Ministry of Education and Science of Ukraine
Black Sea Universities Network

ODESA NATIONAL UNIVERSITY OF TECHNOLOGY

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2022

PROCEEDINGS

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International Competition of Student Scientific Works

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Proceedings of International Competition of Student Scientific Works «Black Sea Science 2022» contain the works of winners of the competition.

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INTRODUCTION

International Competition of Student Scientific Works “Black Sea Science” has been held annually since 2018 at the initiative of Odesa National University of Technology (formerly Odesa National Academy of Food Technologies) with the support of the Ministry of Education and Science of Ukraine. It has been supported by Black Sea Universities Network (the Association of 110 higher education institutions from 12 countries of the Black Sea Region) since 2019, and by Iseki-FOOD Association (European Integrating Food Science and Engineering Knowledge into the Food Chain Association) since 2020.

The goal of the competition is to expand international relations and attract students to research activities. It is held in the following fields:

- Food science and technologies
- Economics and administration
- Information technologies, automation and robotics
- Power engineering and energy efficiency
- Ecology and environmental protection

The jury includes both Ukrainian and foreign scientists. In the 4 years that the competition has been held, the jury included scientists from universities of 24 countries: Angola, Azerbaijan, Benin, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Israel, Italy, Kazakhstan, Latvia, Lithuania, Moldova, Pakistan, Poland, Romania, Serbia, Slovakia, Switzerland, Turkey, USA.

At the same time, every year the geography has expanded and the number of foreign jury members has increased: from 46 jury members representing 25 universities from 12 countries in 2018, to 73 jury members of the 46 universities from 19 countries in 2022.

More than a thousand student research papers have been submitted to the competition from both Ukrainian and foreign institutions from 25 countries: China, Poland, Mexico, USA, France, Greece, Germany, Canada, Costa Rica, Brazil, India, Pakistan, Israel, Macedonia, Lithuania, Latvia, Slovakia, Romania, Kyrgyzstan, Kazakhstan, Bulgaria, Moldova, Georgia, Turkey, Serbia.

The interest of foreign students in the competition grew every year. In 2018, the students representing 15 institutions from 7 countries have submitted 33 works. In 2021 the number of submitted works increased to 73, authored by the students of 40 institutions from 18 countries.

The competition is held in two stages. In the first stage, student research papers are reviewed by members of the jury who are experts in the relevant fields. In the second stage of the competition, the winners of the first stage have the opportunity to present their work to a wide audience in person or online.

All participants of the competition and their scientific supervisors are awarded appropriate certificates, and the scientific works of the winners are included in the electronic proceedings of the competition. Every year the competition receives a large number of positive responses from Ukrainian and foreign colleagues with the desire to participate in the coming years.

5. ECOLOGY AND ENVIRONMENTAL PROTECTION

GEOINFORMATION MODELING OF RADIOACTIVE CONTAMINATION OF TERRITORIES ON THE EXAMPLE OF THE MINES OF THE EASTERN MINING AND PROCESSING PLANT

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***Annotation**: using geoinformation technologies, modeling of the distribution of natural radionuclides for soils and plants based on the actual results of measurements of the volume activity of isotopes ^{234}U, ^{238}U, ^{210}Po, ^{210}Pb, ^{226}Ra. With usage of the methods of mathematical statistics was found correlation between soil / vegetation and soil / root vegetable. The identified dependencies and constructed maps will be useful for assessing the safety of the population within the source of radioactive contamination and the consumption of agricultural products by the local population.*

***Key words:** radionuclides of natural origin, volumetric activity, soil, vegetation, root vegetable, interpolation, modeling, correlation.*

I. PREAMBLE

The problem of radioactive pollution both separate regions in Ukraine and the territory of the whole country generally stays on the front burner during last few decades, which is connected not only to a major accident of Chernobyl Atomic Power Station, but also to utilization of nuclear weapon and to utilization of atomic-industry waste. Uranium ore deposits have been developed and enriched in some regions of Ukraine since the middle of the twentieth century, accompanied by the accumulation of significant amounts of radioactive waste that dangerously affect the ecosystem of the surrounding areas, including the health of the population.

One of such radiation-contaminated regions of Ukraine is the Kirovohrad region, and in particular the outskirts of Kropyvnytskyi, where since 1951. carries out economic activity of the State Enterprise "Eastern Mining and Processing Plant", which develops uranium ore deposits and performs the full range of works on mining and radiometric enrichment of uranium ores [1].

II. ANALYTICAL REVIEW OF SCIENTIFIC LITERATURE

2.1. Natural radionuclides and their threat to people

The main part of the radiation the entire population of the Earth receives from natural sources of radiation: natural radionuclides contained in the earth's crust, building materials, air, food, and water formed in the atmosphere under the action of cosmic rays. On average, they determine more than 80% of the annual effective dose received by the population, mainly due to internal radiation [2-4].

The main radioactive isotopes found in the Earth's rocks are potassium and rubidium and members of two radioactive families, originating from uranium and thorium, respectively, long-lived isotopes that are part of the Earth's rocks.

Much of the effective dose of radiation that a person receives from natural sources of radiation is formed by radionuclides of a number of uranium contained in the soil. Additional impact have natural radionuclides with which people deal because of anthropogenic activity. Process of increasing an amount of natural radionuclides and regular pollutions of environment occur already at the stages of extraction and enrichment of mineral resources. At mining and concentrating plants of neuraunian industries, the sources of constant inflow of aerosols of natural radionuclides into the atmosphere and natural radionuclides into surface and groundwater are dumps of overburden and industrial waste, as well as tailings of concentrators [2]. As a rule, the ratio of uranium radionuclides in the emissions of these enterprises is close to equal.

Natural radionuclides are leached from rocks and pass into surface and groundwater, which with surface runoff accumulate them on the surface of agricultural soils. Mining speeds up this process, so in the extraction and processing of ore with a high content of natural radionuclides, workers in mining companies and the public may be exposed to radiation.

Natural radionuclides are toxic because they are not destroyed in soil and water but migrate in the trophic chain: "soil → plant (feed) → animal → products → humans." But because the bulk of radionuclides are in the root layer of the soil, and their movement into deeper horizons is very slow, this leads to the entry of radionuclides into crop products, and then to animals and humans. As a result, there are hidden negative changes in the overall metabolism in humans [5].

Consumption of radionuclide-contaminated products leads to additional internal exposure of the human body above natural levels. However, their content in food and drinking water should not exceed the accepted annual effective dose of internal radiation up to 1 mSv/year [6]. In areas with contamination levels where agricultural activities are possible, the radiation dose does not exceed the established limit, but a significant proportion of the population is exposed to low regular doses, which increases the likelihood of long-term radiobiological effects (tumors, mutations, decreased immunity) [5].

2.2. Statistical and geostatistical methods of modeling

Statistical modeling methods include correlation analysis, which is performed automatically by using an feature of computer program Microsoft Excel. Correlation analysis is a method of studying the interdependence of features in the general population, which are random variables with a normal nature of the distribution [7]. The main requirements for the application of correlation analysis are a sufficient number of observations, a set of factor and performance indicators, as well as their quantitative measurement and reflection in information sources.

The main tasks of correlation analysis are to determine the form of connection, measure the density (strength) of connection and identify the influence of factors on the performance trait.

The formation of a correlation model involves determining whether it will be a simple (pair) correlation (resultant feature with one factor) or multiple (performance feature and several factors). Conversely, the nature of the relationship correlation models can be linear (rectilinear, with inverse linear dependence) or nonlinear (curvilinear) [7].

Geostatistical modeling methods are used to study spatial data and construct surfaces using advanced statistical methods. Geostatistical Analyst is an ArcGIS software module that has a powerful set of tools that can be used to create a continuous surface or map based on measurements stored in a point vector or raster layer that facilitate visualization, analysis and understanding of spatial phenomena [8].

The Geostatistical Analyst module provides access to several interpolation methods, which are divided into two main types: determination and geostatistical. Deterministic interpolation methods create surfaces from measured points based on either the degree of similarity (inverse weighted distances) or smoothing levels (radial basis functions). Geostatistical methods of interpolation use the statistical properties of the measured points. Geostatistical methods measure the spatial autocorrelation at the measured points and calculate the spatial configuration of the reference points around the interpolated location [8].

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The aim of our research was to model the territorial distribution and statistical assessment of migration by the trophic chain of natural radionuclides released into the environment as a result of uranium ore mining.

There were the following tasks of the research *to achieve the mentioned goal*:

- to perform an analysis of the environmental components' state of pollution within the object of the study;
- to develop models of territorial distribution of natural radionuclides in those soils and plants which were the object of study, using tools of geoinformation modeling;
- to carry out the mathematical modeling of migration of natural radionuclides between the components of environment;
- to substantiate the need to increase the level of radioecological safety of the population, which lives within the existing uranium mines.

The object of research – processes of migration and territorial distribution of natural radionuclides in the environment.

The subject of research – the level of radiation pollution of the environment and methods of modeling the migration of natural radionuclides between components of the environment.

Statistical, geoinformation and experimental *methods of research* were used in the work. Interpolation of the results of volumetric activity of natural radionuclides in the components of the environment and the development of spatial models of their territorial distribution were carried out using the software product ArcGIS; statistical processing of modeling results, development of mathematical models of migration of natural radionuclides between components of the environment were carried out using applications of computer programs Microsoft Excel, ArcGIS Geostatistical Analyst.

The scientific novelty of the achieved results is the following:

- for the first time ever the choice of the method of geostatistical modeling of territorial distribution of volumetric activity of natural radionuclides in soils and plants was substantiated, which allows to model the values of probabilistic indicators of radioecological pollution in the absence of a sufficient array of initial actual research results;

- the methodology of mathematical modeling of migration of natural radionuclides between soil and parts of plants have been further developed, which will take into account the specifics of migration of natural radionuclides in the trophic chain and determine the level of radioecological danger for the environment, the final link of which is the population living within the industrial facilities.

Practical significance of the obtained results:

1. For the first time ever, the radioecological situation around the industrial sites of the "Pivdenna" and "Pivnichna" mines of the Eastern Mining and Processing Plant State Enterprise and the territory of the nearest settlements falling within the area of influence of these mines and dumps of uranium enrichment was simulated. The developed territorial models allow to obtain stochastic data for their further analytical processing and to visually display areas of radioecological danger.
2. The need to increase the level of radioecological safety of the population living within the existing sources of radiation pollution, which means the safety of homestead agriculture of local residents, was substantiated.
3. The results of scientific work were introduced into the educational process of Dnipro State Technical University during lectures and practical classes in the discipline "Radioecology", "Fundamentals of GIS", "GIS in Ecology" for students who obtain higher education, whose specialty 101 - Ecology.

IV. RESULTS OF WORK

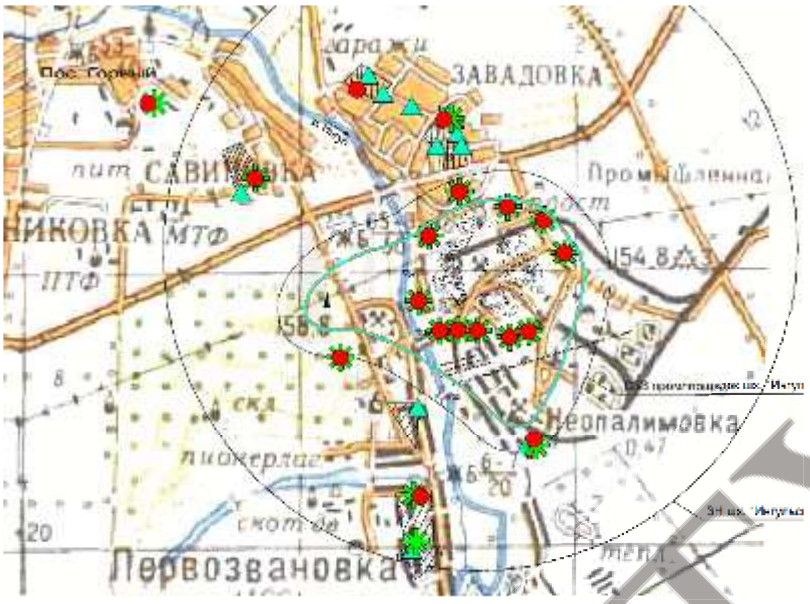
4.1. Characteristics of the object of study and the radioecological situation within it

The industrial sites of the mines "Pivdenna" and "Pivnichna" of the State Enterprise "Eastern Mining and Processing Plant" (Kropyvnytskyi) and the settlements of Pervozvanivka, Zavadivka, Neopalimivka, Sonyachnyi, Hirskyi (Kirovograd region) were selected as the object of this study, which are in the area of influence of these mines and dumps of waste rocks after enrichment of uranium ores.

Samples of soil, aerial parts of plants (perennial grasses) and roots of agricultural plants (potatoes, beets, carrots) were analyzed to assess the volume activity of natural radionuclides (^{234}U, ^{238}U, ^{210}Po, ^{210}Pb, ^{226}Ra). 18 samples of soil and plants were analyzed (10 of which were taken from the territory of the sanitary protection zone of the enterprise), as well as 10 samples of root crops grown in the homesteads of local residents. Sampling sites are shown on the map in Figure 1.

To compare the obtained results, similar samples were analyzed at two background points located within a distance of 30 kilometers from the industrial sites of the mines (the villages of Velyka Vyska and Subotka).

The results of the measurements indicate fluctuations in the volume activity of natural radionuclides in the soils around the dumps and the industrial site of the mines. Also, the soils within the ore-concentrating plant on the industrial site of the Pivnichna mine differ by two orders of magnitude, exceeding the figures around the dumps located within the sanitary protection zone of the mines. Within the dumps, the radioecological situation is characterized by twice the background indicators of the volumetric activity of a number of natural radionuclides.



The boundaries of the industrial site of mines
Coordinates of soil sampling
Sampling points of the aboveground part of plants
Sampling points for root crops of agricultural plants

Fig. 1. Map of the research object and sampling sites

Within of the object of research at the place of residence of critical groups of the population living in the nearest settlements, for all observation points a significant excess of background values was recorded for:

- isotopes of uranium, lead and polonium within the settlements of Neopalimivka, Pervozvanivka, located to the south almost within the sanitary protection zone of the industrial site of the mines "Pivdenna" and "Pivnichna";
- radium isotopes within the settlements of Zavadivka north of the sanitary protection zone of the industrial site of the Pivdenna and Pivnichna mines.

Fluctuations in the measurement of the volumetric activity of natural radionuclides in the treated soil samples are shown in figure the Annex 1.

The highest volume activity in comparison with the background values is possessed by samples of plants, which were taken within the dumps for all studied natural radionuclides except lead. As can be seen from the figure in Annex 2, for all natural radionuclides, the background values were exceeded.

The results of measurements of the volumetric activity of natural radionuclides in samples of root crops grown in the habitats of the population are shown in the figure in Annex 3. The figure shows that potato samples have the highest volume activity compared to beet samples, and twice the excess is observed for isotopes of uranium, polonium and lead, in particular for the village of Pervozvanivka. There is a reverse trend for the same radionuclides for the village Zavadivka.

4.2. Modeling of territorial distribution of natural radionuclides in environmental components using GIS

As shown on the map (Fig. 1), observation points for the studied components of the environment are not always territorially superimposed, which makes it impossible

to establish a correlation between them and predict the territorial distribution of the studied natural radionuclides. The task of forecasting is also complicated by the small amount of initial data with a significant difference in the obtained results of the volumetric activity of natural radionuclides (dumps - sanitary protection zone - observation zone – background radiation).

Given the high population density in the observation area, as shown in the map in Figure 1, with insufficient territorial and quantitative sampling coverage, it is proposed to use the basic set of ArcGIS software interpolation tools (Natural neighbor interpolation, Inverse distance weighted (IDW)). Kriging, Spline) to model the surfaces of the territorial distribution of natural radionuclides within the study area.

The selection of simulation methods with different settings was carried out experimentally, however, the most optimal way of interpolation of the specified data in the conditions of initial parameters is the method Natural neighbor interpolation. The surface obtained in this way makes it possible to smooth the peak values of the indicators and determines a wide gradient that is more similar to the natural distribution, while the background values of the indicators also have a significant impact on surface modeling.

Figure 2 shows the result of surface modeling that interpolates the value of ^{234}U volume activity in soil, plants, and roots.

The constructed surfaces allowed to model the values of volumetric activity of natural radionuclides in soils and parts of plants for any point of the study area and to visualize the territorial distribution of radioactive contamination.

According to the made modelling maps, which interpolate the volume activity of natural radionuclides in the soil, the epicenter of pollution is observed within the waste dumps, located within the southwestern border of the sanitary protection zone of the mine site and more than 10 times higher than the background value for uranium and radium, up to 20 times for isotopes of lead and polonium within the village Pervozvanivka.

Simulated indicators of volumetric activity of natural radionuclides in the aboveground part of plants indicate a tenfold excess of background values within the sanitary protection zone of the industrial site of mines; twice the background values of uranium and lead isotopes were found within the settlements of Gorskiy, Neopalimivka and village Pervozvanivka, respectively.

It was determined that the epicenter of radioactive contamination of rootstocks of agricultural plants is observed within the settlements of Neopalimivka and Pervozvanivka with exceeding background values by 2-2.5 times, and zones of lead isotope contamination with twice exceeding background values extend to Golsky and Sonachnii settlements.

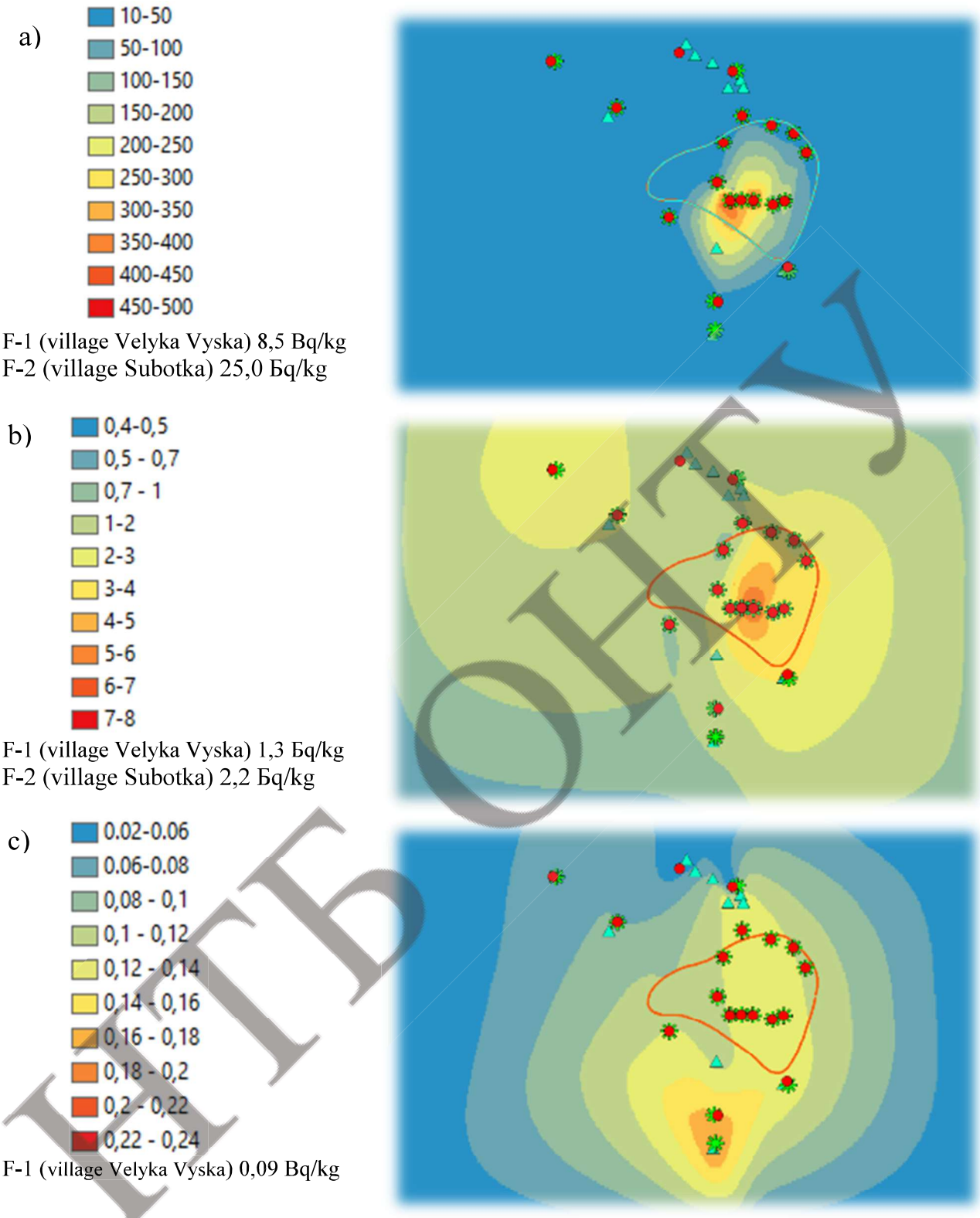


Fig. 2. Map of surface modeling by the method of Natural neighbor interpolation, which interpolates the results of bulk activity on the example of ^{234}U, Bq / kg: a) – in soil; b) – in plants; c) – in root plants

Developed electronic maps of radionuclide distribution will allow a comprehensive approach to assessing the risk of living within the source of radioactive contamination and modeling the spread of radioactive contamination in agricultural plants based on their use by local populations, develop recommendations for agricultural activities within the territory.

4.3. Mathematical modeling of migration of natural radionuclides between environmental components

Constructed surfaces shown in Fig. 2, allowed to simulate the volume activity of natural radionuclides for soils, plants, and roots at any point in the study area. By creating a uniform distribution of virtual points of study, the result of which is shown in Fig. 3, obtained the values of the volumetric activity of natural radionuclides for soils, plants, and roots at each of the 300 set points.

The boundaries of the industrial site of mines
Coordinates of soil sampling
Sampling points of the aboveground part of plants
Sampling points for root crops of agricultural plants
Virtual points

Fig. 3. Map of creating a uniform distribution of virtual research points

It should be noted that the territorial coordinates of the simulated points for all components of the environment coincide and are therefore available to determine the pairwise correlation.

Based on the methods of mathematical statistics using computer programs Microsoft Excel and Geostatistical Analyst, correlations were established between the values of the volumetric activity of natural radionuclides, simulated for virtual points

in the soil and plant elements. The results of mathematical modeling on example ^{234}U using Microsoft Excel tools are shown in Figure 4 and using the Geostatistical Analyst toolkit - in Figure 5.

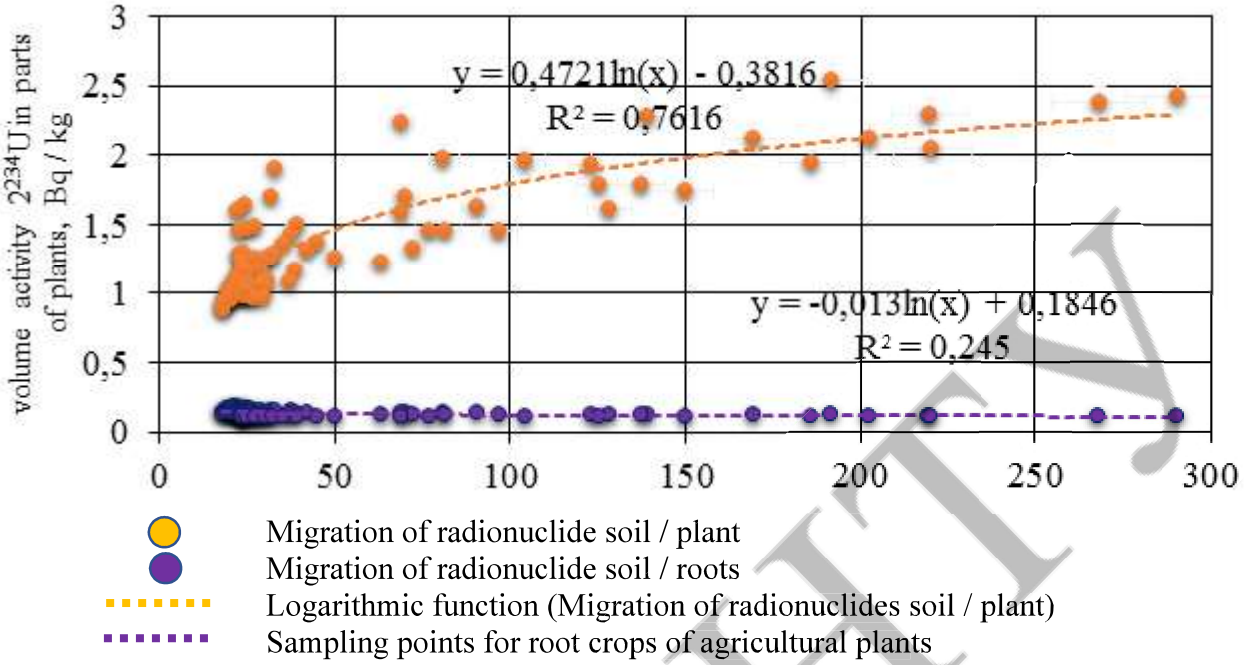


Fig. 4. Mathematical model that characterizes the probability of migration of natural radionuclides between environmental components on the example of ^{234}U, Bq / kg

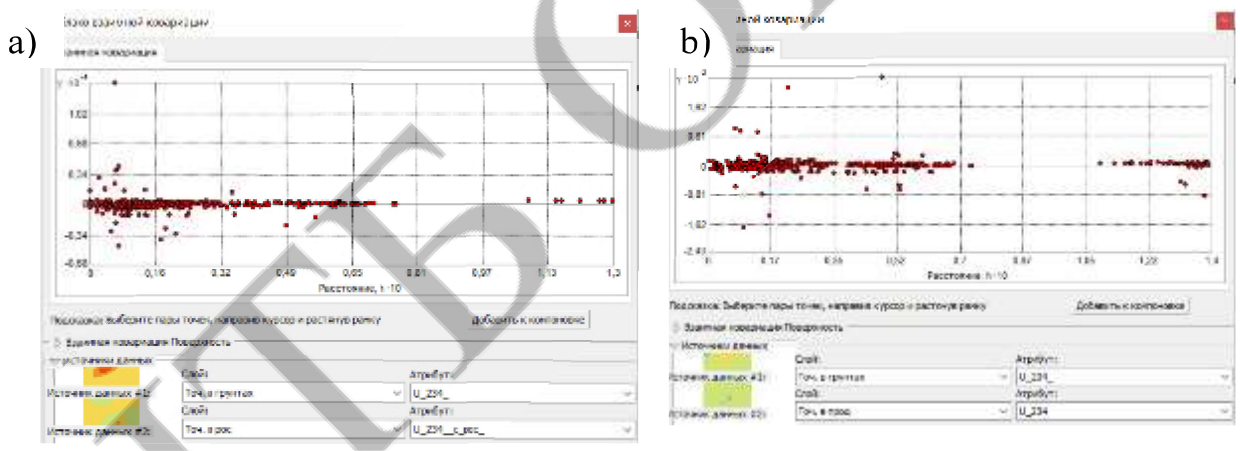


Fig. 5. Statistical covariance model characterizing the probability of migration of natural radionuclides between environmental components on the example of ^{234}U, Bq / kg:
a) pair model Soil / Plants; b) pair model Soil / Root crops

These models show that the closest relationship is observed between the values of volumetric activity ^{234}U in soils and aboveground parts of plants, as indicated by the high correlation coefficient (R = 0.87) and high density of mutual covariance of the pair model Soil / Plants.

Models for all studied natural radionuclides were constructed in a similar way. The simulation results are shown in Table 1. The obtained pairwise correlation models indicate a high correlation (R = 0.78 ÷ 0.87) primarily of the logarithmic nature of such parameters as the value of the volume activity of natural radionuclides in soils and aboveground parts of plants in particular for uranium isotopes, as well as ^{210}Po and

^{226}Ra. For ^{210}Po, this dependence is obtained with a low coefficient of determination, which indicates the presence of other factors that become more important.

Table 1. Results of mathematical modeling of migration of natural radionuclides between soil and plants

Natural radionuclides	Soil / Plant	Soil / Roots
^{234}U	$y_1 = 0,4721\ln(x) - 0,3816$ $R^2 = 0,7616$	$y_2 = -0,013\ln(x) + 0,1846$ $R^2 = 0,245$
^{238}U	$y_1 = 0,4146\ln(x) - 0,3178$ $R^2 = 0,7298$	$y_2 = 0,0005x^2 - 0,0286x + 0,4324$ $R^2 = 0,3666$
^{210}Pb	$y_1 = -0,3312x^2 + 19,007x - 261,22$ $R^2 = 0,2658$	$y_2 = -0,0018x^2 + 0,1082x - 1,4305$ $R^2 = 0,295$
^{210}Po	$y_1 = 68,985e^{-0,144x}$ $R^2 = 0,6352$	$y_2 = 0,0067x^2 - 0,3033x + 3,4542$ $R^2 = 0,23$
^{226}Ra	$y_1 = 0,458\ln(x) - 0,2344$ $R^2 = 0,6055$	$y_2 = -0,0006x^2 + 0,0292x - 0,2709$ $R^2 = 0,5019$

Note: x is the value of the volume activity of natural radionuclides in soils
y_1 is the value of the volume activity of natural radionuclides in vegetation
y_2 is the value of the volume activity of natural radionuclides in root crops

Regarding the dependence of the volume activity of natural radionuclides in root crops on the indicators modeled for soil samples, a much lower correlation than in the previous case (R = 0.48 ÷ 0.71) was found to be mainly polynomial.

4.4. Justification of the obtained results

The obtained simulation results confirm the validity of the chosen method of modeling the migration of natural radionuclides by trophic chain, but certain parameters of mathematical models indicate a more likely accumulation in the surface layer of soil accessible to the root system of perennial grasses. soil horizons from the movement of pollutants, accumulating in their green mass a significant amount of natural radionuclides.

Based on the results obtained for the pair of parameters "Soil / Root crops", the movement of natural radionuclides into deeper soil horizons for these natural conditions is significantly slowed down, which leads to radionuclides entering crop products (roots) less actively than in aboveground green mass of plants.

The developed mathematical models of migration of natural radionuclides between soil and plants, given their high reliability, can be used to predict the levels of radioecological contamination of agricultural products grown by locals in their backyards.

Further calculations of the consumption of agricultural products contaminated with radionuclides grown in the study area will determine the risks of additional internal exposure of the human body. And taking into account possible trophic chains:

«Soil → roots → human»

«Soil → perennial grasses → animal → livestock products → human»

will provide recommendations on the norms of consumption of these agricultural products or the possibility of conducting agricultural activities within the territory in general, as regular exposure, although not significant doses, increases the likelihood of radiobiological effects in the local population.

V. CONCLUSIONS

1. The analysis of the state of pollution of environmental components within the industrial site of the mines "Pivdenna" and "Pivnichna" of the State Enterprise "Eastern Mining and Processing Plant" and the surrounding villages and recorded a significant excess of volumetric activity of natural radionuclides relative to background values. Plant elements for isotopes of uranium, lead and polonium within the settlements located south of the sanitary protection zone of the mine site, and radium isotopes - north of them.

2. Models of territorial distribution of natural radionuclides in soils and plants of the object of research have been developed, using the basic set of interpolation tools of ArcGIS software. It is established that the most optimal method of geospatial modeling is the method Natural neighbor interpolation, which provides the ability to smooth the peak values of indicators and determines a wide gradient taking into account the significant influence of background values of indicators. The constructed surfaces allowed to model the values of the volume activity of natural radionuclides in soils and parts of plants for any point of the study area. Visualized territorial distribution of indicators indicates the epicenter of radioactive contamination within waste heaps, territorially located within the sanitary protection zone of the mine site, 10-20 times higher than the background values of the studied natural radionuclides in soils within soils within 2-10 parts adjacent settlements.

3. Modeling of migration of natural radionuclides between environmental components by mathematical statistics using computer programs Microsoft Excel and Geostatistical Analyst and a close correlation between the values of volumetric activity of natural radionuclides in soil and aboveground plants, which confirms the reliability of the selected method of modeling the migration of natural radionuclides by the trophic chain. The obtained simulation results indicate a more probable accumulation of natural radionuclides in the surface layer of the soil, which slows down with deepening to the soil horizons available for root crops.

4. The necessity of increasing the level of radioecological safety of the population living within the existing uranium mines is substantiated. The danger is due to the migration of natural radionuclides through food chains, the final link of which is the population consuming home-grown agricultural products, which is a source of regular exposure to small doses, but increases the likelihood of radiobiological effects in the local population.

Approbation of research results.

The main scientific and practical results of the research were reported and received a positive assessment: International Scientific Symposium "Ecologist's Week" (Ukraine, Kamyanske, 2021); VI International Scientific and Practical Conference «Scientific community: interdisciplinary research» (Hamburg, German, 2022); 7th International

Youth Congress "Sustainable Development: Environmental Protection. Energy saving. Balanced nature management "(Ukraine, Lviv, 2022).

Publications. According to the research results, 3 printed works were published, including 1 article in a foreign edition, including:

- Kornienko O, Huba O Neposhivaylenko N, Soroka Y; “Assessment of the volumetric activity of natural radionuclides in natural waters within the activities of uranium mines” // Collection of abstracts of the international scientific symposium "Ecologist's Week - 2021", October 18-20, 2021 - Kamyanske: DDTU. - 2021.– P. 100-103.
- Natalia Neposhyvailenko, Oleksandr Korniienko, Oleksandr Huba; “Geoinformation modeling of radioactive pollution on the example of mines of Eastern mountain-concentrating plant” // VI International Scientific and Practical Conference «Scientific community: interdisciplinary research». January 26-28, 2022. - Hamburg, Germany: Busse Verlag GmbH, 2022. – С. 786-792.
- Kornienko O, Guba O Neposhivaylenko N; “Geoinformation modeling of radioactive contamination of territories on the example of the mines of the Eastern Mining and Processing Plant” // Collection of abstracts of the 7th International Youth Congress "Sustainable Development: Environmental Protection. Energy saving. Balanced Nature Management”, February 10-11, 2022 - Lviv: Lviv Polytechnic National University. – 2022.

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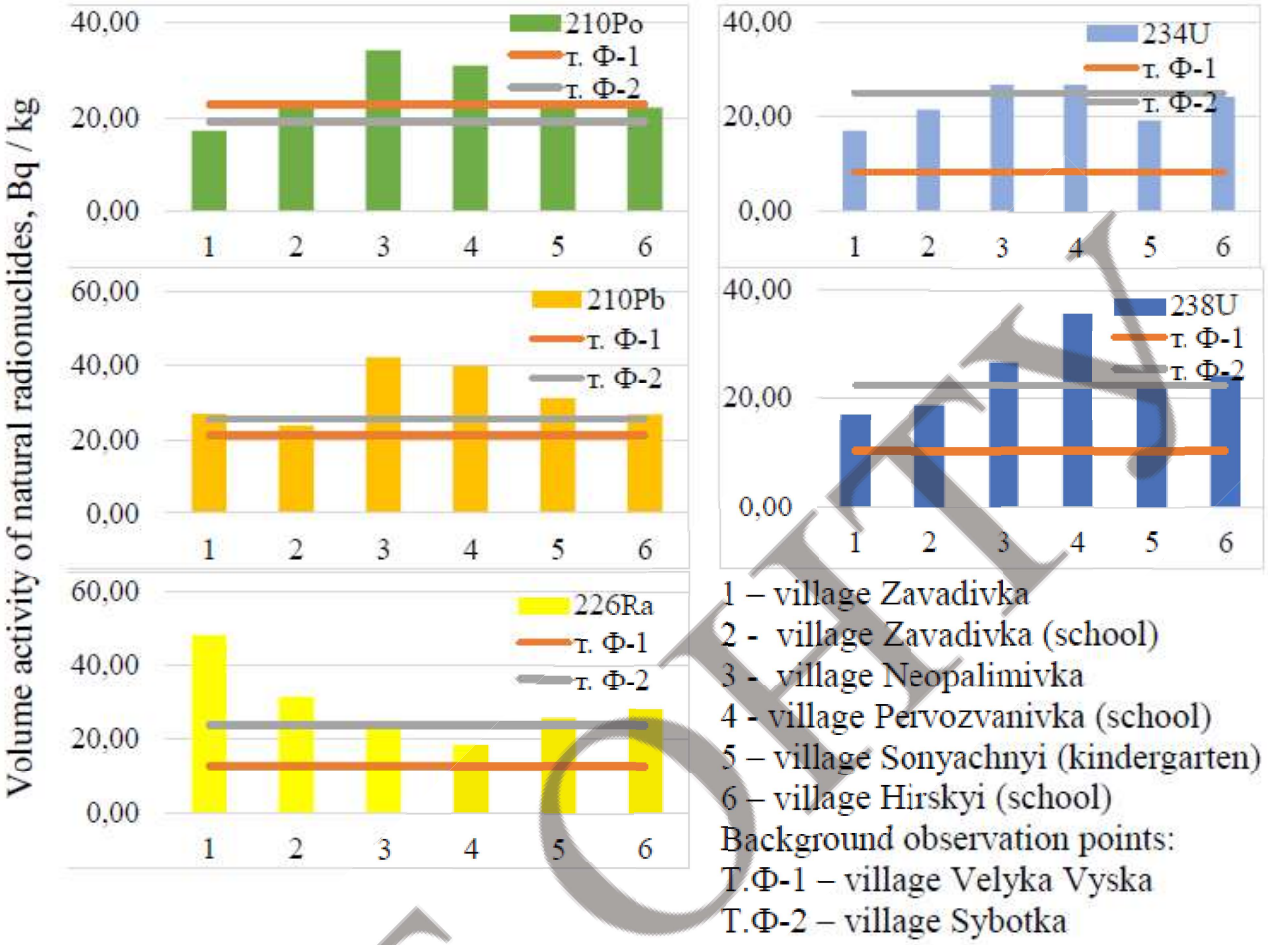
APPENDIX 1

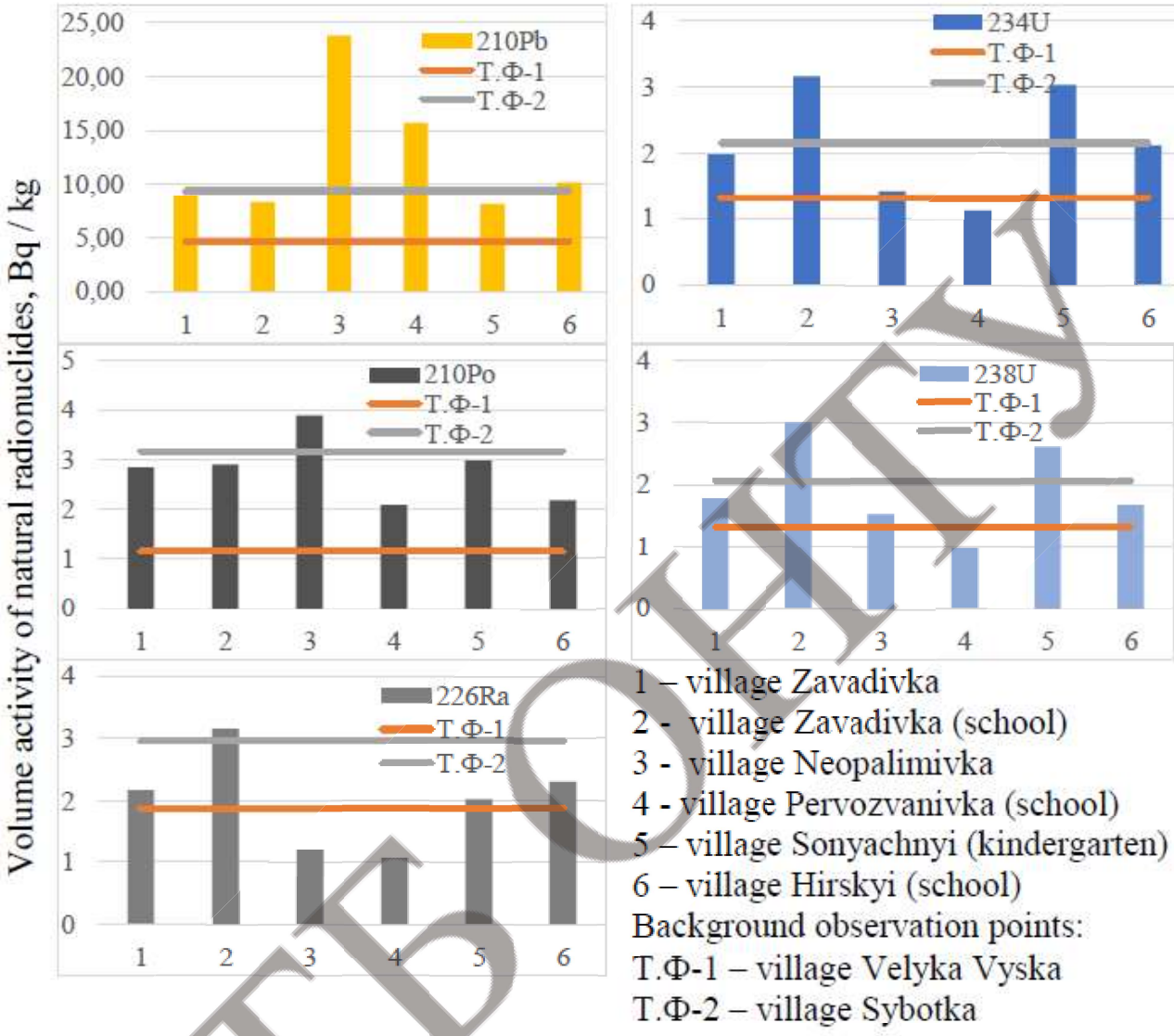
Fluctuations in the measurement of volumetric activity of natural radionuclides in soil samples of the object of study at the place of residence of critical groups



1 – village Zavadivka
2 - village Zavadivka (school)
3 - village Neopalimivka
4 - village Pervozvanivka (school)
5 – village Sonyachnyi (kindergarten)
6 – village Hirskyi (school)
Background observation points:
T.Ф-1 – village Velyka Vyska
T.Ф-2 – village Sybotka

APPENDIX 2

Fluctuations in the measurement of the volumetric activity of natural radionuclides in plant samples of the object of study at the place of residence of critical groups



APPENDIX 3

Fluctuations in the measurement of the volumetric activity of natural radionuclides in the samples of root crops of the object of study at the place of residence of critical groups