mosses in the Vicinity of Industrial Sites. *Journal of Atmospheric Chemistry*, *49*(1-3), 461–477. doi:10.100710874-004-1260-5

KEY TERMS AND DEFINITIONS

Monitoring: The assessment of chemical pollution by measuring the chemicals (metals, organics compounds) in a biological sample.

Moss Survey: The procedure of moss collection in the same sites every five years.

Mosses: Small flowerless plants, without roots, that typically grow in dense green clumps or mats, often in damp or shady locations.

Neutron Activation Analysis: Highly sensitive analytical technique for metal concentration determination in different type of samples.

Pollution Source: Sector of human activity or natural process, which lead to the release of the pollutants in the environment.

Post-Soviet Countries: Countries formed after collapse of the USSR.