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ACCUMULATION OF RADIONUCLIDES BY PYLAISIELLA MOSS (PYLAISIA POLYANTHA) UNDER URBOECOSYSTEM CONDITIONS

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ABSTRACT

Contamination of environment by radionuclides in territories under urboecosystem conditions is actual problem. The search of new express methods for radioactivity determination of environment is important task of research. In present work it was shown that mosses are bioindicators of radioactive contamination, because they accumulate radioactive substances in high concentrations. Using of bryoindication methods are promising techniques for the assessment of the contamination of ecosystems with radionuclides. The use of epiphytic mosses is the most efficient technique for assessing the contents of radionuclides in the surface air layer. The epiphytic moss (*Pylaisia polyantha)* growing in different zones of the city of Rostov-on-Don, was used for the radioactivity biomonitoring of urbosystems. The accumulation features of radionuclides in the epitaphic pylaisiella moss (Pylaisia polyantha) in the territory of the city of Rostov-on-Don have been considered. It was shown that *Pylaisia polyantha* is effective indicator of radioactivity for biomonitoring. The activity concentration of ^{137}Cs, ^{226}Ra, ^{40}K and ^{232}Th in the samples of moss, soils and aerosol air have been compared. The capacity of Pylaisia polyantha to accumulate radionuclides has been estimated for four radionuclides (^{137}Cs, ^{226}Ra, ^{232}Th and ^{40}K) with consideration for the background level. On the basis of radionuclide analysis, zones in the city of Rostov-on-Don with the highest accumulation coefficients of ^{137}Cs, ^{226}Ra, ^{40}K and ^{232}Th were revealed. These were primarily the zones with both industrial and traffic loads and the motor transport zones. The results of investigation showed that the epiphytic moss (*Pylaisia polyantha)* can be used as indicator of radioactivity pollution in different polluted zones.

Keywords: Pylaisiella Moss, Radionuclides, Activity Concentration, Build-Up Factor

1. INTRODUCTION

There are about 300 radionuclides (both natural and artificial, i.e., human-made) in the environment. The Earth biosphere contains more than 60 natural radionuclides. About 80 radionuclides are formed in nuclear reactors; about 200 radionuclides result from nuclear explosions and more than 140 radionuclides are produced by the Russian industry. Nuclear explosions; environmental contamination with radioactive waste; exploitation of various mineral deposits, including uranium-thorium deposits; accidents on enterprises of the nuclear fuel cycle result in the radioactive contamination of the atmosphere and the ingress of radioactive

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materials into living organisms and their habitats (atmosphere, hydrosphere, soil) (Ajlouni *et al*., 2009; Mandzhieva *et al*., 2014).

Radionuclides get into the surface air layer due to different processes: The generation in the atmosphere and stratosphere and aerial transfer (for ^{7}Be) with the wind-blown dust from the geological substrate (radionuclides of terrestrial origin, artificial radionuclides); the emissions from the thermal enterprises and power stations working on hydrocarbon fuels (^{210}Pb); the direct input caused by accidents on the enterprises of the nuclear fuel cycle (artificial radionuclides) (Ajlouni *et al*., 2009).

Mosses are known to be excellent biological indicators (accumulators of atmospheric emissions). The moss cover is developed for 2-5 years; therefore, the analysis of biomass can assess the level of atmospheric contamination in different regions of the studied area during this period (Maxhuni *et al*., 2012).

The moss cover is a good sorbent due to the highly developed surface (the specific surface area of mosses is higher than that of herbaceous plants by 10 times) and the low level of metabolism favors the accumulation of many mutagenic agents (including radionuclides, heavy metals) in the biomass.

It was shown that bryophytes accumulate large amounts of metals and radionuclides compared to vascular plants. From isolated data, the relative accumulation efficiencies of ^{137}Cs and ^{90}Sr by living mosses exceed the corresponding values for the metabolism products (fallen leaves) and fruits of woody plants (*Robinia pseudoacacia* and *Tilia* sp.). The mosses fulfill functions of a sorbing surface and a living sorbent; they accumulate ^{90}Sr and ^{137}Cs primarily from atmospheric fallouts and, to a lesser degree, the soil. By the interception of global ^{137}Cs, the mosses occupy the first position in the series: Mosses-lichens-higher plants.

The radioactivity of bryoflora objects was assessed in a number of works, in which the isotope ratios were determined and the seasonal variations of radionuclide concentrations were investigated (Ajlouni *et al*., 2009; Kiliç *et al*., 2014; Carvalho, 2011; Carvalho *et al*., 2012).

In the study of the radioactive contamination of regions in the environs of the Marmara Sea (Turkey) during the period from 2001 to 2008, the moss *Hypnum cupressiforme*, which is most prevalent in the seaboard areas, was used as a bioindicator (Kiliç *et al*., 2014). The accumulating capacity of *Hypnum cupressiforme* was compared with that of the lichen *Cladonia rangiformis*. It was noted that the contents of natural radionuclides in the lichens and mosses are within the same range for the territory of Turkey, as well as for Norway, Greece and Serbia. The concentrations of the radioactive elements in the mosses are in the ranges of 17.1-181.1 (^{40}K), 1.51-6.17 (^{232}Th) and 0.87-6.73 (^{238}U) Bq/kg, their average values being 114.4±41.4, 3.79±1.34 and 3.04±1.46 Bq/kg, respectively.

The content of ^{40}K in the moss samples is significantly higher than those of ^{232}Th and ^{238}U. This is related to the fact that potassium is an essential macroelement for the metabolism of living organisms, in distinction from thorium and uranium, which are not involved in the vital activity of mosses and lichens. In the soil, the content of the potassium isotope also exceeds those of thorium and uranium, which is a norm, according to the data on the average activity concentrations of ^{40}K (300-400 Bq/kg), ^{232}Th (25-35 Bq/kg) and ^{238}U (25-30 Bq/kg) in soils throughout the world. It is important to take into consideration that the adsorption of these radionuclides by mosses occurs in two main ways: First, at the adsorption of soil particles suspended in the air and, second, at the adsorption of liquid atmospheric precipitations (rain, dew, snow).

Terrestrial mosses are frequently used for the detection of ^{7}Be, ^{214}Bi and ^{210}Pb in the atmospheric air and the analysis of the spatial distribution of ^{7}Be in the precipitations. Hypnum moss (*Hypnum cupressiforme*) is used for assessing the activity concentrations of ^{137}Cs, ^{40} K, ^{232}U and ^{238}U. It was shown that the concentrations of ^{137}Cs, ^{40} K, ^{232}U and ^{238}U in the hypnum moss are higher than those in the lichen *(Cladonia rangiformis*) on the area studied (Krmar *et al*., 2014).

Terrestrial mosses are used for assessing the contents of the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K, as well as the artificial radionuclide ^{137}Cs, in soils, as well as their seasonal behavior (Krmar *et al*., 2014). The terrestrial mosses were analyzed for the comparative estimation of the ^{234}U/^{238}U content in the soil and bryoflora objects. Samples of epiphytic and terrestrial mosses were selected for the radioanalytical monitoring to measure the potential contamination of areas with ^{239}Pu, ^{240}Pu, ^{238}Pu and ^{241}Pu; determine their origin; and assess their hazard for the food chain (Krmar *et al*., 2014).

Thus, mosses are bioindicators of radioactive contamination, because they accumulate radioactive substances in high concentrations. It was shown that the bryoindication methods are promising techniques for the assessment of the contamination of ecosystems with radionuclides (Smith *et al*., 2014; Minkina *et al*., 2013a; 2014; Motuzova *et al*., 2014; Batukaev *et al*., 2014).

2. OBJECTS AND METHODS

The use of epiphytic mosses is the most efficient technique for assessing the contents of radionuclides in the surface air layer. In our work, the epiphytic moss (*Pylaisia polyantha)*, which grows in different zones of the city of Rostov-on-Don, was used for the biomonitoring of urbosystems (**Fig. 1**). Samples of *P. polyantha* were taken from poplar dark at a height of 1.5-2.0 m on the test plots of Rostov-on-Don. A total of 350 samples of *P. polyantha* were used for the radionuclide analysis.

The background plot was located in the relatively clean area of the Kamenskii district (Rostov Region, Russia) with the natural and climatic conditions similar to those of the area studied in the course of biomonitoring and located at more than 100 km from industrial centers.

The following parameters were also determined: The radionuclide composition in the 0- to 2-cm layer (more than 100 soil samples), as well as the specific contamination and radioactivity of the surface soil layer (more than 300 samples).

For the determination of radioisotope composition, the samples were dried in an oven at 105-110°C to a constant weight (for 24 h) and ground.

The contents of the radionuclides in the selected samples were determined by the gamma-spectrometric method of radionuclide analysis on a customized low-background REUS-II-15 unit with a GeHP semiconductor detector and Dent containers of 0.02 and 0.04 L according to the standard analytical procedures.

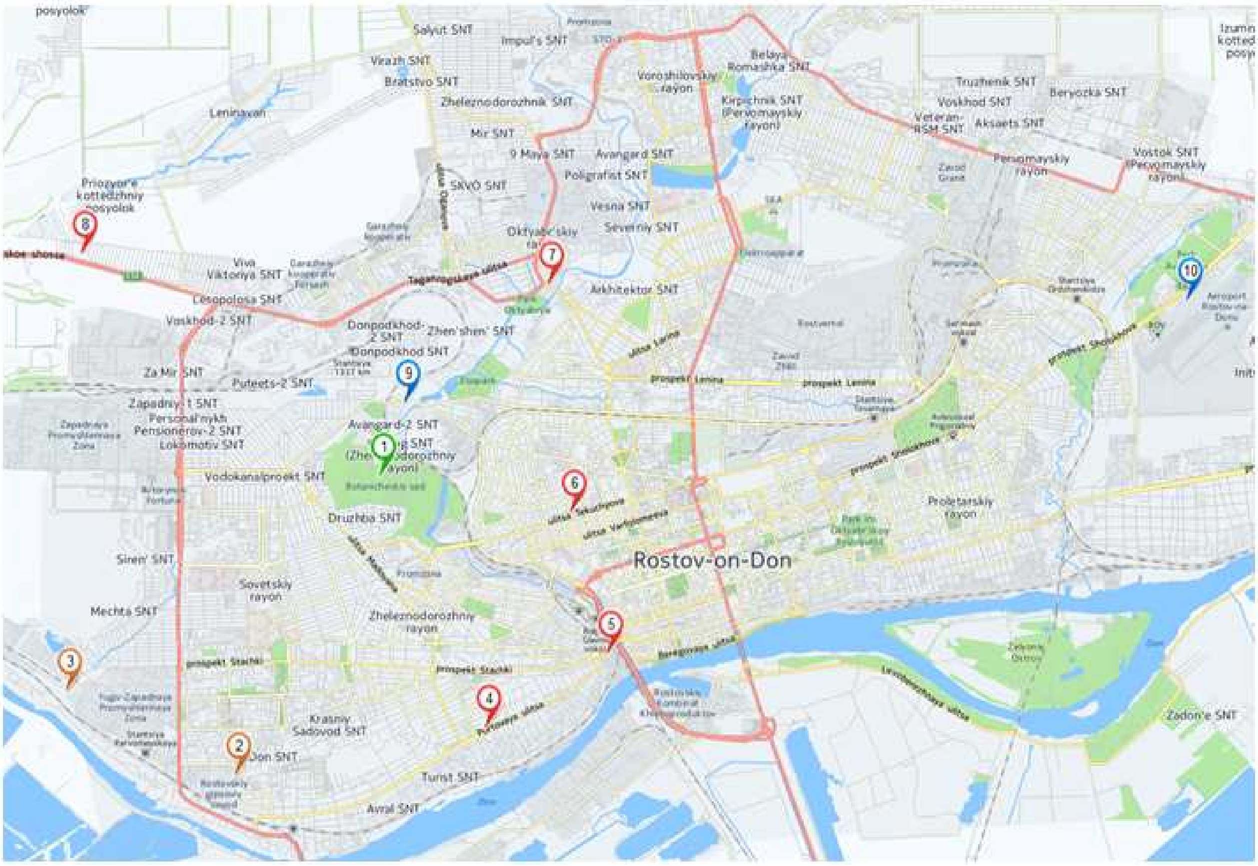

Fig. 1. Schematic map of biomonitoring plots: Transport emission zone (plot 9, Zmievskii St.; plot 10, Sholokhova Ave.); industrial emission zone (plot 2, thermal power plant; plot 3, thermal power plant 2; plot 10, bearing plant); industrial and transport emission zones (plot 4, Portnova St.; plot 5, Siversa St.; plot 6, Budenovskii Ave, Dolomanovskii St./Tekucheva St. and Mechnikova St.; plot 7, Vavilova St.; plot 8, Taganrogskoe sh.); recreation park zone (plot 1 (relative control), Botanic Garden)

The build-up factor of radionuclides Kc were calculated from the formula Kc = Ks/Kb, where Ks is the activity concentration of radionuclides in the sample and Kb is the activity concentration of radionuclides in the background. The accumulation coefficients of radionuclides with respect to the aerosol dust (Kaa) and the soil (Kas) were also calculated.

The capacity of pylaisiella moss to accumulate radionuclides was assessed for four radionuclides: ^{137}Cs, ^{226}Ra, ^{232}Th and ^{40}K with consideration for the background level. These radionuclides were used as the objects of study, because their presence mainly determines the ecological and radiation situation in the city of Rostov-on-Don and its district. The activity concentration of radionuclides in the samples of pylaisiella moss on the test plots of Rostov-on-Don was compared to that in the background mosses, the surface air layer and the soil. The degree of radionuclide accumulation in pylaisiella moss was determined from the concentration coefficient (Kc).

3. RESULTS

The results of determining the activity concentration of radionuclides and the build-up factor (Kc) in the samples of pylaisiella moss are given in **Fig. 2 and 3**.

In previous research it was detemined that activity concentration of radionuclides in the mosses coud be used as effective indicator of radioactivity pollution in different polluted zones (El-Gamal *et al*., 2013; Minkina *et al*., 2014). In research El-Gamal *et al*. (2013) it was shown that mosses are used for urboecomonitoring for definition of high radioactivity levels around assiut thermal power plants. In investigation of Minkina *et al*. (2014) describes additional influence of of heavy metal attendant anion on adsorbtion of polluted material by plants system.

The build-up factor of radionuclides with respect to the atmospheric air (Kaa) and the soil (Kas) are given in **Fig. 4-7**.

Investigation of the build-up factor of mosses gives a linear attenuation coefficient can be considered as the fraction of photons that interact with the shielding medium per centimeter of shielding. This coefficient assumes that all photons that interact are removed and ignores compton scatter and pair production photons (underestimates the shielded dose rate and the shielding required) (Kolupaev *et al*., 2014). It is also known as narrow beam conditions because the source and detector are assumed to be collimated and the measurement made at a short distance (Laxman Singh *et al*., 2014).

The factors of accumulation whis is a parameter of ability of biological objects to accumulate radionuclides from natural objects of their habitat were determined in samples of mosses (Hansson *et al*., 2014). The results compares with previous research which explained the possibility using *P. polyantha as an effective bioindicator* of radioactivity contamination of the total environment (Osman *et al*., 2005; Minkina *et al*., 2013b; Sushkova *et al*., 2014;).

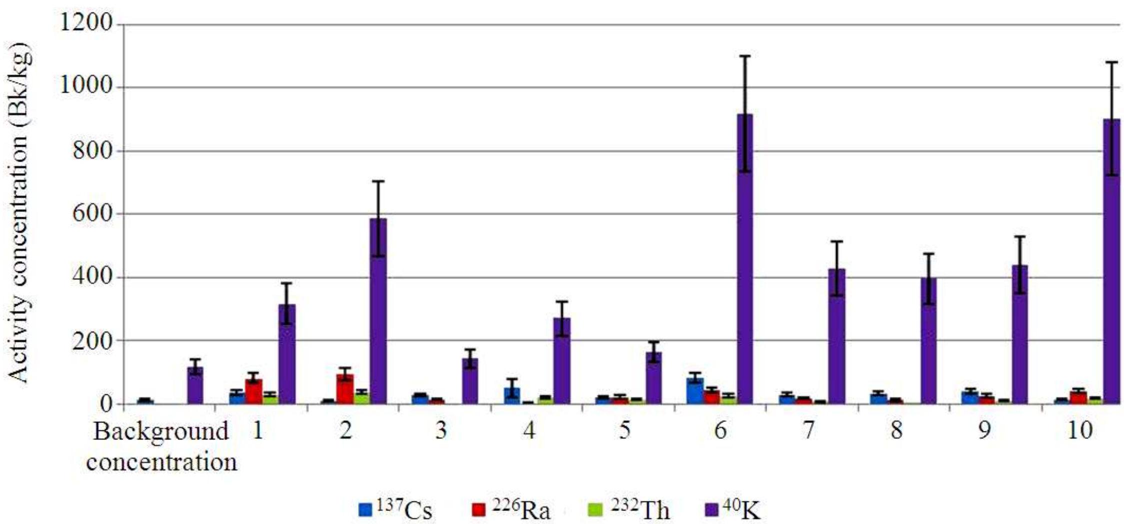

Fig. 2. The activity concentration of ^{137}Cs, ^{226}Ra, ^{232}Th and ^{40}K in the samples of pylaisiella moss (Pylaisia polyantha) from the test plots in the city of Rostov-on-Don

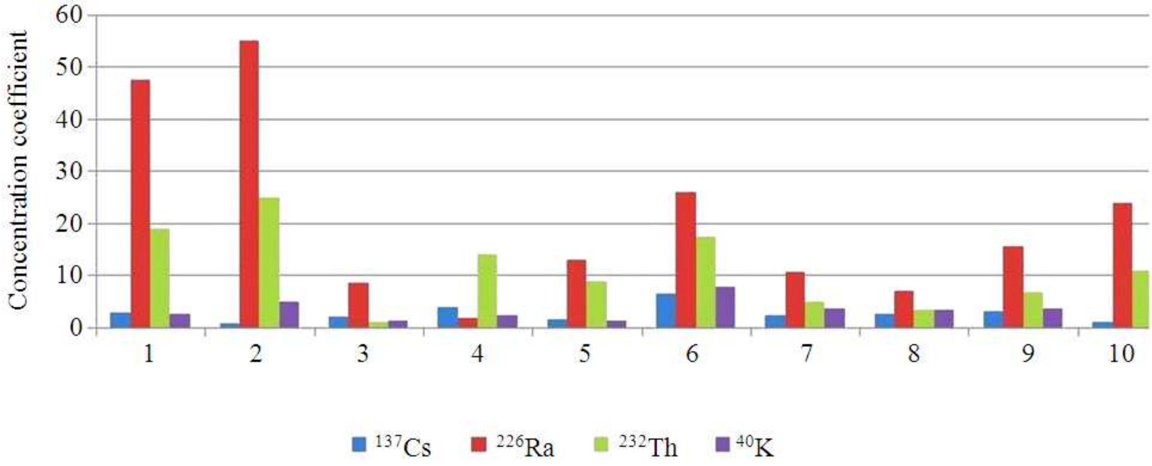

Fig. 3. Concentration coefficient (Kc) of ^{137}Cs, ^{226}Ra, ^{232}Th and ^{40}K in the samples of pylaisiella moss (Pylai-sia polyantha) from the test plots in the city of Rostov-on-Don

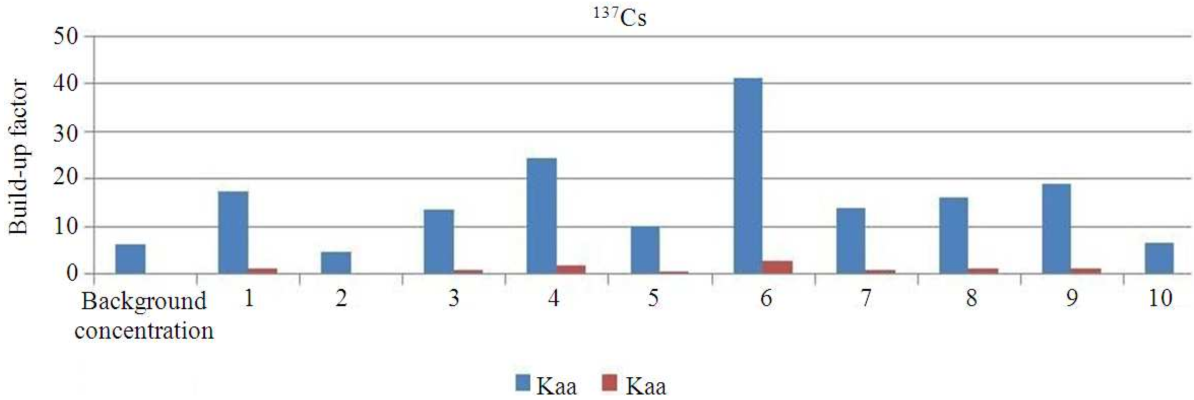

Fig. 4. Build-up factor (Kaa and Kas) of ^{137}Cs in the samples of pylaisiella moss (Pylaisia polyantha) from the test plots in the city of Rostov-on-Don

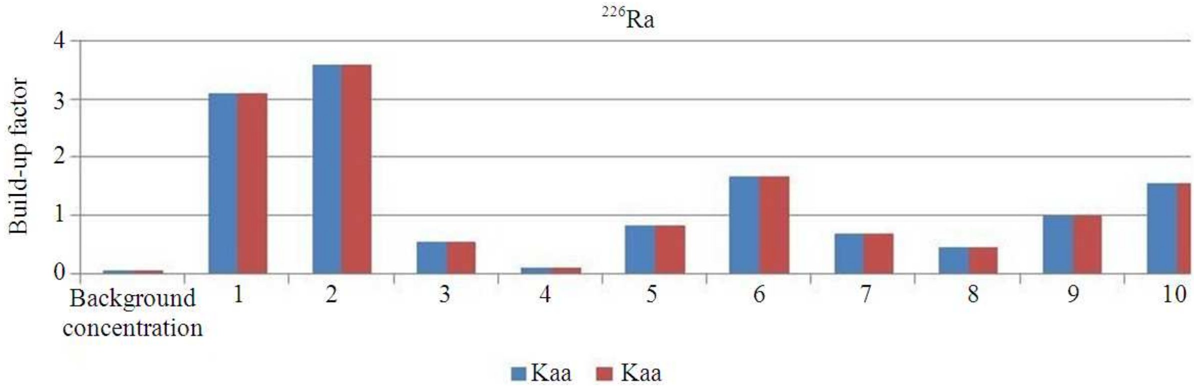

Fig. 5. Build-up factor (Kaa and Kas) of ^{226}Ra in the samples of pylaisiella moss (Pylaisia polyantha) from the test plots in the city of Rostov-on-Don

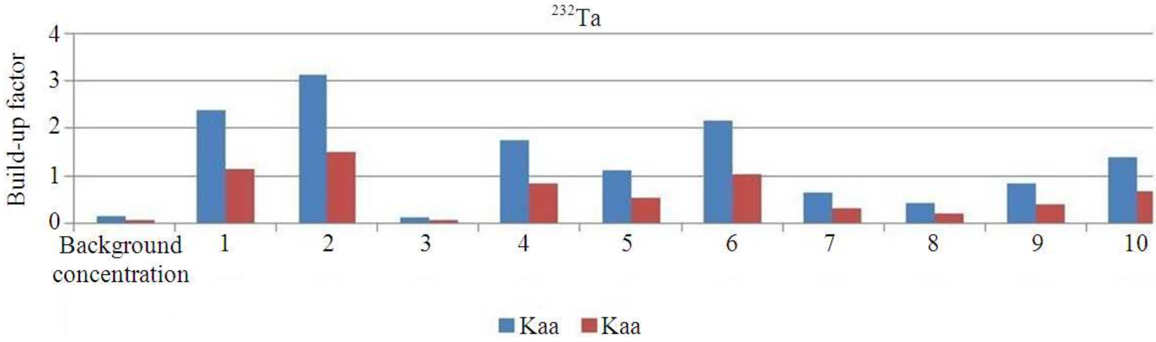

Fig. 6. Accumulation coefficients (Kaa and Kas) of ^{232}Th in the samples of pylaisiella moss (Pylaisia polyantha) from the test plots in the city of Rostov-on-Don

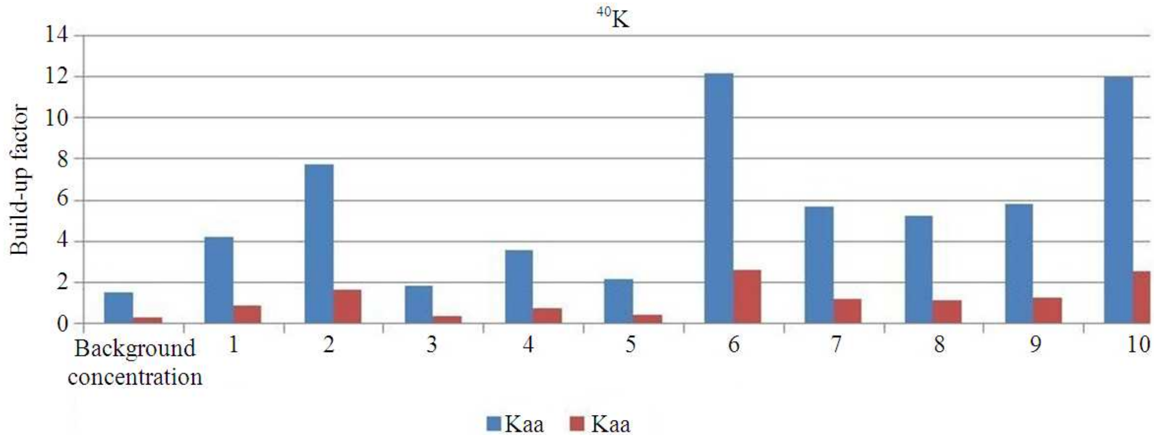

Fig. 7. Accumulation coefficients (Kaa and Kas) of ^{40}K in the samples of pylaisiella moss (Pylaisia polyantha) from the test plots in the city of Rostov-on-Don

4. DISCUSSION

The activity concentration of radionuclides in the aerosol dust in the surface air layer Aas (Bq/kg) was determined from their volume activity in aerosols Ava (Bq/m^3) with consideration for the content of dust in the atmosphere (m, g/m^3). The average activity concentrations of ^{137}Cs, ^{224}Ra, ^{232}Th and ^{40}K in the samples of moss, soil and aerosol dust coincided within the error of determination (20%). The value of Kc for ^{137}Cs in the points, where its activity concentration exceeded the background levels, varied in the range from 1.05 to 6.6 (**Fig. 4**). The maximum Kc values were recorded in the Leninskii, Zheleznodorozhnyi and Oktyabr'skii districts.

The maximum values of Kaa and Kas were found for ^{137}Cs in the Leninskii district. The maximum build-up factor Kaa for ^{137}Cs was 41.5 (which exceeded the background value by 17.6 times); the values of Kas for ^{137}Cs varied from 0.34 to 2.96 (**Fig. 4**).

The values of Kc for ^{226}Ra varied from 1.8 to 55. Its maximums were recorded in the Sovetskii and Pervomaiskii districts (**Fig. 3**); the maximum Kaa and Kas values (3.6) were found in the Sovetskii district (**Fig. 5**).

The values of Kc for ^{232}Th varied from 1.06 to 25, the maximums being recorded in the Sovetskii and Leninskii districts (**Fig. 3**); the values of Kaa for ^{232}Th varied from 0.06 to 1.5, the maximum being of 3.13 (**Fig. 6**).

The values of Kc for ^{40}K varied from 1.2 to 7.8. The maximum values were recorded in the Leninskii district for Kc and in the Leninskii, Pervomaiskii and Sovetskii districts for Kaa and Kas (**Fig. 7**). The value of Kas for ^{40}K with respect to aerosol dust was 12.21; the Kas variation range was from 0.4 to 2.622 (**Fig. 7**).

The increase of the activity concentration of ^{226}Ra in the samples of *P. polyantha* can be also related to the functioning of coal-fired power plants in the close vicinity of the test areas. It is known that the average global activity of ^{226}Ra in the power-plant volatile ash is 240 Bq/kg. The specific pollution density of the surface air is the main factor directly affecting the specific activity of ^{137}Cs in this air layer. The activity concentration of the artificial radionuclide ^{137}Cs in the samples of pylaisiella moss can be due to the atmospheric emissions and the wind-blown dust from the geological substrate.

The activity concentration of ^{40}K in the samples was significantly higher than those of ^{137}Cs (by 14.6 times), ^{226}Ra (by 14.3 times) and ^{232}Th (by 30.4 times). This is related to the fact that potassium is an essential macroelement for the metabolism of living organisms. In soil and air, the activity concentration of the potassium isotope also exceeds those of ^{137}Cs, ^{226}Ra and ^{232}Th.

5. CONCLUSION

The activity concentration of ^{137}Cs, ^{226}Ra, ^{40}K and ^{232}Th in the samples of pylaisiella moss were found to be generally higher than in soils and aerosols. Radionuclide analysis revealed zones in the city of Rostov-on-Don with the highest accumulation coefficients (Kaa and Kas) of ^{137}Cs, ^{226}Ra, ^{40}K and ^{232}Th, including the zone with both industrial and traffic loads and the motor transport zone. The limitations of activity concentrations of ^{137}Cs, ^{224}Ra, ^{232}Th and ^{40}K in the samples of moss, soil and aerosol dust exceeded the background levels, varied in the range from 1.05 to 6.6. The maximum activity concentration values were recorded in the Leninskii, Zheleznodorozhnyi and Oktyabr'skii districts of the city.

This allows using pylaisiella moss to determine the radioactivity of the surface air layer, assess the accumulation of radionuclides during a long time period and study the contribution of radionuclides to the entire range of genotoxic substances affecting the genetic apparatus of pylaisiella moss. The obtained data gives a unique possibility to study environmental contamination by using simple and effective method of radioactive bioindication by pylaisiella moss in future.

6. ACKNOWLEDGEMENT

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