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RESEARCH ARTICLE

Beta radioactivity of urban surface–deposited sediment in three Russian cities

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Abstract

Study of gross beta activity was conducted in Russian cities Ekaterinburg, Rostov-on-Don, and Nizhny Novgorod. The cities were characterized by continental climate, although they are located in different geographical zones. The bulk urban samples were fractionated with three size fractions: dust (0.002–0.1 mm), fine sand (0.1–1 mm), and coarse sand (> 1 mm). Measurement setup equipped with beta radiometer BDPB-01 was designed to measure the low levels of gross beta-activity in a small amount of the obtained size-fractionated samples. According to the results of the study, the gross beta activity depends on the size fraction and the city. The highest beta activity concentration was found in the dust fraction which is about the same in all cities 0.8–0.9 Bq g^{-1}. In size fractions of fine sand and coarse sand, the beta activity depends on the city. Among other cities, the highest average beta concentration was found in Ekaterinburg (0.8 and 0.6 Bq g^{-1} in fine and coarse sand fractions, respectively), while the lowest is 0.28 and 0.44 Bq g^{-1}, respectively. The relationship of beta activity concentration with mineral and chemical composition is studied. Average beta activity in the different fractions of the surface–deposited sediment correlates with uranium, thorium, and organic matter concentration. The gross beta activity may be considered an indicator of high contribution of dust and high pollution with Pb, Cu, and Zn in the urban environment.

Keywords Gross beta activity · Radioactivity · Surface sediment · Dust · Organic matter · Potential heavy metal

Introduction

Radioactivity in the environment substantially changes and sometimes increases as a result of the rapid urbanization and infrastructural development. There are various risks due to natural and anthropogenic activities in the urban environment (Gulan et al. 2017; Yadav et al. 2019). Natural sources are found in the Earth's crust from ^{238}U and ^{232}Th series of terrestrial radionuclides and ^{40}K. In addition, cosmic radiation has produced cosmogenic radionuclides (^{3}H, ^{14}C, ^{7}Be, and ^{22}Na) (Abdel-Razek et al. 2015; Hanfi 2019; UNSCEAR 2010). While in the presence of some artificial radionuclides (such as ^{137}Cs and ^{90}Sr) in the environment, it may be due to nuclear weapon testing and nuclear accident that has occurred, such as Chernobyl (Buraeva et al. 2015). Release of ^{106}Ru in 2017 registered in Central and Eastern Europe is a recent example of environmental radioactivity changes due to anthropogenic influence (Bossew et al. 2019; Masson et al. 2019).

In addition to radiation, heavy metals and various chemical compounds arising from anthropogenic activities are impacted by certain hazards in the urban environment, primarily due to traffic contaminants and industrial processes and building materials used for path, pavement, and construction growth (Han et al. 2002; Nowak and Solecki 2015; Sayyed and Sayadi 2011; Seleznev et al. 2018; Seleznev and Rudakov 2019). Population in the urban environment can be exposed to all kinds of pollutants; pollution of air, soil, and water has led to a steady increase in demand for more efficient emissions control, particularly in developing countries (Ghorani-Azam et al. 2016; Vallius 2005; WHO 2000). In the urban environment, heavy metal, organic pollutants, and natural radionuclides have been almost a serious

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threat to the countries (Akhtar and Tufail 2011; Alshahri and El-Taher 2019).

Urban surfaces are a source of contaminants resulting from runoff, disposal of waste water, and atmospheric precipitation; hence, they are an indication of environmental contamination (Hanfi et al. 2020a; Hanfi and Yarmoshenko 2020). Roofs, roads, and driveways over a period of dry weather are urban surfaces include particles composed of sediment, soil, leaves, rubbish, and organic and inorganic materials (Biggins and Harrison 1980; Ma et al. 2016; Quiñonez-Plaza et al. 2017; Taylor and Owens 2009; Wijesiri et al. 2015). Numerous environmental research focused on the radioactivity and industrial emissions of these contaminants in the urban areas (Al-Hamarneh and Awadallah 2009; Attia et al. 2015; Stajic et al. 2016).

Recently, further focus has been paid to the atmospheric deposition within the urban environment. Particulate matter (PM) is a complex mixture of various structures of small particles. PM derives from both natural and anthropogenic origins. Estimated and reported various health consequences were related to particulate matter (PM) (Anderson et al. 2012; Brunekreef and Holgate 2002; Talbi et al. 2018).

The radioactivity of environmental objects in the urban environment thus constitutes a potential worsening of natural radioactivity or radioactive contamination in the metropolitan region. On the other side, this represents the significant environmental displacement processes (Hanfi et al. 2020b).

Measurement of gross beta activity concentration in urban environment compartments has become increasingly important due to concerns regarding radioactive environmental contamination by natural and anthropogenic behaviors that result in human exposure (Alharbi 2018). The gross beta-activity analysis gives information on all beta-related radionuclides in the urban environment. For all of these purposes, it is important to note that gross beta assessments are considered one of the best forms of either natural or artificial causes of radiation being detected.

The objective of the present work is to analyze the gross beta activity concentration in three Russian cities; Ekaterinburg, Rostov, and Nizhny Novgorod in a small amount of the size-fractioned samples collected from the accumulated urban sediment.

Materials and methods

Study cities

The study was conducted in three different urban environments in Russia: Ekaterinburg, Nizhny Novgorod, and Rostov-on-Don. The description of studied cities is documented in Table 1.

Sampling and measurement procedures

The main object of the study was urban surface–deposited sediment, which is the compartment of the urban environment sensitive to anthropogenic influence including radioactive contamination (Seleznev et al. 2010).

Urban sediment samples were collected over the study regions in residential areas. From 1 to 2.5 kg of the sediment material was collected by a plastic scoop at each point and directly put in vacuum plastic bags to avoid the atmospheric humidity. All collected samples were transported into the laboratory and dried under the room temperature for 1 or 2 weeks. Seleznev and Rudakov (2019) described the processes sequence used to classify each represented sample into the six fraction grain sizes: 0.002–0.01 mm, 0.01–0.05 mm, 0.05–0.1 mm 0.1–0.25, 0.25–1 mm, and > 1 mm (Seleznev and Rudakov 2019). For each particle fraction sample, the solid material obtained was dried and weighed. According to Whitlow (1995), textural and grain size of urban sediment samples were characterized (Whitlow 1995), where grains with diameter ranging from 0.002 to 0.1 mm, from 0.1 to 1 mm, and larger than 1 mm comprise the dust, fine sand, and coarse sand size fractions, respectively.

The fractionated samples were measured by low background radiometer detector BDPB-01, (Hanfi et al. 2019b). The sample was mounted on a planchet with a diameter of 2 cm and a height of 0.6 cm, and the weight was determined. Measurements have been recorded three times every 1000 s and statistical analysis has been performed. The detector background was detected using measurements for the same period of counting that routine samples were counted and measured using a clean, empty detector planchet. Repetitive background determination served as a system operation check, with average values of 0.017 cpm for beta background counting.

The concentration of gross beta activity (Bq g^{-1}) was determined using Eq. (1):

$$A_{\beta} = \frac{I_{c} - I_{BG}}{\varepsilon(m) \cdot m}, \tag{1}$$

where I_c is the beta count rate (s^{-1}), I_{BG} is the background beta count rate (s^{-1}), m is the weight of sample (g) and $\varepsilon(m)$ is the efficiency dependent on m.

To estimate the activity concentration in different grain size, the detection system was calibrated for beta radiation by using the KCl standard samples of with ^{40}K activity concentration 13.7 Bq/g in grained material (with 99.8% in form of grain size 0.5–1 mm) and material crushed by pounder (below 0.5 mm). The sensitivities for different mass of two grain size KCl material were calculated. Obtained difference between sensitivities $6 \pm 4\%$ is considered insignificant (Hanfi et al. 2019b; Zorer et al. 2009). According to Hanfi et al. (2019), the samples with mass < 5 g are negligible.

Table 1 Description of studied cities

Parameter	Ekaterinburg	Nizhny Novgorod	Rostov-on-Don
Area	495 km^2	460 km^2	348.5 km^2
Population	1,468,833	1,259,013	1,130,305
Main rivers	Iset	Oka and Volga	Don
Latitudes and longitudes	56°50′N, 60°35′E	56°19′37″N, 44°00′27″E	47°14′N, 39°42′E
Temperature July (night/day) C	14/24	14/24	18/29
Temperature January (night/day) C	− 15/− 9	− 11/− 5	− 5/− 0.1
Climate	Temperate continental	Humid continental	Moderate continental, steppe
Geographical region	Eastern slope of the Middle Urals	Valley of the Volga and Oka rivers	Valley of the Don river
Geology	Ural mountains	Alluvial river sediment	Alluvial river sediment
Main industries	Productions of machinery, metal processing, metallurgical production, and chemical production	Production of machinery and river shipping	Productions of machinery, river shipping, food industry

Chemical analysis

The urban sediment chemical analysis was carried out at the Chemical Analytical Centre of Institute of Industrial Ecology, Russia. Concentrations of Pb, Cu, and Zn and in addition to the content of U and Th in the fractionated samples were determined using inductively coupled plasma mass spectrometry (ELAN 9000; Perkin Elmer Inc., USA). The sample preparation and analysis procedures were performed using the metal content measurement technique in solid objects with inductively coupled plasma certified by the Russian Federation's State Bureau for Environmental Protection (Seleznev and Rudakov 2019). The fractionated sediment samples were digested using three acids (HNO_3, $HClO_4$, and HF, pure for analysis) before determining the total content of the elements (Melaku et al. 2005). The sample preparation method is similar to the United States Environmental Protection Agency (US EPA) method (EPA 2001) and provides the necessary completeness of dissolving (Vogel et al. 2020).

Organic matter content was detected in a solution prepared from the fractionated urban samples using a photoelectric colorimeter, according to the Russian National Standard Soils: Methods for determination of organic matter (Seleznev and Rudakov 2019). The use of certified methodologies and accreditation of the Chemical Analytical Center of the Institute of Industrial Ecology by the Russian System of State Accreditation Laboratories provided the quality control for the measurements.

Results

The gross beta activity was conducted in three Russian cities, Ekaterinburg, Rostov-on-Don, and Nizhny Novgorod. The urban sediment samples were collected in autumn in 18, 35, and 35 points in the different residential zones in Ekaterinburg, Rostov-on-Don, and Nizhny Novgorod, respectively. The observed results of the average beta-activity concentration in the urban sediment for the different cities, size fractions are presented in Fig. 1. As clarified from Fig. 1, the obtained results of the gross beta activity concentration depend on the size fraction and the city. The highest average gross beta-activity concentration was found in the dust fraction which is about the same in three cities 0.8–0.9 Bq g^{-1}. In fine sand and coarse sand–fractionated size, the average gross beta-activity concentration depends on the city.

The urban sediment is characterized by the content of a different fraction size which derived from natural and anthropogenic processes. The obtained results of the average gross beta-activity concentration among the studied cities are significant. The highest average gross beta-activity concentration

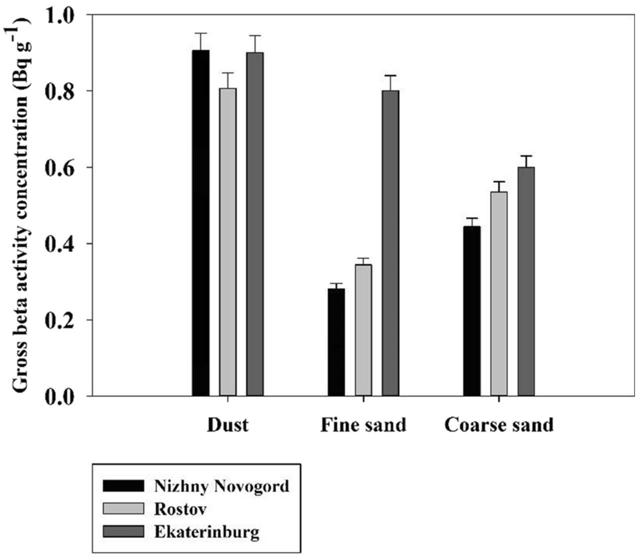

Fig. 1 The average gross beta activity concentration (Bq. g^{-1}) with error bar at different fraction size in three different cities

was found in Ekaterinburg (0.8 and 0.6 Bq g^{-1} in fine and coarse sand fractions, respectively), while the lowest in Nizhny Novgorod (0.28 and 0.44 Bq g^{-1} in fine and coarse sand fractions, respectively), while the gross beta activity concentration was found in Rostov-on-Don (0.34 and 0.54 Bq g^{-1} in fine and coarse sand fractions, respectively).

The variation gross beta activity in the different fractions of urban sediment may be due to the correlation with mineral and chemical compositions which were previously defined (Seleznev et al. 2019, 2020, 2018). Table 2 presents the obtained average mineral and chemical composition in dust and fine sand fraction size in Ekaterinburg, Rostov-on-Don, and Nizhny Novgorod. As clarified in this table, in Ekaterinburg, the analysis of mineral composition is represented with the percentage of dust and fine sand (38 and 31%, respectively) in the total fraction and the percentage of quartz (18 ± 9 and 13 ± 8.4%) and organic matter (10 ± 5 and 14 ± 7.6%). Furthermore, the radioactive content and the potentially harmful elements in the dust and fine sand fraction sizes were studied. U and Th are 2.1 ± 1.8 and 4.7 ± 4.5 mg kg^{-1}, respectively in dust and 1 ± 2 and 2.2 ± 0.64 mg kg^{-1} in fine sand, respectively. Moreover, Zn, Cu, and Pb are 317 ± 282, 130 ± 121, and 41 ± 39 mgkg^{-1} in dust, respectively, while 165 ± 149, 105 ± 84, and 27 ± 17mgkg^{-1} in fine sand.

In Nizhny Novgorod, the percentage of dust and fine sand fraction size for all fractions was 30% and 34%, respectively. In dust fraction size, quartz and organic matter are represented 47% and 9.0%, respectively, while in the fine sand, fraction size are 81 ± 6% and 2.3 ± 0.96%, respectively. Moreover, U and Th content are measured in the dust and fine sand fraction size. Total Th content in the dust and fine sand are 5.0 ± 0.50 and 0.91 ± 0.20 mg kg^{-1}, respectively, and U content are 2.0 ± 0.6 and 0.52 ± 0.15 mg kg^{-1}, respectively. High concentration of potentially harmful elements was found in the dust fraction as well: mean Pb concentration – 41 ± 6 mg kg^{-1} is higher 340% than of concentration in the fine sand fraction, Cu – 92 ± 13 mg kg^{-1} is higher than 350%, and Zn − 288 ± 53 mg kg^{-1} is higher than 520%.

In Rostov-on-Don, the dust and fine sand are represented 31% and 58%, respectively in the total sample of urban sediment. The percentage of quartz and organic matter in the dust is 52.4 ± 8.1% and 8.7 ± 3.5%, respectively, while in the fine sand is 80.4 ± 11.7% and 3.8 ± 2.8%, respectively. U and Th content in dust are 1.9 ± 0.26 and 6.9 ± 1.7 mg kg^{-1}, respectively, and in fine sand 0.7 ± 0.27and 1.5 ± 0.59 mg kg^{-1}, respectively. Moreover, the Zn is the highest mean concentration in the dust and fine sand as followed with Cu and then Pb.

Discussion

Gross beta-activity analysis provides information on all the radionuclides that are attributed to the urban environment (Alharbi 2018). The presence of beta radioactivity is an indicator of the migration and transport of radionuclides to the urban environment from the main source. The occurrence of natural radioactivity in the analyzed environment can therefore be clarified by the existence of igneous rocks and quartz in the urban sediment, the leaching of natural radionuclides from rocks and soils into the urban surfaces together with rainwater (Malanca et al. 1998; Zorer et al. 2009). In addition, potassium-40, uranium, radium, and its daughter are the major known radionuclide contributors to gross beta activities in urban-accumulated sediments (Ivanovich and Harmon 1992; Missimer et al. 2019).

All three cities have the greater concentration of gross beta activity in the fraction of the dust size. During fractionation, high dust beta activity can be associated with leaching significant amounts of organic matter to the dust fraction. Organic matter in all cities can produce potassium-40 with the same efficiency. The disparity in the concentration of beta activity in coarse and fine sand in Ekaterinburg and other cities may be due to various geologic conditions, while in Ekaterinburg, the geology is predominantly defined by the mountain of the

Table 2 Average mineral and chemical composition in dust and fine sand fraction size with 95% confidence intervals (by materials published in (Seleznev et al. 2019, 2020, 2018)

	Ekaterinburg (August, 2017)		Nizhny Novgorod (August, 2018)		Rostov-on-Don (October, 2018)	
Parameter	Dust	Fine sand	Dust	Fine sand	Dust	Fine sand
Fraction in total sample (%)	38	31	30	34	31	58
Quartz (%)	18 ± 9	13 ± 8.4	47 ± 3	81 ± 6	52.4 ± 8.1	80.4 ± 11.7
Organic matter (%)	10 ± 5	14 ± 7.6	9.0 ± 0.8	2.3 ± 0.96	8.7 ± 3.5	3.8 ± 2.8
Th (mg kg-1)	4.7 ± 4.5	2.2 ± 0.64	5.0 ± 0.5	0.91 ± 0.20	6.9 ± 1.7	1.5 ± 0.59
U (mg kg-1)	2.1 ± 1.8	1.0 ± 2	2.0 ± 0.6	0.52 ± 0.15	1.9 ± 0.26	0.7 ± 0.27
Zn (mg kg^{-1})	317 ± 282	165 ± 149	288 ± 53	55 ± 21	335 ± 197	87 ± 65
Cu (mg kg^{-1})	130 ± 121	105 ± 84	92 ± 13	26 ± 7	75 ± 52	26 ± 16
Pb (mg kg^{-1})	41 ± 39	27 ± 17	41 ± 6.0	12 ± 5	45 ± 28	17 ± 10

Urals, and in Nizhny Novgorod and Rostov Don, the geology is connected with alluvial processes of rivers.

Recently, elevated concentration of ^{106}Ru in air was recorded by monitoring stations across Central and Eastern Europe in September and October 2017. It was supposed that the radionuclide was released from some facilities in the Southern Urals. One can expect some contributions of ^{106}Ru and its progenies to beta activity of USDS samples from Rostov-on-Don. In other cities, the USDS were sampled before the ^{106}Ru release episode. According to Saunier et al. (2019) and Bossew et al. (2019), Rostov-on-Don was exposed to the radioactive cloud. As can be seen from Fig. 1, supposed fallout did not contribute to gross beta activity of urban surface–deposited sediment in Rostov-on-Don in comparison with other cities.

The variation of gross beta activity with mineral and chemical composition in urban surface–deposited sediment is studied for the fractions of dust and fine sand in the cities. Gross beta activity in the dust fraction was correlated with the presence of organic matter, quartz, and radionuclides in the urban sediments.

Urban sediment study was performed in the late summer season and revealed high values for the gross beta activity. Consequently, most significant contribution to the gross beta activity is from K-40 as its components and environmental applications (Harben 1999). Moreover, organic matter has been studied in urban surface–deposited sediment, fresh organic residues that have appeared since the spring bloom to autumn wilting contain high amounts of potassium and may contribute to gross beta activity in addition to leaching natural radionuclides from rocks and soils to urban areas along with rainwater. The quartz-rocks are collector of radioactive elements (Zorer and Öter 2015). NCRP (1987) also showed that agricultural fertilizer products contain various series of natural radionuclides. The use of these products for example increased the potassium content of sediments (NCRP 1987).

Besides the radionuclides, the potentially harmful elements were also detected in the urban environment (Seleznev et al. 2020). From the obtained results, the dust size fraction has a higher concentration of potentially harmful elements than the fine sand fraction size. The last is related to the anthropogenic activities in cities. Productions of machinery, metal processing, metallurgical production, chemical production etc. are developed in Ekaterinburg. Production of machinery and river shipping is the main industries in Nizhny Novgorod. Machinery, river shipping, and food industry are present in Rostov-on-Don. Domestic emission, weathering of building facades, pavement surface and precipitation of previously suspended particles (atmospheric aerosols), and so on are source of pollution in the residential areas as well (Baptista and De Miguel 2005; De Silva et al. 2016; Zereni and Alt 2006; Hjortenkrans and H 2006, 2007; Winther and Slento 2010). These indicate that the gross beta activity in the urban environment reflects the migration and transport of radionuclides and potentially harmful elements through natural and mechanical mechanisms such as wind, traffic, and industrial activities in urban areas. Pollutants are closely bonded to the size of the dust fraction.

Conclusion

Gross beta activity analysis was carried out in three Russian cities located in various geographical and climatic zones. The urban-deposited sediments were sampled from various parts of the cities and divided into three main fractional sizes: dust, fine sand, and coarse sand. The results obtained explained the concentration of gross beta activity based on the fractional size of the urban sediments and the area. The size of the dust fraction has approximately the same concentration of gross beta activity in the studied cities. This can be attributed to the presence of radionuclides that migrated and transferred through the same natural and anthropogenic processes and to the presence on organic matter of a certain potassium-40 content. According to the geological nature of the areas analyzed, the quality of mineral components, and the level of anthropogenic activity, Ekaterinburg has the highest gross beta activity in the sand fraction. The gross beta activity with Pb, Cu, and Zn concentrations can be considered an indicator of high anthropogenic contribution to dust content and high pollution in the urban environment. ^{106}Ru nevertheless did not contribute to gross beta activity.

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