РОЗДІЛ V. БУДІВНИЦТВО ТА ГЕОДЕЗІЯ

DOI: 10.25140/2411-5363-2022-3(29)-169-177
UDC 528.946

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WEB CARTOGRAPHY OF SOIL QUALITY IN LVIV REGION

A web map of soil pollution in Lviv region was developed. To create the web map of soil quality in Lviv region, we used a very convenient and popular platform "ArcGIS Online". For our case, Excel tables were developed: soil samples from the places of pollution by industrial enterprises and landfills provided by the Department of Instrumental and Laboratory Control of the State Ecological Inspectorate in Lviv region; content analyses of labile forms of salts of heavy metals in soil samples; observations on the quality of agricultural soils in Lviv region.

Keywords: *web mapping; geospatial data; threshold limit value; ecological mapping; soil pollution; interactive web map; "ArcGIS Online".*
Fig.: 5. Table: 5. References: 13.

Urgency of the research. It is known that the basis of agricultural production and forestry is soil. Field and fodder crops, forest crops, gardens and berry orchards are grown on soil. In recent years, people stopped caring about soil, farmers and industrialists abandoned systematic crop rotations that improved the physical properties of soil and distorted it by abusing nitrates and pesticides. As of today, about 6.5 million hectares of Ukrainian soil are already unsuitable for agricultural work.

Target setting. We want to carry out analytical control of soils within sanitary and protective zones and in places of waste accumulation of enterprises of Lviv region and find out polluters of land resources. With this purpose, geospatial statistical data relating to the ecological state of the soils of Lviv region was collected and systematized. This allows us to make a choice of software for the development of a soil pollution web map, select the application template for the development of the web map based on the indicators of 428 soil samples in the places of their pollution by industrial enterprises and landfills and develop the web map of soil pollution of Lviv region in the "ArcGIS Online" software environment.

Actual scientific researches and issues analysis. The analysis of modern scientific publications showed that the problem of environmental pollution requires significant attention and detailed study, since a negative change in nature affects the environment and the conditions of existence of all mankind. We can visually display the ecological quality of the environment and draw certain conclusions through interactive or web mapping. Such scientists N.P. Yarema, O.V. Serant, M.S. Heba and A.R. Sohor were engaged in creating ecological maps of Lviv region based on atmospheric air monitoring data [8]. Such scientists as N.P. Yarema, A.M. Brydun, I.P. Lekh and A.R. Sohor were engaged in the problem of web mapping of environmental atmospheric air pollution in Lviv region [7]. The topic of interactive mapping of ecological pollution of surface waters of Lviv region was studied by such researchers as Yu.I. Holubinka, V.V. Shapoval, M.A. Sohor and A.R. Sohor [9]. Issues of web mapping of landfills in Lviv region were studied by N.P. Yarema, O.V. Serant, O.D. Kubrak, T.M. Terech [13]. The problem of mapping pollution of the natural environment with solid household waste was studied by such

scientists as N.P. Yarem, T.B. Marko and V.A. Lozynskyi on the example of Lviv region [11, 12]. The creation of an interactive map of landfills in Lviv region was carried out by such researchers as N.P. Yarema, Yu.M. Polyukhovich, O.D. Kubrak, O.V. Serant [10].

Uninvestigated parts of general matters defining. Currently, the soil quality in Ukraine and, in particular, in the Lviv region is at unsatisfactory level. The main problems in this area are the progressive nature of the negative impact on the ecological state of the environment and human health.

Unfortunately, at the moment, there is no interactive cartographic material that can visualize the problem of ecological soil pollution in Lviv region.

The research objective is to create the web map of soil quality in Lviv region. To achieve this goal, the following tasks were set and solved:

- Collection of geospatial statistical data related to the ecological condition of the soils of Lviv region.
- Choice of proper software for the development of a web map of soil pollution.
- Selection of an application template on the ArcGIS Online platform.
- Creation of the web map of soil pollution in the Lviv region.

The statement of basic materials. Disturbance (destruction) of soils is a complex set of anthropogenic and natural processes of change in physicochemical and mechanical characteristics of soil. As a rule, the first reason for soil disturbance are human-initiated processes (such as mechanical tillage, transformation of soil layers in construction, soil compaction due to transport, livestock grazing, irrigation or other changes in groundwater and surface water, soil pollution, etc.). The results of these primary changes can be multiplied by natural factors, such as wind, rainfall, etc. That is, the soil is a very complex and vulnerable system that has developed over the centuries, but by improper human activities can be destroyed in years, months and even days [1; 2].

Erosion has the greatest destructive effect on soils. Soil erosion is the process of capturing soil particles and carrying them away by water or wind, as well as the process of destroying the upper, most fertile layers of soil.

Under the influence of human activity, there is an accelerated (excessive) erosion, which often causes the complete destruction of soils. At the same time, the losses of soil components are not compensated and there is a sharp decrease in its fertility. Soil destruction happens in hundreds and even thousands of times faster than destruction under natural erosion processes. In natural conditions, soil fertility is constantly renewed because the nutrients taken by plants re-enter the soil with precipitation, mineralize and enrich it again. In agriculture, only a small part of the biomass is returned to the soil, the other is collected with the harvest. Monocultures deplete the soil especially strongly. Erosion is also facilitated by deforestation, which deprives the soil of a protective layer [2, 3].

In addition to erosion, the most significant reasons for the deterioration of land resources in Ukraine are:

1. secondary salinization of soils;
2. flooding and drying of lands;
3. anthropogenic and man-made soil pollution.

The reaction of soil solution is an important indicator of soil fertility, which significantly affects the growth and evolution of plants and the activity of microbiological chemical and biochemical processes. The reaction of the soil to a large extent depends on the assimilation by plants of soil nutrients and fertilizers, mineralization of organic matter, the efficiency of applied fertilizers, crop yield and its quality. In general, active and potential acidities are distinguished. Potential acidity is divided into metabolic and hydrolytic. Hydrolytic acidity characterizes the total acidity of the soil, as it includes all potential and active acidity. Metabolic acidity is expressed by the pH value of the salt extract. The pH value of the salt extract determines the degree of acidity of the soil. According to the degree of acidity, soils are divided into few groups [2; 4; 5]:

- ultra acidic (pH < 4,0),
- extremely acidic (pH 4,1 – 4,5),
- very strongly acidic (pH 4,6 – 5.0),
- strongly acidic (pH 5,1 – 5,5),
- moderately acidic (pH 5,6 – 6,0),
- neutral (pH 6,1 – 7,0),
- slightly alkaline (pH 7,1 – 7,5).

The soil is most often contaminated with compounds of metals and organic matters, oils, tar, pesticides, explosives and toxic substances, radioactive, biologically active combustible materials, asbestos and other harmful products. The source of these compounds is most often industrial or household waste buried in certain places, or in unauthorized landfills. Contamination of soil with heavy metals such as mercury, cadmium, lead, chromium, copper, and zinc is quite dangerous. Heavy metals are present in the soil as natural impurities. The reasons for increasing impurities concentrations are related to

- industry (non-ferrous and ferrous metallurgy, energy, chemical industry);
- agriculture (irrigation with contaminated water, use of herbicides);
- burning fossil fuels and waste;
- motor transport.

Heavy metals are toxic and interfere with the activity of soil microflora. Their concentration in the soil can persist for decades or even centuries. Content of heavy metals, radionuclides, nitrates and pesticides in soils is shown in table 1.

Table 1 – Content of heavy metals, radionuclides, nitrates and pesticides in soils in 2020

Type of pollutant	Number of samples	Maximum permissible concentration, mg/kg	Min soil concentration, mg/kg	Max soil concentration, mg/kg
Cd	1831	0.7	0.1	0.35
Pb	1831	6.0	0.8	2.24
Cu	1479	3.0	0.8	2.20
Zn	1479	23	0.42	1.83
Co	1479	5.0	0.8	2.24
Mn	1479		7.0	33.8

The Lviv branch of the State Institution “State Soil Protection” monitors the quality of agricultural soils in Lviv region. In 2020, the Lviv branch of the “State Soil Protection” Institution carried out agrochemical certification of agricultural lands on farms in nine administrative districts. The area of surveyed lands is 36,589 hectares. The degree of acidity is dominated by soils with a neutral reaction of the soil solution (pH 6.1–7.0), the area of which is 17,909 ha or 48.9% of the surveyed lands. The area of acid soils (pH <5.5) is 10,400 ha, which is 28.4% of the surveyed lands. The weighted average soil acidity is 6.3 units. The content of humus (organic matter) varies from very low (<1.1%) to very high (> 5.0%). Soils with an average (2.1–3.0%) content of humus predominate; the area of these soils is 11,950 ha or 32.7%. According to the content of easily hydrolysed nitrogen compounds, the largest area (23956 ha or 65.5%) is occupied by soils with a low degree of supply. The content of labile phosphorus compounds is dominated by soils with increased (10407 ha or 28.4%) and high (9722 ha or 26.6%), labile potassium compounds – medium (10373 ha or 28.4%) and increased (9114 ha or 24.9%) degree of support [4].

Humus is the most important component of the soil and a determining indicator of its fertility. Humus has the greatest effect on the acceleration of the circulation of substances in the soil–plant system, and when its reserves increase, the energy level of processes taking place both in the soil and in the plant increases too. Humus activates biochemical and physiological processes, enhances metabolism and the overall energy level of processes in the plant body, and promotes the increased intake of nutrients, which is ultimately accompanied by an increase in

harvest, and improvement of quality. The humus state of soils is a matrix that determines all their properties, including all soil regimes. That is why the humus content in the soil is an integral indicator of the level of its potential and effective fertility. Improving the humus condition of soils is the main direction of their fertility and increasing the ecological stability of agricultural landscapes. The agrochemical characteristics of the surveyed lands in terms of humus content are given in table 2.

Table 2 – Characteristics of soils by humus content

Soil area, %						Weighted average index, %
very low < 1.1	low 1.1–2.0	average 2.1–3.0	increased 3.1–4.0	high 4.1–5.0	very high > 5.0	
1.7	25.5	32.7	27.7	7.7	4.8	2.8

The nitrogen fund of the soil consists of organic and mineral compounds of nitrogen contained in the soil and is determined by the genetic properties of soils, depending on the rate of mineralization of organic matter. The main part of the nitrogen is contained in the soil in the form of complex organic matters. The portion of these organic matters is 93-97% of the total nitrogen-containing matters, and only 3-7% are mineral nitrogen compounds. Nitrogen-containing organic compounds are represented by humus, amino acids, their condensation products and other organic matters. Soils, richer in organic matter, have a higher nitrogen content. The nitrogen of organic compounds becomes available to plants only after mineralization. Nitrogen-organic compounds (amides, amino acids, etc.), which decompose quickly and turn into minerals, are considered to be easily hydrolysed.

Plants absorb nitrogen from labile mineral compounds, namely ammonium salts and nitric acid. The amount of labile mineral nitrogen compounds in the soil is very small (about 1% of total nitrogen). A sufficient supply of plants with nitrogen depends on the mineralization of nitrogen-containing organic matter. Along with the process of mineralization of organic nitrogen compounds in the soil, nitrogen is used by microorganisms to build their body (immobilization). After the death of microorganisms, this nitrogen is again partially mineralized and partially fixed in the humus. To establish the supply of plants with nitrogen, determine the content of easily hydrolysed nitrogen in the soil and the nitrifying capacity of the soil. The agrochemical characteristics of the surveyed lands in terms of easily hydrolysed nitrogen content are given in table 3.

Table 3 – Characteristics of soils in terms of nitrogen content, which is easily hydrolysed

Soil area, %				Weighted average index, mg/kg
very low < 100	low 101.0–150.0	average 151.0–200.0	increased > 200	
16,5	65.5	13.5	4.5	121.9

The phosphorus content in the soil is one of the main signs of its fertility and cultivation. It should be noted that up to 55% of phosphorus in the soil is represented by organic compounds, and the composition of mineral phosphates available to plant forms do not exceed 1-3%. Phosphorus of organic compounds is available to plants after their hydrolytic decomposition by phosphatases and soil microorganisms. Much of the soil phosphorus is in hard-to-reach forms, which become available due to the action of root secretions and micro-organisms. The mineral compounds of phosphorus, in particular, labile phosphates, determine the conditions of plant nutrition with phosphorus. Agrochemical characteristics of the surveyed lands on the content of labile phosphorus compounds are given in table 4.

Table 4 – Characteristics of soils by the content of labile phosphorus compounds

Soil area, %						Weighted average index, mg/kg
very low < 20	low 21-50	average 51–100	increased 101–150	high 151-200	very high > 200	
0.7	3.7	26.3	28.4	26.6	14.3	136.9

The content of exchangeable potassium in the soils of the region is different and depends on the mechanical components of the soil, fertilizer application, climatic conditions and method of its use. The agrochemical characteristics of the surveyed lands in terms of the content of labile potassium compounds are given in Table 5. The increase in the content of exchangeable potassium in the arable soils of the region is explained by a sharp change in climatic conditions. In conditions, when long humid and cool weather is sharply changed with long and arid weather with high temperature that became characteristic of the territory of the area in the last 3 years, there is fast and excessive evaporation of moisture from soil that encourages the return of water-soluble salts by capillaries with soil moisture in upper horizons, where moisture evaporates into the atmosphere and salts remain in the soil. Thus, there is a secondary saturation of the arable layer with water-soluble salts from deep horizons, among which is largely potassium [2].

Table 5 – Characteristics of soils by the content of labile potassium compounds

Soil area, %						Weighted average index, mg/kg
very low ≤ 20	low 21-40	average 41-80	increased 81-120	high 121-180	very high > 180	
3.1	19.4	28.4	24.9	16.9	7.3	79.07

In 2020, the Department of Instrumental and Laboratory Control of the State Ecological Inspectorate in Lviv region performed 428 soil samples at the sites of their contamination (industrial enterprises, landfills, etc.). As a result of the analytical control of soils in places of accumulation of waste, it can be concluded that pollutants of land resources are mainly accumulators of household waste (landfills) and industrial waste [2, 4].

The creation of the web map is performed in several stages:

- Prepare and download the source data.
- Select a base card.
- Download layers with source data.
- Download auxiliary layers.
- Save the map.

To perform the first stage, we determine the location of each soil sampling point, in which we recorded the physical and chemical characteristics of the soil. To do this, we use the environment “Google Maps”, to determine the place where the soil sample was taken. Then we display the coordinates of the point, which we copy and paste into our “Microsoft Office Excel” spreadsheet and save the file in csv format.

To display points on the map, we use the function “Add – Add a layer from the file”. Then a program window will appear showing all the data that was in the “Microsoft Office Excel” file.

For orientation on the map, those columns were selected from the table, which are responsible for each type of data: longitude, latitude and information about the physical-chemical composition of the soil (Fig. 1).

The Department of Ecology and Natural Resources of the Lviv Regional State Administration provides only an approximate location of the points of fixing soil contamination. Moreover, the coordinates of the soil sample will also be not exact but close to the true values.

For better visualization, we used the “Change Style” option. You can use it to select two styles of character display: types (Unique characters) and location (Single character).

In our case, the Unique Symbols style is selected to display districts and Amalgamated Territory Communities (ATCs). This style can change objects: colour, shape, size, visibility range and transparency.

The icons on the map are selected and displayed according to the theme of the map, household and industrial waste are displayed with different icons so that users can navigate to which category the surface contamination belongs.

For better orientation on the map, other layers, districts of Lviv region, and Amalgamated Territory Communities were also added.

For better display, we configure the visibility of regions, districts and territory communities, and adjust the visibility range of these layers.

Schyrota	Dovgota	inform	Copper (Cu)	Zinc (Zn)	Lead (Pb)	Chromium (Cr)	Cadmium (Cd)	Cobalt
		to the breakdown ♦ 4 is contaminated with oil products						
49,54	23,50	Land plot of dissolved chemicals, North-East. the angle of the well	0,84	2,16	1,92	1,48	0,56	1,67
49,54	23,50	Land plot of the bypass ditch near the bridges, South-East. the angle of the well	1,03	4,8	2,15	1,04	0,17	1,95
49,54	23,50	Background, land approximately 30 m from the well	1,1	2,23	3,02	1,28	0,20	2,16
50,35	24,22	Land on the south-east of the heap on the bypass channel	0,84	1,26	2,10	1,03	0,14	0,53
50,35	24,22	Background, a plot of land 200 m on the Mon from the heap, near the administration	1,13	2,2	3,06	1,15	0,25	0,81

Fig. 1. Exported data to "ArcGIS Online" software environment

To display the regions, we chose the range "World – District" (Fig. 2), for districts "District – Town" (Fig. 3), and for ATC "City – Room" (Fig. 4).

After compiling the map, we use the "Share" option, which can transfer the map to public access. This function allows to embed the map on a website or create your own web application.

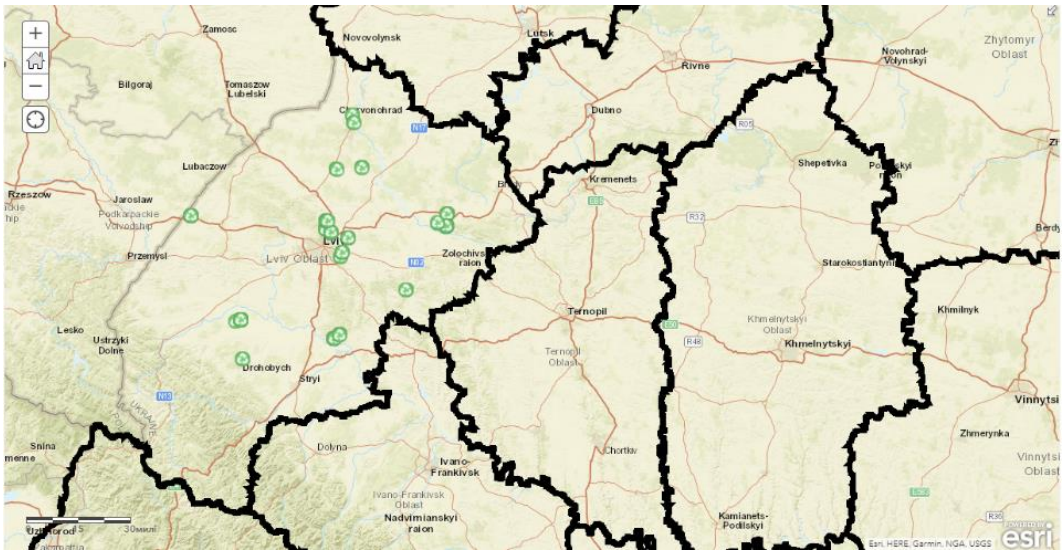

Fig. 2. Visibility of regions in "ArcGIS Online"

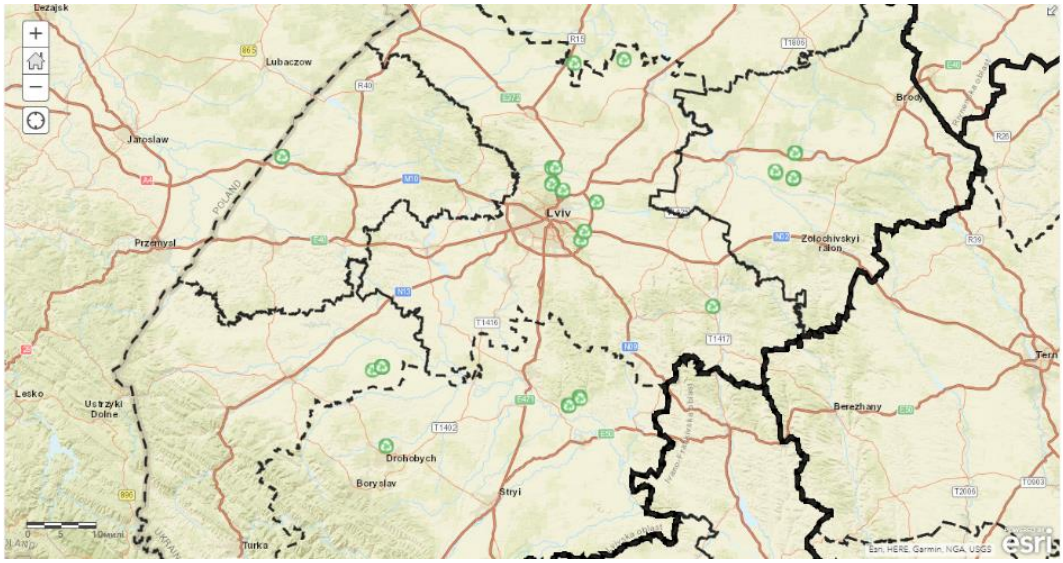

Fig. 3. Visibility of districts in "ArcGIS Online"

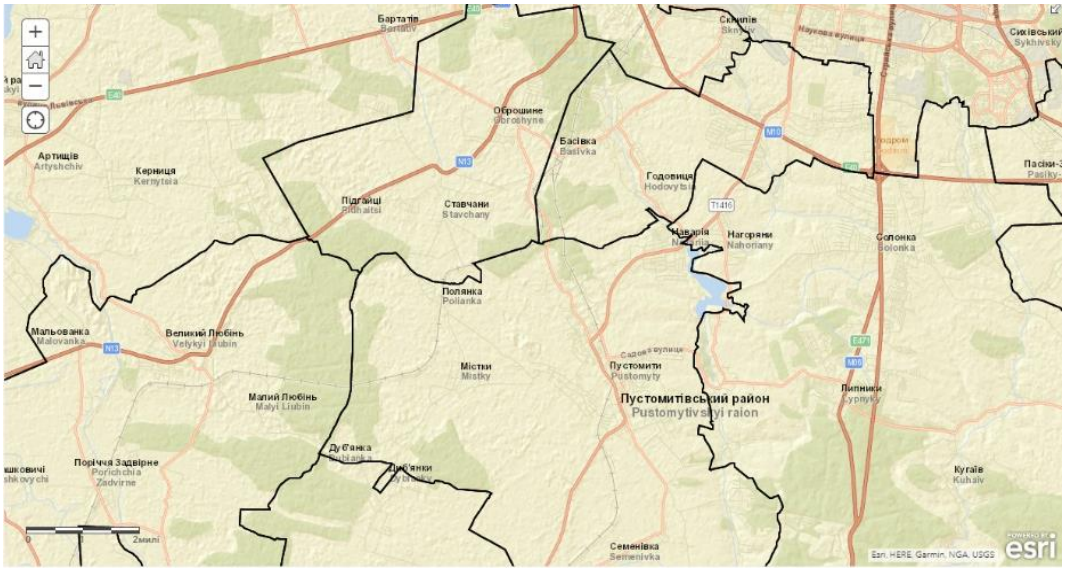

Fig. 4. Visibility of ATCs in "ArcGIS Online"

Summing up, to create the web map of soil quality in Lviv region, we used a very convenient and popular platform "ArcGIS Online". In order to start working on this platform, it is necessary to collect and structure data in the environment of "Microsoft Office Excel" [6, 7].

For our case, we developed the following Excel spreadsheets:

- samplings of soils in places of their contamination by industrial enterprises and landfills, provided by the Department of Instrumental and Laboratory Control of the State Ecological Inspectorate in Lviv region;
- content analysis of labile forms of salts of heavy metals in soil samples conducted by the Lviv branch of the State Soil Protection State Institution;
- observations on the quality of agricultural soils in Lviv region, carried out by the Lviv branch of the State Institution "State Soil Protection".

To visualize the map of Lviv region, the "OpenStreetMap" was used in the "ArcGIS Online" platform with the borders of Lviv region and the districts of the region [7, 8, 9, 10]. In order to map our data, "ArcGIS Online" first created the map with the coordinates of each soil contaminant and soil quality values. To do this, we exported the created "Microsoft Office Excel" spreadsheet to "ArcGIS Online" [11; 12; 13].

Further, we combine the map with the borders of Lviv region and the soil quality map and get our web map (Fig. 5).

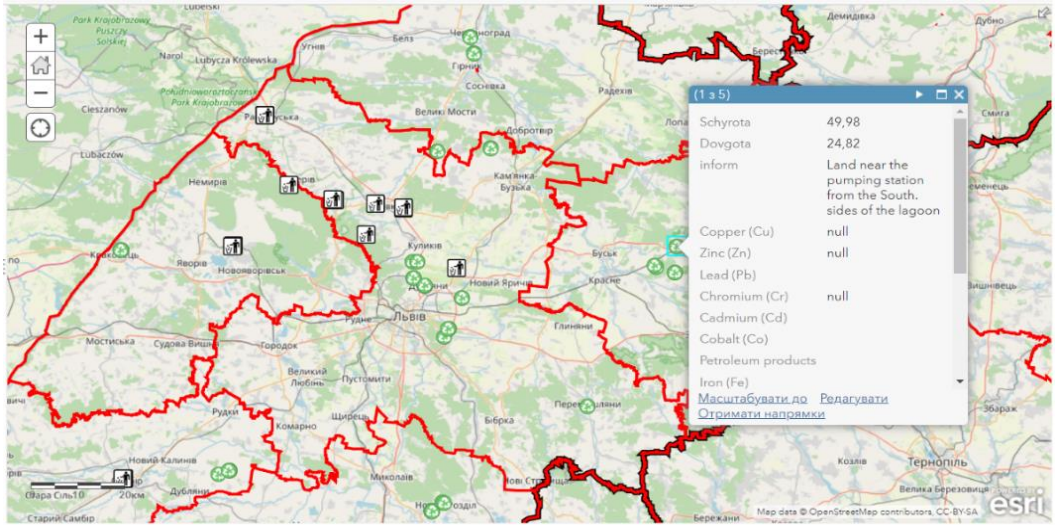

Fig. 5. Map of soil quality of Lviv region in the environment "ArcGIS Online"

You can view the created web map using the following link:
https://nulp.maps.arcgis.com/home/webmap/viewer.html?webmap=a951c2c9da804f2b9e78a7f8c837e143&extent=22.8696,49.2556,26.2424,50.4018

Conclusions. Studying the problem of soil quality in Lviv region in terms of environmental pollution, we have:

1. Collected and systematized geospatial statistical data related to the ecological condition of the soils of Lviv region.
2. Chosen software for the development of a web map of soil pollution.
3. Selected a template for applications for the development of the web map on the indicators of 428 soil samplings in places of contamination by industrial enterprises and landfills.
4. Developed the web map of soil pollution in Lviv region in the "ArcGIS Online" environment.

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Отримано 29.08.2022

УДК 528.946

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ВЕБКАРТОГРАФУВАННЯ ЯКОСТІ ҐРУНТІВ У ЛЬВІВСЬКІЙ ОБЛАСТІ

Головною метою цієї роботи є створення вебкарти якості ґрунтів у Львівській області. Створення вебкарти виконується в декілька етапів: підготовка та завантаження вихідних даних; вибір базової карти; завантаження шарів з вихідними даними; завантаження допоміжних шарів; збереження карти. Для виконання першого етапу, ми визначаємо місце розташування кожної точки відбору ґрунту, на якому фіксували фізико-хімічні характеристики ґрунту. Для визначення місця проб ґрунту використовуємо середовище «Google Maps». Після чого відображаємо координати точки в середовищі «Microsoft Office Excel». Для орієнтування на карті, було вибрано стовпці із таблиці, які відповідають за кожний вид даних: довгота, широта та інформація про фізико-хімічний склад ґрунту. Департамент екології та природних ресурсів Львівської обласної державної адміністрації надає лише наближене розташування пунктів фіксації забруднення ґрунту, очевидно й координати проби ґрунту також будуть наближені до істинних значень. Для кращої візуалізації ми скористались функцією «Змінити стиль». З її допомогою можна обрати два стилі відображення символів: типи (Унікальні символи) та місце розташування (Одиничний символ). У нашому випадку, для відображення районів та об'єднаних територіальних громад (ОТГ) нами було підібрано стиль «Унікальні символи», в яких є можливості змін об'єктів: зміна кольору, форми, розміру, діапазону видимості, редагування прозорості. Значки на карті вибрані та відображені відповідно до тематики карти, побутові відходи та промислові відходи були відображені різними значками, щоб користувачі орієнтувались до якої категорії належить забруднення поверхні. Для кращої орієнтації на карті, було додано також інші шари: райони Львівської області та межі об'єднаних територіальних громад. Після компонування карти було використано функцію «Поділитись», за допомогою якої можна перенести карту у відкритий доступ для користувачів. Ця функція дає можливість вбудувати карту у вебсайт або створити власний вебдодаток. У результаті проведеного аналітичного контролю ґрунтів в межах санітарно-захисних зон та в місцях накопичення відходів підприємств Львівської області слід зазначити, що забруднювачами земельних ресурсів є в основному промислові відходи та накопичувачі побутових відходів (сміттєзвалища, мулові майданчики). Ми зібрали та систематизували геопросторові статистичні дані, що стосуються екологічного стану ґрунтів Львівщини. Здійснено вибір програмного забезпечення для розробки вебкарти забруднення ґрунтів. Підібрано шаблон аплікацій для розробки вебкарти за показниками 428 відборів проб ґрунтів у місцях їх забруднення промисловими підприємствами та сміттєзвалищами. Таким чином, було розроблено вебкарту забруднення ґрунтів Львівщини у програмному середовищі «ArcGIS Online». Враховуючи вище сказане, для створення вебкарти якості ґрунтів у Львівській області ми скористалися досить зручною та популярною платформою «ArcGIS Online». Для нашого випадку було розроблено Excel-таблиці: відборів проб ґрунтів у місцях їх забруднення промисловими підприємствами та сміттєзвалищами, наданих відділом інструментально-лабораторного контролю Державної екологічної інспекції у Львівській області; аналізів на вміст рухомих форм солей важких металів у ґрунтових пробах; спостережень за якістю ґрунтів сільськогосподарського призначення у Львівській області.

Ключові слова: *вебкартографування; геопросторові дані; гранично-допустима концентрація (ГДК); екологічне картографування; забруднення ґрунтів; інтерактивна вебкарта; ArcGIS Online.*

Рис.: 5. Табл.: 5. Бібл.: 13.

Sohor, A., Brydun, A., Buha, A. (2022). Web cartography of soil quality in Lviv region. *Technical sciences and technologies*, (3(29)), 169-177.