

Specific Activity of Radionuclides in Soils Disturbed by Forest Fires

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ABSTRACT

Fires in natural ecosystems have a detrimental effect on all biota components. In the global scale, many scientific studies of prominent scientists are devoted to this topic. It should be noted that scientists have always been interested in the influence of thermal destruction of soil genetic horizons on the specific activity of radionuclides. Most of these studies began after the Chernobyl (1986) and Fukushima (2011) radiation disasters. The conducted research is focused on the specific activity of radionuclides due to the thermal effects of fires in natural ecosystems. It has been established that the edaphotopes affected by fires are naturally restored causing the restoration of soil formation processes. The specific activity of radionuclides decreases with the duration of the ground fire. Comparing the obtained data with the regulatory documentation, it was found that they do not exceed the minimum significant activity of radionuclides in the workplace. However, the increased activity of radionuclides in soils has a detrimental effect on the ecological condition and flora and fauna development. During the fire season in natural ecosystems and forests, careless handling of fire should be avoided and preventive measures should be taken to inform the public about the harmful effects of wildfire.

Keywords: forest fire, fire danger, radionuclides, soil pollution.

INTRODUCTION

Fires in natural ecosystems cause irreversible changes in the environment. Due to the temperature influence on the soil, its genetic structure, physicochemical, mechanical properties, as well as the mineral composition and content of heavy metals in it change. Some of these aspects have already been studied and published (Popovych et al., 2021). Many scientific works of researchers from all over the world are devoted to the impact of fires in natural ecosystems on soils, vegetation and microorganisms. In the paper (Shevchuk et al., 2021) scientists analyzed the reasons of fires in forests of the Lower Dnieper sands of Kherson region (Ukraine). The differences in the gradation of forest fire hazard classes on the territory of the Lower Dnieper sands and other plantations were determined. The main factors of forest fires in the Lower Dnieper sands over a fifteen-year period were identified. The analysis of forest fires

in different districts of Kherson region was carried out. The fires that caused the greatest material and environmental damage at the present stage of forest use were identified (Shevchuk et al., 2021). The current state of trees in the research areas affected by the grassland fire of 2007 was described. The change of trees condition categories and resistance of pine species to the influence of grassland fires during the research period was studied. Stem pests were identified in fire-affected pine stands. The dynamics of dechromation and defoliation of trees in the experimental areas over a ten-year period was described (Shevchuk et al., 2021).

The scientific studies that take into account the investigation of radionuclide migration, in soil and air, surface and groundwater, are extremely important. Such studies became exceptional, in particular after the explosion at the Chernobyl nuclear power plant in Ukraine in 1986. In situ tests (Azarov et al., 2020) indicate that the content of radioactive smoke particles in the surface layer

of the atmosphere of the Exclusion Zone can increase sharply by several orders of magnitude due to forest fires. Short-term (several days) increased the content of radioactive combustion products in the surface layer of the air can reach the level of radiation danger to the environment and directly to the life safety of the population living in a clean area at considerable distances (up to 30 km along the trail axis) (Azarov et al., 2020).

Scientists in (Kuzyk et al., 2019) argue that the peculiarities of forest fire extinguishing in a radiation-contaminated area depend on the method of extinguishing, the use of appropriate forces and means that allow effective localization as well as elimination of fire. In addition to the traditional threats related to forest fire-fighting, with the presence of radioactive contamination, the radiation-related hazards should be taken into account and appropriate protections should be applied. In the case of large and intensive fires, a fire aircraft should be used, which will not only extinguish the fire, but also avoid the direct contact of firefighters with radiation-contaminated environment (Kuzyk et al., 2019).

It is noted (Landin et al., 2021) that in the areas contaminated by the Chernobyl accident, natural vegetation plays the role of stabilizer of the radioecological situation. Due to stable succession processes, removal of substances outside the landscape is practically absent and it significantly reduces secondary contamination of adjacent areas with radionuclides. The methodology and criteria for assessing the vegetation state by means of remote sensing of the Earth and methods of geographic information technologies were proposed. A map of the spatial distribution of fire-damaged vegetation was obtained. It contains: types of plant communities (biocenosis), type of forest plantations (coniferous, deciduous, mixed) and herbaceous vegetation, degree of damage, their area, time of fire (Landin et al., 2021). It was concluded that after the accident in the exclusion zone and the zone of unconditional mandatory resettlement of the Chernobyl nuclear power plant, changes in vegetation and nature objects took place in two directions, i. e. destructive and regenerative. As a result of the cessation of agricultural production, agricultural lands: arable land, hayfields and pastures, moved into the category of fallows (dry meadows) and floodplain meadows with changes in plant species composition. The dry meadows associated with drier and poorer soils are dominated by the formations of

red fescue (*Festuca rubra*), creeping wheatgrass (*Elytrigia repens*), thin-leaved koeleria (*Poa angustifolia*), and common bentgrass (*Agrostis capillaris*). The biocenoses corresponding to lowland boggy landforms include sedges and wetland reed vegetation (Landin et al., 2021).

The authors in (Voron et al., 2016) experimentally identified the peculiarities of temperature changes in different layers of forest litter in the air-dry and absolutely dry state during the passage of the combustion front. For air-dry monoliths of fresh coniferous litter the maximum temperature from the lower to the upper layers varied in the range of + 131°C–+ 295°C. Comparative layer-by-layer analysis of litter combustion temperatures shows that with increasing of litter depth, the speed of the combustion front decreases. An exception is the surface of monoliths, on which, in addition to the release of heat, during combustion there is a simultaneous cooling by convective air flows. Increased airflow leads to a higher temperature and burning rate of the litter. This is due to increased convection in the surface layers of the litter and increased access of oxygen to the deep layers of the litter, which increases the intensity of combustion and the temperature in these layers (Voron et al., 2016).

The study of soils in the post-fire period is reflected in (García-Orenes et al., 2017). At the control site, the soil properties remained unchanged for 2 years of monitoring, and the microbial parameters affected by the fire were restored faster at the control site than at the recovery site. Restoration of plants also showed some differences – there were no differences in number of species in the areas, but in the experimental area the number of species was higher than in the control.

The impact of forest fires and restoration activities on the content and structure of soil organic matter under the sub-pine (*Pinus pinea*) from the Donyana National Park (Southern Spain) was studied (Jiménez-Morillo et al., 2020). The samples were taken from the burned areas before and after the fire restoration and compared to the unburned area. It was established that soil management actions after a fire lead to an increase in aromaticity, which corresponds to the accumulation of lignin and polycyclic aromatic compounds. This involves additional inputs of charred lignocellulosic biomass, including black carbon, incorporated into the soil during rehabilitation.

The investigation described in (Perez-Quezada et al., 2020) reflects a study of the

effects of a fire occurred more than 50 years ago in the temperate rainforest, causing flooding in Placik Andosol (Chile). It was found that the CO₂ emissions from soils were higher in unburned forest than in burnt one. It positively correlates with temperature and negatively with the groundwater content in both areas. Both plots were CH₄ adsorbers (higher in unburned forest), and flows positively correlate with groundwater content and negatively correlate with temperature (stronger ratio in burned forest). The N₂O emissions were low in both areas.

The results of the study (Drach et al., 2020) show that the absolute humidity and temperature of spontaneous combustion of individual plant species cause differences in their fire-fighting properties. According to the results of complex thermal analysis for each plant species, there are three stages at different temperatures: evaporation of free and bound water, spontaneous combustion of samples and combustion of carbon dioxide residues. The maximum exothermic effect was characterized by different values of temperature, as well as ash content, which hinders the combustion process.

The issue of studying the content of radionuclides in post-pyrogenic soils, as well as the age dynamics of their concentration by genetic horizons was not fully considered. No such studies have been identified in the territory of Lviv

Roztocze. According to the above-mentioned results of experimental studies, it can be concluded that the peculiarities of the impact of landscape fires on biota and their prevention requires more in-depth research.

MATERIALS AND METHODS

The aim of research was to define the qualitative and quantitative composition of radionuclides in post-pyrogenic soils of Lviv Roztocze and to establish their migration in edaphic horizons. Sampling was carried out during the fire-dangerous period in May 2017 near Rava-Rusky forestry in the village of Lavrykiv, Zhovkva district, Lviv region (Ukraine). The temperature was + 22°C, the wind was from the east with a speed of 2.5 m/s. The region involved land-water-saturated arable land. A total of 12 soil samples were taken from depths of 5 cm, 10 cm and 20 cm. Site 1 (samples 1, 2, 3) comprised young pine plantations, the fire broke out 3.5 years before the experiment. Site 2 (samples 4, 5, 6) was dominated by meadow vegetation, which completely burned out 2 years before the experiment. Site 3 (samples 7, 8, 9) was dominated by meadow vegetation, which completely burned out 1.5 years before the experiment. An artificial model hearth of landscape fire (grassland, forest) was also created

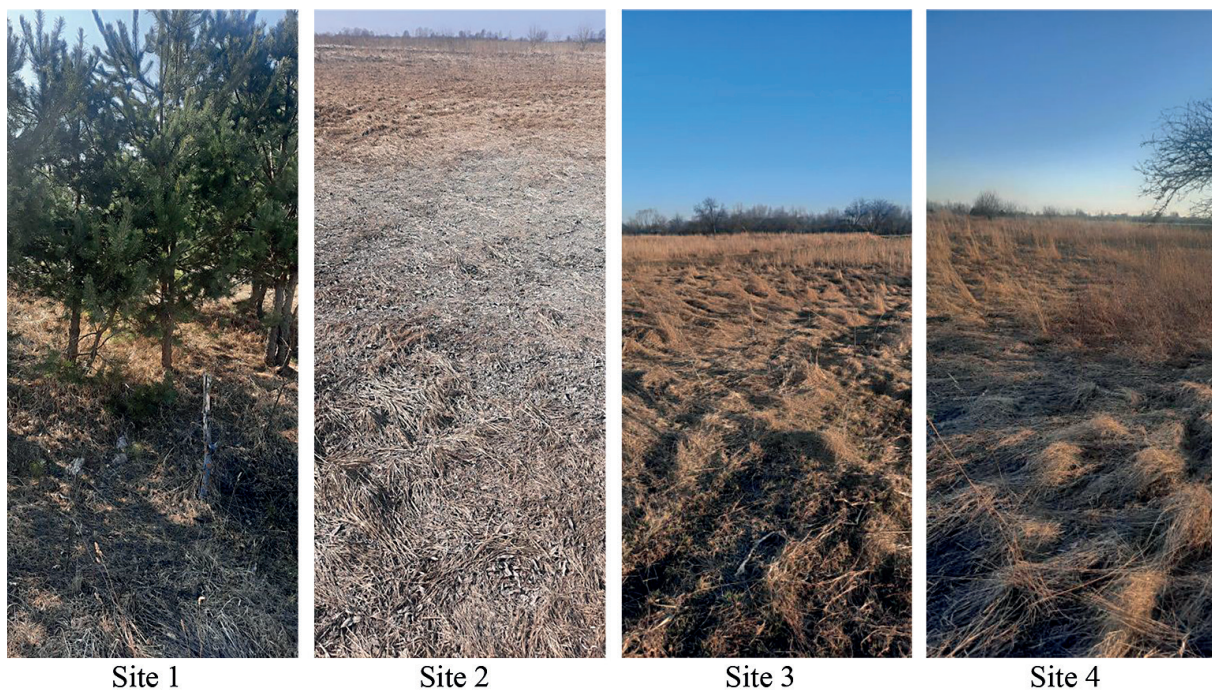


Figure 1. Sites of investigation of forest fires influence on edaphotopes

in the open space in compliance with all requirements of the Rules of fire safety in the forests of Ukraine (Fire safety rules, 2004) in order to record soil temperature and humidity in the combustion zone and analyze radionuclide content in selected soil samples. (site 4, samples 10, 11, 12).

The radionuclides content was determined in the “Laboratory of Industrial Toxicology” (Lviv, Ukraine, certificate № RL 086/17 from 26.06.2017 on compliance of the measurement control system with the requirements of DSTU ISO 10012: 2015, protocol № 172/3 from 23.02.2018). The research method was scintillation using a gamma-ray energy spectrometer with digital data calculation software (the average value of the relative measurement error at a confidence level of 0.95 does not exceed 25%). The test conditions were as follows: ambient temperature was + 19–21 °C, humidity - 55–60%. The power of the equivalent dose of photon ionizing radiation was measured directly at each sampling site at a distance of 1.3 m from the surface.

The employed research instruments included: spectrometer of beta radiation energies SEB-01-150 (calibration certificate UA 01 № 751 dated

March 23, 2017), spectrometer of gamma radiation energies SEG-001 “AKP-S” (calibration certificate UA 01 № 751 from March 23, 2017); environmental tester “Soeks”.

RESULTS AND DISCUSSION

As a result of investigation the content of radionuclides in the edaphic horizons of pyrologically transformed soils due to grassland fires, it was found that their specific activity depends on the age of combustion processes. It was found that the highest specific activity of radionuclides K 40, Ra 226, Th 232 is inherent in the site 3, where combustion processes were observed 1.5 years before the experiment and the site 4 with a model hearth. In the site 3 the specific activity of K 40 in the genetic horizons was 168-181 Bq/kg, Ra 226 - 9.85–27.3 Bq/kg, Th 232 - 0.8–22.6 Bq/kg. In the site 4, the specific activity of K 40 - 164–192 Bq/kg, Ra 226 - 7.68–11.1 Bq/kg, Th 232 - 1.3–12.8 Bq/kg. In sites 1 and 2, the values of the specific activity of the presented radionuclides were much lower. Such data indicate the

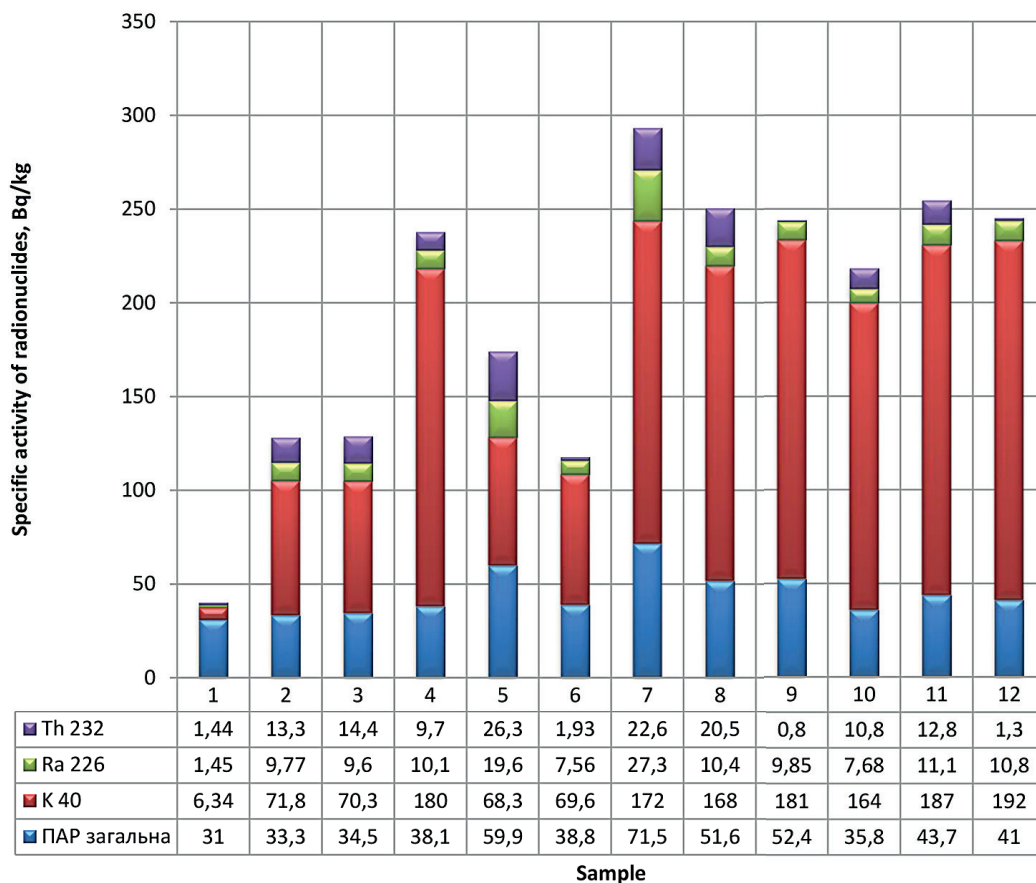


Figure 2. Specific activity of radionuclides in edaphic horizons in selected samples, Bq/kg

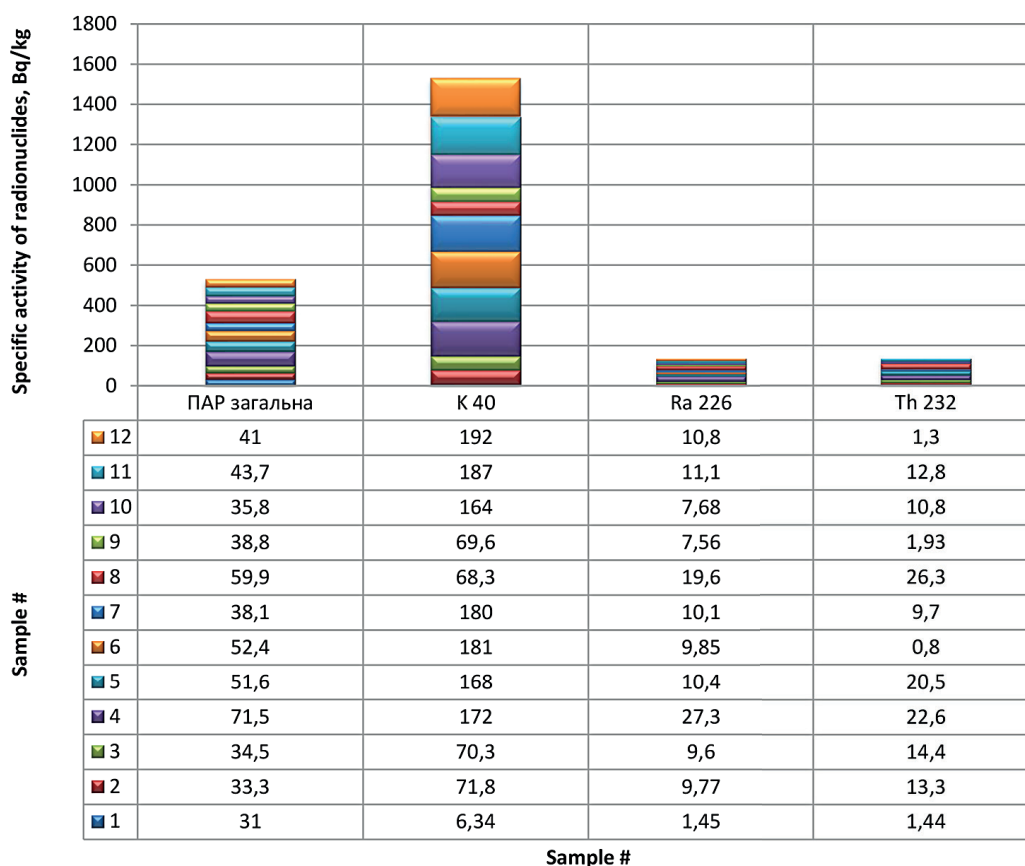


Figure 3. Total activity of radionuclides in edaphic horizons, Bq/kg

natural restoration of edaphotopes due to soil-forming processes that have suffered as a result of thermal destruction from forest fires (Fig. 2).

The maximum total indices of specific activity of radionuclides were observed for K 40 and were 1530.34 Bq/kg for all sites and horizons. The total specific activity of radionuclides for Ra 226 was 135.21 Bq/kg, Th 232 - 135.87 Bq/kg. According to the normative documentation (Order of the Ministry of Health of Ukraine, 2005), the obtained values do not exceed the minimum significant activities (MPA) of radionuclides in the workplace. However, the increased activity of radionuclides in soils has a detrimental effect on the ecological condition and development of flora and fauna. The total indicators of the specific activity of radionuclides are presented in Figure 3.

Regarding the distribution of the specific activity of radionuclides, it can be stated that their largest share is in the range of 0–50 Bq/kg. Such values are inherent in all types of studied radionuclides. Visually it is presented in Figure 4.

Calculating the Pearson correlation coefficient between different concentrations of radionuclides in edaphic horizons, it was found that the total concentration is most affected by Ra 226

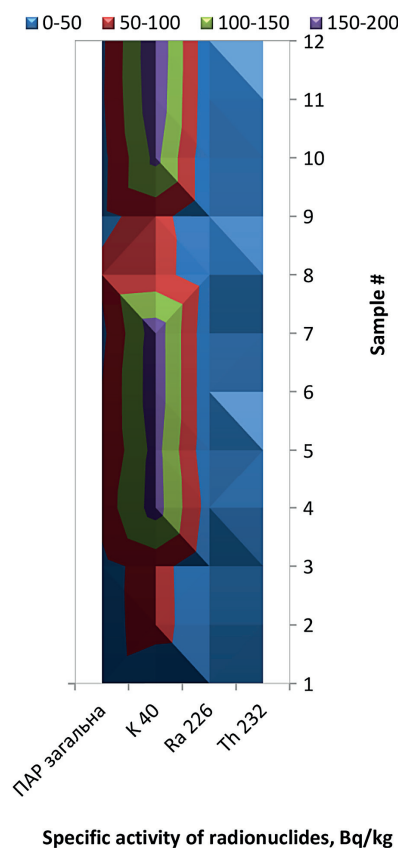


Figure 4. Range of radionuclide distribution in edaphic horizons, Bq/kg

Table 1. Pearson correlation coefficients between different concentrations of radionuclides in edaphic horizons

Variable	SAR total	K 40	Ra 226	Th 232
SAR total		0.370756	0.887023	0.590989
K 40			0.317106	0.034471
Ra 226				0.71124
Th 232				

(K = 0.887023). Ra 226 and Th 232 also have high interaction rates the correlation coefficient is high, positive (K = 0.71124). In other values, the correlation is almost absent (Table 1).

The power of the equivalent dose of photon ionizing radiation at the site of the experiment was 0.11 $\mu\text{Sv/h}$. and did not exceed the maximum allowable concentrations (0.3 $\mu\text{Sv/h}$).

CONCLUSIONS

Fires in natural ecosystems affect the specific activity of radionuclides depending on the age of the grassroots fire. It was found that the highest specific activity of radionuclides K 40, Ra 226, Th 232 is inherent in the site, where combustion processes were observed 1.5 years before the experiment and the site with a model hearth. In particular, the specific activity of K 40 in the genetic horizons was in the site 3 – 168–181 Bq/kg, Ra 226 - 9.85–27.3 Bq/kg, Th 232 - 0.8–22.6 Bq/kg. In the site 4, the specific activity of K 40 - 164–192 Bq/kg, Ra 226 - 7.68–11.1 Bq/kg, Th 232 - 1.3–12.8 Bq/kg. The highest specific activity of radionuclides on pyrogen-transformed soils was in the range of 0–50 Bq/kg.

During the fire season in natural ecosystems and forests, careless handling of fire should be avoided and preventive measures should be taken to inform the public about the harmful effects of wildfire.

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