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Analysis of the Results of Soil Condition Monitoring in the Territory of the City of Rivne (Ukraine)

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ABSTRACT

The study was conducted with the aim of improving the environmental monitoring of soils in the Rivne urban ecosystem using geo-information technologies, followed by visualization of the results based on indicators of total and accumulated pollution with heavy metals (HM). It was found that for the gross form of HM at 54% of soil sampling points, the soils are classified as "Significantly contaminated", 28% of the soils are "Moderately contaminated", and 18% of the soils belong to the category "No contamination" with HM. According to PLI values of the mobile form of HM, 62% of the soils are of the "No contamination" category. The soils in the "No contamination" category are predominantly of insular localization and are located near water bodies and on the outskirts of the city. The "Moderately contaminated" soils are identified as 26%, "Substantially contaminated" and "Significantly contaminated" – 4% and 8%, respectively. The "Significantly contaminated" category characterizes the soil cover near large enterprises, near main highways and railways. For visualization, interpolated surfaces of the distribution of total and accumulated contamination with HM were constructed.

Keywords: monitoring, heavy metals (HM), contamination, hazard degree, PLI, GIS technologies, maps.

INTRODUCTION

The beginning of the 21st century was marked by the introduction of geographic information systems (GIS) into the environmental protection activities of Ukraine, which makes it possible to effectively work with spatial information within the boundaries of territorial and administrative division, supplementing it with visual representation (Peresadko, 2009; 2013, Zatserkovnyi et al., 2016). GIS technologies are used to ensure relationships between the quantitative and qualitative characteristics of an object and to solve monitoring problems: conducting a comprehensive assessment of the environmental situation of the study area, creating digital maps that clearly characterize the problem being studied, demonstrating environmental changes occurring in the region (Pitak et al., 2012) etc. It should be noted that the application of geographic information systems and technologies for monitoring the soil environment in conditions of climate change has great prospects. (Almashova et.al., 2023, Hammam et.al., 2022).

It should be noted that in developed countries of the world, GIS technologies are widely used in various fields to solve problems in the sphere of human activities. Awareness of the potential opportunities and importance of GIS in Ukraine has intensified over the last decade. According to some data, up to 90% of all information can be presented in the form of GIS (Shevchenko et al., 2001). One of the advantages of GIS is its use for the preparation, systematization and analysis of data, visualization of spatial characteristics and publication of research results. Thus, data

visualization through cartographic images helps in quickly understanding the situation, assessing it and making decisions. A quantitative GIS is a map containing coded colors, or rather shades of the same color, illustrating the quantitative difference in the available data (Shypulin, 2012). In this way, the problem of visualizing multiple data over a large area is solved. Unlike traditional maps, a GIS map is dynamic and interactive.

GIS technologies can also be used in monitoring soil contamination with HMs (Behairy et al., 2022, Wei et al., 2017). It is known that HM are characterized by low migration activity in the soil cover and are almost completely accumulated in its upper layers (Achasova, 2003), and soil areas remain contaminated for decades: (Myslyva et al., 2009, Fatieieva et al., 2003). It should be noted that the application of geographic information systems and technologies for monitoring the soil environment in conditions of climate change has great prospects. Features of translocation and accumulation of HM in the "soil-plant-agricultural products" system is considered in (Braininher et al., 2022), assessment of the intensity of contamination with mobile forms of HM of the main types of soils in the Polissia zone of Rivne region were studied by the authors (Dmitrievtseva et al., 2023). A number of studies are aimed at theanalysis of pollution of urban areas with HM (Andrusyshyna et al., 2020, Kovalchuk et al., 2017, Splodytel et al., 2020).

The patterns of migration and accumulation of HM in different types of soils are described in the works of a number of scientists: (Solgi et al., 2017, Toth et al., 2008; 2013, Jolivet et al., 2006, Yakovyshina, 2016, Shepeliuk, 2019, Malovanyy et al., 2022). The impact of HM on soil contamination in the city of Rivne and monitoring studies of this problem are described in scientific works (Melnyk et al., 2010; 2015; 2023, Siaska. et al., 2023).

This publication does not analyze information on modern technological approaches to reclamation; this has been the subject of research by many other authors (Tymchuk et al., 2020; 2021). As for remediation of soils and groundwater from pollutants, which is not considered here either, it should be noted that today preference is given to adsorption methods, in particular, using natural sorbents (Malovanyy et al., 2020, Stepova et al., 2023, Konanets et al., 2024) and biological methods that imitate natural processes of self-regeneration (Malovanyy et al., 2021), but which are much more effective due to their special organization. The purpose of the article is to improve the environmental monitoring of soils in the urban ecosystem of Rivne using geoinformation technologies and to visualize the results based on indicators of total and accumulated contamination with HM.

MATERIALS AND METHODS

Environmental monitoring of the natural environment in Ukraine is carried out according to national and regional (local) programs. The main tasks of environmental monitoring include monitoring the contamination of soil cover with HM in the zone of influence of industrial enterprises and local transport highways.

The article used data from monitoring studies of the Region data bank created in the MS Access 97 software environment. The data bank stores the results of analytical monitoring of the network of continuous observations of the department of instrumental and analytical control of the State Environmental Inspectorate of the Polissia District over the condition of soils in the Rivne region since 2001. Additionally, we used data from the laboratory of the Hydrometeorological Center of Ukraine (Kyiv) which conducts monitoring of the total content of HM in soils in the territory of the city of Rivne once every 5 years to determine the dynamics of their accumulation.

The territory of the city of Rivne is characterized by a compact location of industrial enterprises, which forms 5 conventional zones: northern, southern, western, eastern, and central. The characteristics of these zones are described in the scientific work (Melnyk et al., 2015).

Ultimately, the results of 1.893 determinations in the soil for the following indicators were used to accomplish the assigned tasks: Cd, Co, Mn, Cu, Ni, Pb, Cr and Zn. The results of the study characterize the gross and mobile forms of the elements. The gross form of HM was extracted with 1 M HNO_3, and the mobile form was extracted with ammonium acetate buffer solution with a pH value of 4.8 M. (Malovanyy et al., 2022).

The assessment of the level of soil cover contamination with gross and mobile forms of HM was carried out using the calculated concentration factors (C_f) and total contamination index (TCI) (Malovanyy et al., 2022).

The concentration factor C_f is calculated using the formula 1:

$$C_f = C_i / C_{bi} \quad (1)$$

where: C_i – the actual content of each i-th element, mg/kg; C_{bi} – the background content of each i-th element, mg/kg.

The total contamination index TCI was calculated based on data on concentration factors in the Excel software environment using the formula 2:

$$TCI = \sum Cf - (n-1) \quad (2)$$

where: n – the number of chemical elements.

Categories of soil contamination of the study territory were determined by the total contamination index given in Table 1.

PLI is calculated as the geometric mean of the concentration factors (C_f) of n HM ($C_f i$ = 1...n), where, formula 3:

$$PLI = \sqrt[n]{Cf1 \cdot Cf2 \cdot \ldots \cdot Cfi} \quad (3)$$

C_f of each i-th metal is the ratio of the metal content in the soil sample to the background content of this metal; n is the number of polluting metals:

To determine the degree of soil contamination with HM, the following scale was used (Tomlinson et al., 1980; Yakovyshina, 2016):

- PLI < 1 – no contamination;
- PLI 1–3 – moderately contaminated soils;
- 3 < PLI < 6 – substantially contaminated soils;
- PLI > 6 – significantly contaminated.

The study applied methods of mathematical statistics using Excel 2016 software, the method of GIS technologies (interpolation, visualization of the distribution of the content of gross and mobile forms in the soils of Rivne through the method of graduated colors).

To build a map of soils in the city, we used ArcGIS 10.8 software using manual vectorization. When vectorizing, materials describing the soil cover of the city of Rivne (Korotun et al., 1996) and the base map (Open Street Map) in ArcGIS 10.8 software were used. To control the geometric accuracy of the data, the topology rules are taken into account, namely:

- the polygons under study should not intersect;
- there should be no empty space inside the polygons and between them, except for the outer perimeter.

A polygonal layer was added to the created map, reflecting the boundaries of the polygons under study and the points of soil sampling which represented spatial objects, Figure 1.

In order to estimate the distribution of gross and mobile forms of HM throughout the territory of Rivne, the IDW - Inverse Distance Weighted interpolation method was used in the ArcGIS 10.8 software. The interpolation involved developing a continuous surface from discrete points. Since the soil samples were collected at different points in the territory of the city of Rivne, the intermediate values were calculated by interpolation. To perform the interpolation using the IDW method, it was necessary to create a tool of the same name for downloading data. For this purpose, tables were drawn up with data from soil sampling points that had specified coordinates. The fields of study were the concentration factors of each studied HM of gross and mobile forms. The environmental parameters were adjusted so that interpolation completely filled the data within the city territory.

Tables were drawn up with the coordinates of soil sampling points and data on their contamination: the content of gross and mobile forms of HM, concentration factors, total contamination indexes (Malovanyy et al., 2022). Using the Add XY data tool made it possible to create a temporary point object which was exported to a previously created database for storing. As a result of such actions, all the necessary information for creating maps was entered into the table.

Table 1. Assessment of technogenic soil contamination with HM based on the TCI

Soil contamination hazard category	Values TCI	Changes in public health indicators in pollution centers
Permissible	< 16	There are virtually no diseases in children and a small number of manifestations of dysfunctions of systems and organs
Moderately dangerous	16–32	Increased number of common diseases among the population
Dangerous	32–128	An increase in the number of children suffering from chronic diseases and cases of disorders of the functional state of the cardiovascular system
Extremely dangerous	> 128	A high sickness rate in children, significant violations of reproductive functions in women, namely: an increase in the number of premature childbirths, stillbirths, etc.

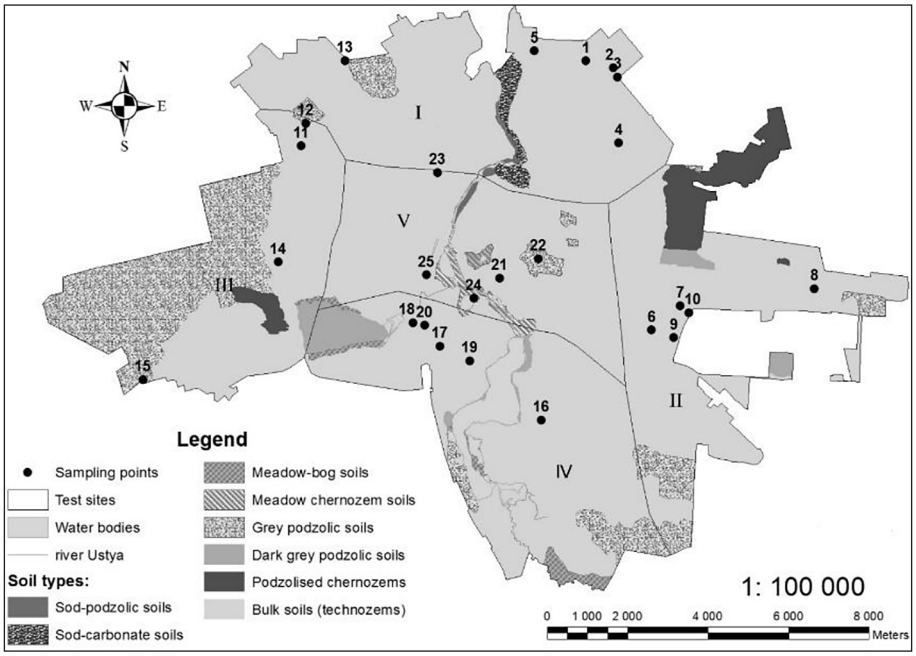

Figure 1. Soil map of the territory of the city of Rivne

RESULTS AND DISCUSSION

The presence of a large array of quantitative analytical information on soil contamination with HM in the city of Rivne, stored in the Region data bank, and a comprehensive study of the problem by scientists of the region, made it possible to apply GIS technologies to present monitoring studies of this problem in the form of maps.

An analysis of the indicators of total soil contamination by the gross form of HM shows that most of the city's territory (52%) is in the "Moderately dangerous" category of contamination. The "Permissible" hazard category of contamination is 14%, and 34% belong to the total contamination indexes (TCI) corresponding to the "Dangerous" hazard category. In particular, this category of contamination is identified near the following enterprises: the Rivne Flax Mill LLC, the Rivne Nonwoven Materials Factory PJSC, the Aquaton Manufacturing Enterprise LLC, the Agroresurs PJSC, the Rivne plant of high-voltage equipment – RZVA LLC, the Rivnekholod ALC and near railways. In our opinion, this may be due to the mechanical composition of the soil, which is capable of accumulating HM. The localization of the HM gross form according to the total contamination index is reflected in the map for assessing the hazard of soil contamination, Figure 2.

Contamination of the city's soil with HM of mobile form within the hazard category «Permissible» is 74%. 8% is classified as "Moderately dangerous" and 18% is classified as "Dangerous". To assess the degree of soil contamination hazard by the mobile form of HM, an interpolated surface was created using the IDW method. The map visualizes most of the territory that is within the values of the "Permissible" contamination hazard category. "Moderately dangerous" and "Dangerous" categories of contamination hazard are concentrated locally in the southern part of the city near the railway, bypass highways and the enterprise Agroresurs PJSC, where pest control equipment for agricultural products is located, Figure 3.

Thus, the territories with contamination of the "Moderately dangerous" and "Dangerous" categories correlate with the location of industrial enterprises and the main transport arteries of the city. To assess the level of soil contamination in the urban ecosystem of Rivne, the accumulated pollution index PLI (Pollution Load Index), proposed by Tomlinson et al., was calculated (Tomlinson et al., 1980).

Based on the results of PLI, categories of soil contamination with HM in the territory of Rivne were established. Thus, for the gross form, 54% of soil sampling points in the city according to PLI values are in the "Substantially contaminated" category, 28% of the samples are in the "Moderately contaminated" category, and 18% of the samples are in the category of "No

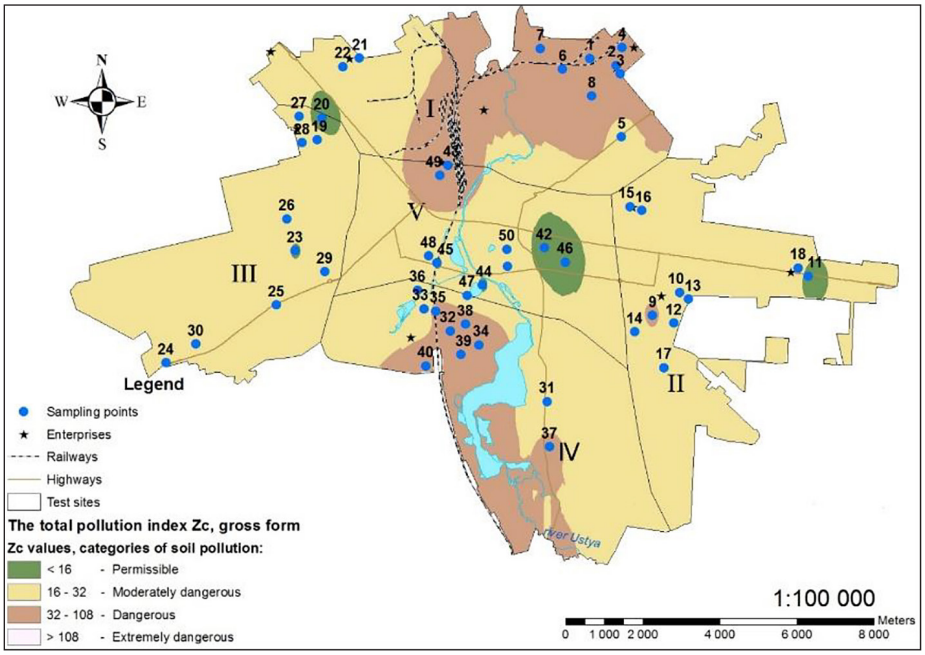

Figure 2. Assessment of soil contamination hazard based on the index of total contamination with HM of gross form

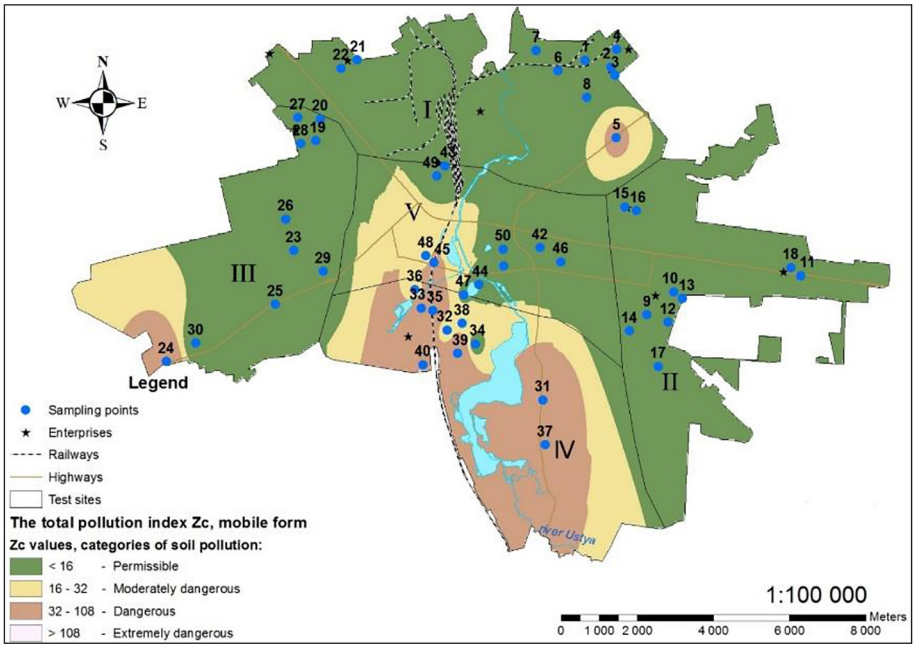

Figure 3. Assessment of soil contamination hazard based on the index of total contamination with HM of mobile form

contamination" with HM. Based on this indicator, the degree of soil contamination with HM was visualized and an interpolated distribution surface of the total index of heavy metal contamination of the gross and mobile forms of soils in the territory of Rivne was constructed.

Using PLI values to visualize the degree of contamination of the city's soil cover a map was created, Figure 4. Regarding the gross form of HM content, the vast majority of the territory is occupied by soils corresponding to the "Moderately contaminated" category. The "Substantially contaminated" category is defined for large industrial enterprises, namely: the Rivne Flax Mill LLC, the Rivne Nonwoven Materials Factory PJSC, the Aquaton Manufacturing Enterprise LLC, the

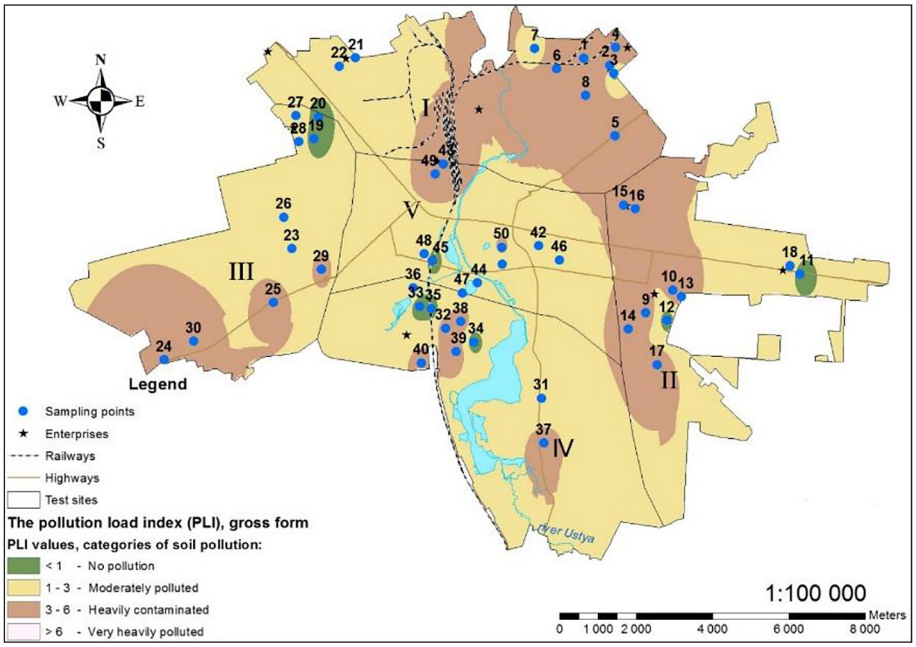

Figure 4. Assessment of the degree of soil contamination based on the index of accumulated contamination with HM of gross form

Agroresurs PJSC, the Rivne plant of high-voltage equipment – RZVA LLC, the Rivnekholod ALC, the Radiozavod JSC. Soils in this category are concentrated both near major highways and around railways.

A different situation is for the mobile form of HM. Thus, according to PLI values, 62% of the soil is of "No contamination" category. It should be noted that soils with "No contamination" category have an insular localization and are located near water bodies and on the outskirts of the city. "Moderately contaminated" soils are found in 26% of samples, 4% and 8% of samples fall into the "Significantly contaminated" and "Substantially contaminated" categories, respectively. The category "Substantially contaminated" soils belong

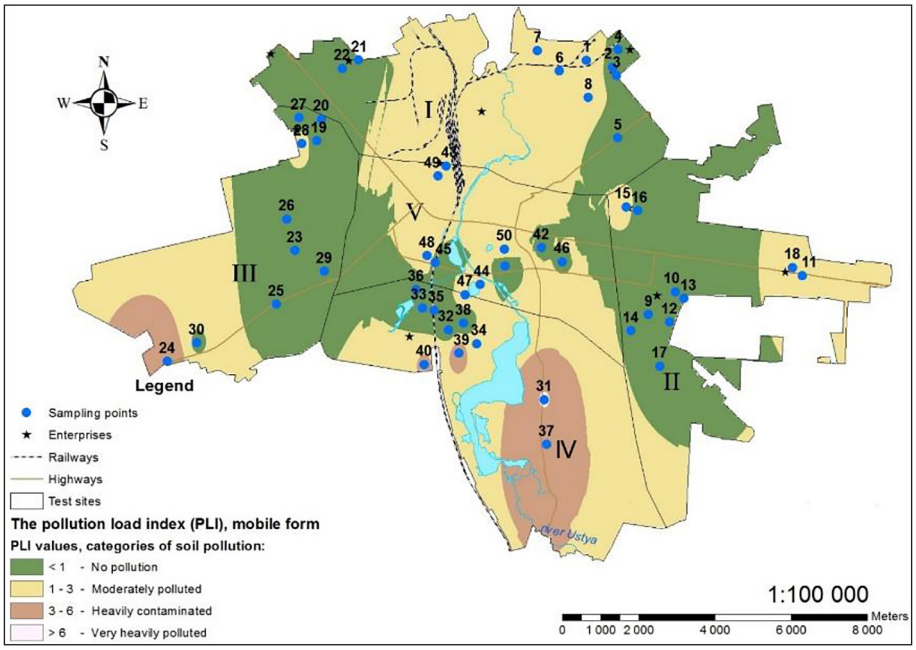

Figure 5. Assessment of the degree of soil contamination based on the index of accumulated contamination with HM of mobile form

to the territories of large enterprises, namely: the Rivne plant of high-voltage equipment – RZVA LLC, the Radiozavod JSC, the Aquaton Manufacturing Enterprise LLC, the enterprise Agroresurs PJSC and others. This category also includes soils located near major highways and railways.

The created map of the distribution of accumulated soil contamination with HM of mobile form according to the PLI index made it possible to clearly assess the degree of soil contamination with HM, Figure 5.

Regarding the mobile form of HM, an uneven distribution of territory between two categories is visualized: "No contamination" and "Moderately contaminated". The soils near such enterprises as the Aquaton Manufacturing Enterprise LLC, the Rivne plant of high-voltage equipment – RZVA LLC, the Rivnekholod ALC, and the territory of the railway right-of-way are classified as "Moderately contaminated". "Substantially contaminated" and "Significantly contaminated" soils are located near highways.

It should be noted that the results of the mapping of the city's territory according to the index of total contamination with gross and mobile forms coincide with the index of accumulated contamination with gross and mobile forms of HM. Thus, the construction of interpolated surfaces based on the above indexes is reliable and can be taken into account in further monitoring studies and when predicting soil contamination of urban ecosystems with HM.

CONCLUSION

An analysis of soil contamination in the city of Rivne shows that the largest polluters of the soil cover are: the Rivne plant of high-voltage equipment – RZVA LLC, the service area of the Lviv Railway within the city of Rivne, the Rivne Flax Mill LLC, the Aquaton Manufacturing Enterprise LLC, the Radiozavod JSC, the enterprise Agroresurs PJSC and an extensive network of highways.

It was found that, except for cadmium, the concentration factors of the gross form of HM exceed the background values several times, and in some places of the territory the excess of zinc is dozens of times C_f of the mobile form of HM almost do not exceed their background value, except for copper and zinc, in which the excess reaches dozens of times.

It was found that, in terms of the total index (TCI), soils of the "Moderately Hazardous" and "Permissible" contamination hazard categories prevail in most of the city's territory.

An analysis of accumulated contamination indexes showed that, according to PLI results, most soils are in the "Substantially contaminated" category, and those around enterprises are "Significantly contaminated."

The created map visualizes the city's territory by categories of accumulated soil cover contamination index. The results of mapping the territory of the urban ecosystem of Rivne, based on the total indexes of soil contamination with HM of gross and mobile forms, correlate with the indexes of accumulated contamination of the above forms of HM.

In order to develop and substantiate measures to improve the condition of the soil cover of the city's territory, it is promising, in our opinion, to further study the contamination of the territories with HM to obtain indicators in dynamics and predict and achieve safe sustainable development of the urban ecosystem of Rivne.

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