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Geophysical research in the pre-Carpathian hydrosphere situation for the environmental civil protection purposes

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Object of research is to develop and carry out a methodology investigation of the regional ecological changes in the Pre-Carpathian hydro-lithosphere in a state of emergency caused by flooding. Method involves obtaining the results by integrating experimental field-path studies and theoretical model research, laboratory scientific comparison, the analysis and synthesis of final results. The studied model is the flooding in the Carpathian region east of the Carpathian arc in Ukraine, flooding parts of Pre-Carpathians Lviv region — industrially and recreationally important regions: Stebnyk, Borislav and Drohobych cities. Scientific novelty: the article aims to develop a method for an integrated approach to study of the territory in the question of flooding through a combined interpretation of geophysical, geological, and chemical data when considering a strategically important Pre-Carpathian region. The theoretical and practical significance of the results obtained is substantiating the feasibility and possibility of the complex application of geophysical-geological and chemical data for the practical interpretation of geoinformation data. Results will be of use to applied research in geophysics and ecology and contribute to improving of the ecological situation in selected regions. Obtained results contribute to the development of geoinformation technologies for complex geophysical-geological and chemical research in the environmental safety of territories in the event of emergencies.
Key words: develop, study, methodology, geophysics, ecology, emergency, flooding.

Introduction. Modern scientific research is becoming more and more interdisciplinary every time, resulting in novel results often characterized by important innovative components and practical values.

A number of scientists nowadays defines the stage of development of science as post-neoclassical, which is characterized primarily by interdisciplinarity; and interdisciplinarity means, firstly, the combination of various scientific fields during the study of the same object. Interdisciplinarity is a characteristic of such research, which passes through disciplinary boundaries beyond the boundaries of specific sciences [Bronnikova, 2015]. Science of in late XX — early XXI century is undergoing the next revolution. This is the period of the interdisciplinary organization of science, the emergence of a new post-neoclassical scientific paradigm. The transition to post-neoclassical methods is associated with applying science to a new type of objects — complex systems that have an internal self-development (in particular, ecosystems, biosphere) [Bronnikova, 2015]. One of the following is the complex systems of the hydrosphere and lithosphere (hydrolithosphere) [Lukner, Shestakov, 1976] in the state of intensive technogenic influences, which lead to emergencies of natural and artificial genesis.

The term «hydrolithosphere» was introduced by V. Shestakov [Lukner, Shestakov, 1976] and was used by him to denote the outer «water-stone» layer of the Earth's crust. The hydrolithosphere is the lithogenic basis of landscape geosystems and is interconnected with energy and mass transfer processes. At the present stage of development of scientific thought, the hydrolithosphere is understood as a complex multicomponent (rocks, groundwater, gases, biota, geophysical fields) system, which can be divided into vertical sections taking into account the laws of energy and mass transfer into two subsystems corresponding to traditional hydrogeological zones active and difficult water exchange. Obviously, the upper part of them, can be attributed to the lower reaches of the geographical or landscape shell.

According to [Kolot, 2014], interdisciplinarity is not only a simple borrowing of methods and tools from other sciences (disciplines) but also the integration of the latter at the level of constructing interdisciplinary objects, the subjects whose elaboration allows obtaining new scientific knowledge.

Utilizing interdisciplinary and transdisciplinary approaches, new scientific disciplines of civil protection, socioecology, sociohydrology [Sivapalan et al., 2012] are being developed; practical projects are being implemented in the conservation case [Ruiz-Frau et al., 2015], the assessment of complex natural processes [Kura et al., 2014; Starodub et al., 2020], and environmental and civil protection management [Khorolskyi et al., 2019; Malovanyy et al., 2019; Lund, 2015; Starodub et al., 2016].

There are always some issues on the way of combining different methods, including terminological coherence, consistency in time and space, etc.

The object of our research is a part of the Pre-Carpathian complex of hydrosphere and lithosphere in the state of intense natural and man-made influences, which lead to a sharp worsening of environmental safety and the appearance of emergencies.

The purpose of the work is to develop a methodology for a comprehensive regional forecast of flooding of territories and ecological-geochemical changes, and the risk of emergencies caused by predicted flooding.

The research method involves obtaining results by integrating experimental field and route studies, theoretical model research, comparison, analysis, and synthesis of results. During the construction of the model, satellite data from NOAA satellites were used to create a hypsometric map of the relief model.

Study area and materials. To develop the method of interdisciplinary investigation of the dangerous regions specifically connected with the West Ukraine area, the GIS satellite data arranged with geological information for the mentioned area are taken into account. The method is based on consuming the geological informational aspects obtained by the known geologists who investigated that region and the modern approach by mixing GIS and geological information. Also, existing geophysical and chemical data are taken into account. The area investigated is the Pre-Carpathian region foredeep rich in valuable mineral resources, where the high technogenic loading is pressed by the highly developed mining industry in the region. Also, seismicity phenomena connected with the Vrancea zone earthquakes, foreshocks, and aftershocks occur.

The natural conditions of the research territory are shown in Fig. 1. The map is presented on the basis of the works [Dolenko et al., 1980; Orlov et al., 2014].

The area of research in the geophysical aspect belongs to the Pre-Carpathian foothills [Giletsky, 2012]. In terms of tectonic most researchers [Stupka, 2013] refer to Pre-Carpathians as the Carpathian foredeep. Pre-Carpathian deflection is mostly made up of molasses formations. Some strata contain sodium, potassium, and sulfur, causing contamination risks for the hydrosphere. Deeper in the Outer Zone of the Pre-Carpathian Depression, many gas and condensate deposits have been explored in Neogene deposits, which occur in traditional tectonic shielded or stratigraphically shielded traps. To the North of the Silurian deposits are shale gas deposits [Lazaruk, Karabyn, 2020]. In the Inner Zone of the Precarpathian Depression, oil deposits are developed from Cretaceous and Paleogene deposits. Oil production began here in the 18th century with the help of digging pits. As a result of the long-term extraction of hydrocarbon resources in this region, a pre-crisis situation has arisen, creating risks of emergencies. The territory of the Folded Carpathians and Precarpathians is divided by a system of deep faults. Faults, es-

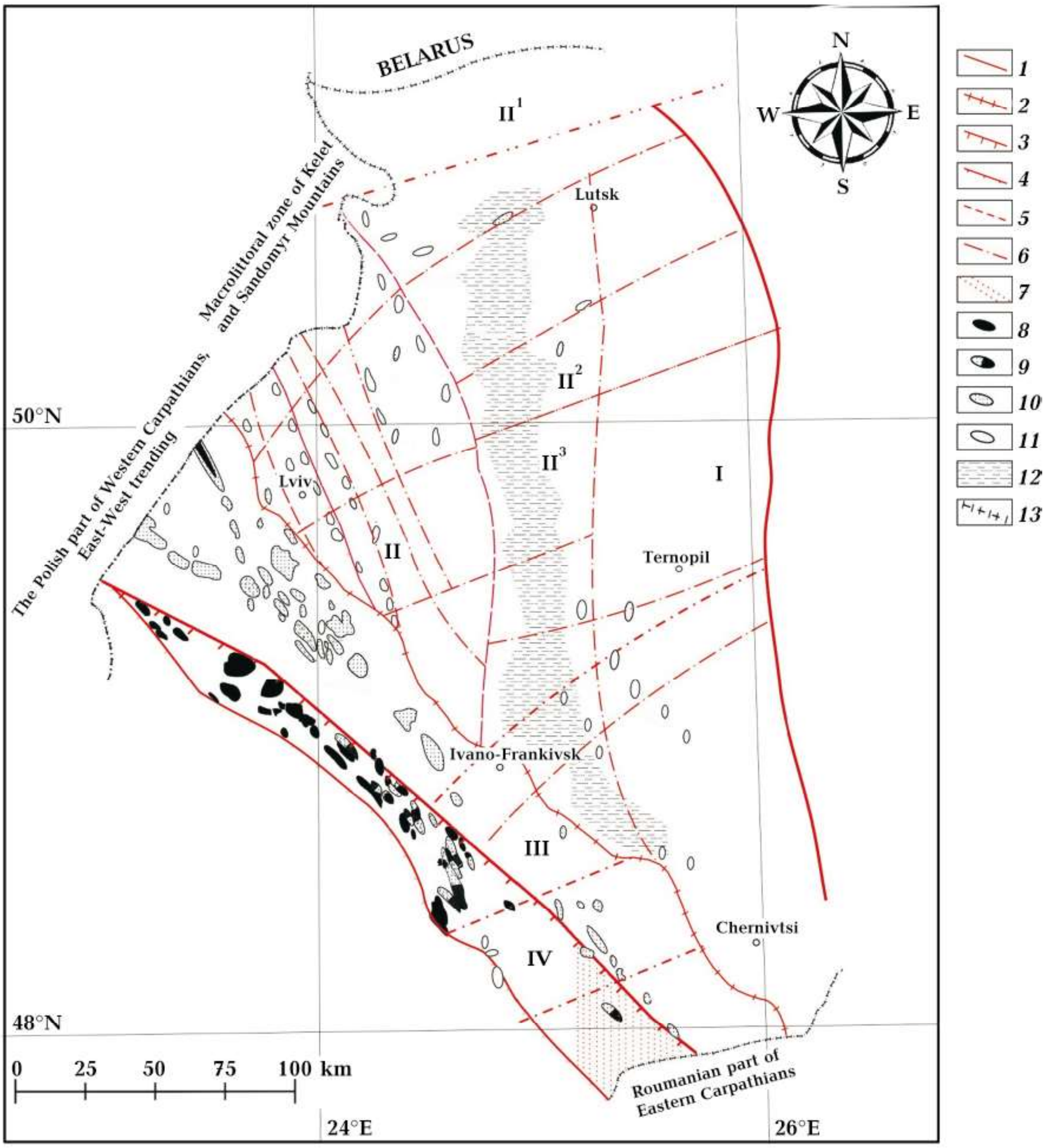

Fig. 1. Tectonic scheme of the bitumen-oil and gas-bearing area of the Pre-Carpathian deflection: *1* — North-Western border of Volyn-Podilska plate; *2* — conditional boundary of the Outer zone of the Pre-Carpathian deflection and Volyn-Podilska plate; *3* — inward line of the Inner zone to the Exterior zone of the Pre-Carpathian deflection; *4* — line of the Carpathian Skyba zone to the Inner zone of the Pre-Carpathian deflection; *5* — North-Eastern and South-Western border of the Lviv Paleozoic deflection; *6* — faults and regional tectonic disturbances; *7* — sub-zone part of the Bukovinian Carpathians of Meso-Paleozoic platform rocks; *8* — oil fields; *9* — oil and gas fields; *10* — gas fields (investigated numerically); *11* — not fully investigated structures (numeric); *12* — zones of prediction of organogenic structures in Paleozoic sediments; *13* — state borders. I — the Western slope of the Ukrainian shield; II — Volyn-Podilska plate; II^1 — Volyn part of the plate; II^2 — Lviv Paleozoic deflection; II^3 — Pre-Carpathian part of the plate; III — the outer zone of the Pre-Carpathian Trench (its platform slope); IV — Inner zone of the Pre-Carpathian deflection (according to the works [Dolenko et al., 1980; Orlov et al., 2014]).

pecially deep ones, are accompanied by various geophysical and geochemical anomalies, which can also negatively affect the population's health. For a long time, the activity of fluids in the zones of influence of deep break structures leads to an increase in the concentration of certain chemical elements (including harmful ones) and compounds and the formation of mineral deposits. In particular, in the Folded Carpathians and adjacent depressions, deep faults control deposits of oil and gas, sulfur, salts, ozokerite, iodine, mineral waters, gypsum, menilitic shales, and other minerals. The main components in the composition of deep fluids are water, carbon dioxide and oxide, nitrogen, methane and its homologues, hydrogen sulfide, Na^{+}, K^{+}, Li^{+}, Ca^{2+}, Mg^{2+}, Ba^{2+}, Fe^{2+}, Fe^{3+}, Mn^{6+}, HCO^{3-}, CO_3^{2-}, SO_4^{2-}, SI^{-}, F^{-}, $HSiO_3^{-}$, hydrogen, helium, radon and other radioactive elements (especially radon), mercury vapor, lead, zinc, copper, astatine, antimony, bismuth and many other metals and compounds having different carcinogenic activity, mutagenicity, toxicity, etc. The presence of elevated concentrations of these components in soils poses risks to humans and the environment, especially with the manifestations of other dangerous processes, including floods.

Methodology. Method of achieving the goal involves obtaining the results by integrating experimental field-path studies and theoretical model research, the scientific comparison, analysis, and synthesis of results. The model is the flooding in the Carpathian region East of the Carpathian arc in Ukraine, flooding parts of Pre-Carpathians Lviv region — regions important in industrial and recreational values: Stebnyk, Borislav, and Drohobych cities.

The model differs from other mentioned investigation modelling methodology for wider territories and regional data. The model includes a case of the small rivers of the Pre-Carpathian region and creates the scientific basis for the design of the civil protection measures in case of emergencies.

In general, the proposed approach utilizing geophysical, geological, and chemical data can be presented in the form of an execution program algorithm shown in Fig. 2.

In the case of flooding, the algorithm of the modelling process utilizing the methodology involves the listed methods on each step.

After the collecting of the field data and the processing of the investigations, the need to use the ArcGIS programming algorithm became evident. The ArcGIS programming software is more convenient than the formerly developed MapInfo, QGIS, and MapPlot programs, etc., in our case. To run the ArcGIS program (see Fig. 2), we start with the drawing of a geometric object in a river analysis system (RAS). Geology and geochemical data refer to the water influents by pollution of chemical elements that spread in the delaminated by satellite data for specific water streams and also for the simulating utilizing the ArcGIS program. Based on the last information, the RAS file is created for the specific water flows under investigation. Thus the next step (see Fig. 2) is running the HEC-RAS program software. Then the question arises of whether necessary cross-sections are used for the flood predicted by the model? If the data are not sufficient for the interpretation, additional cross-sections are chosen utilizing the interactive approach. This is shown in the algorithm methodology with step «No» (see Fig. 2). If the data give the possibility of future flooding, a RAS GIS export file is created. The process is prolonged by executing the RAS mapping possibilities of the ArcGIS file. If the flood simulation is corrected, we go further; if not, we go again to run HEC-RAS and repeat previous formulated steps to achieve sufficient iterative results. Compared with the existing mapping information in the next step experts use the solution decision. The map detailing is taken into account to finish the step. If not, we re-execute the step. If enough cross-sections are taken for the interpretation with no negative answer, we move to the next step, where the RAS object's geometry is given. Otherwise, if «Yes», we go to the step of detailed geological-geophysical flood analysis. The alone branch of the algorithm consents to the reduction of grid cell size, which is done by the RAS geometry algorithm. Then the process of execution in RAS geometry mapping is fulfilled again in the flood simulation step. Finally, the completion of the study is indicated by obtaining the seek algorithm for the region investigated.

This shows the modelling methodology algorithm and its execution.

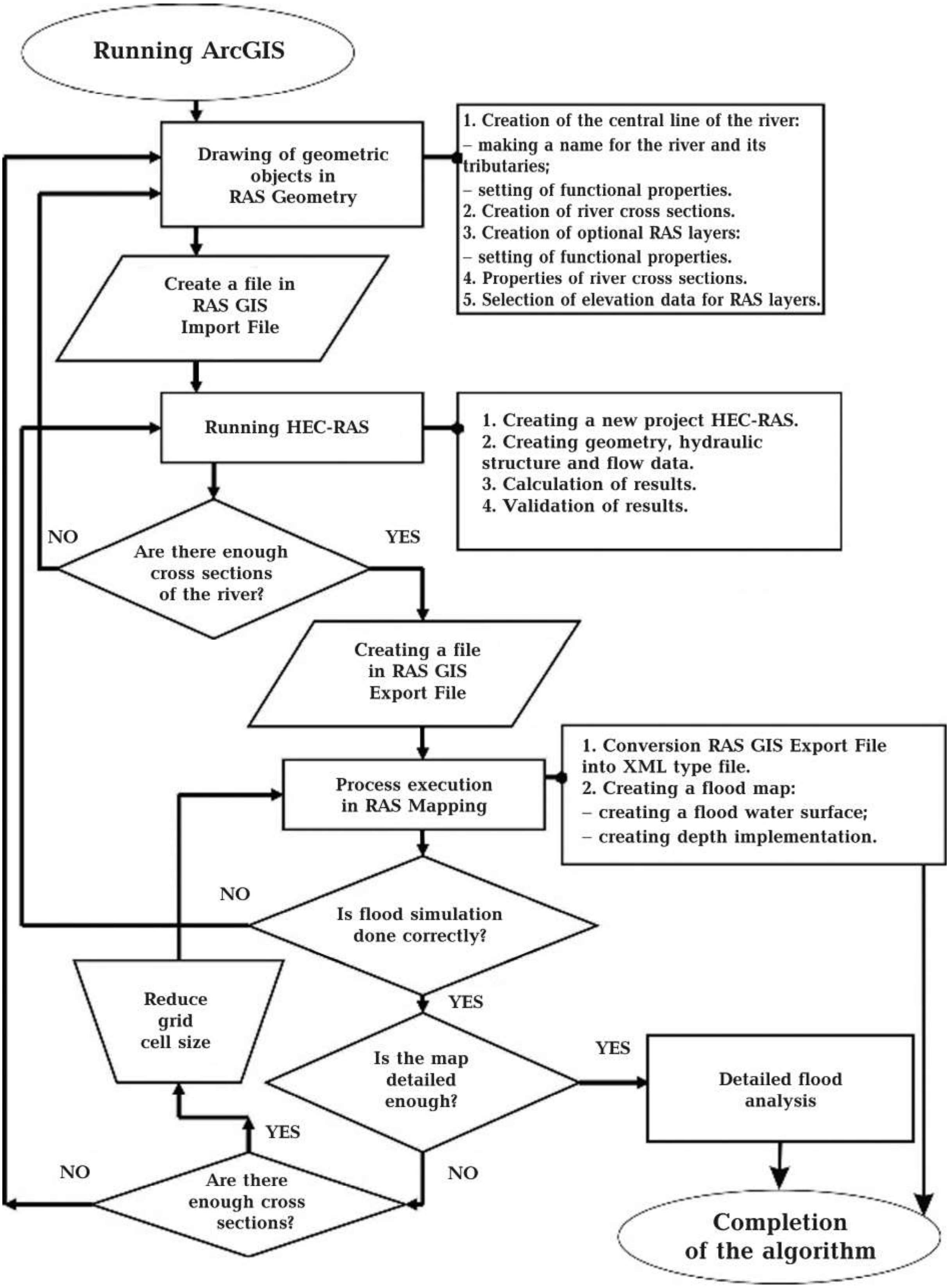

Fig. 2. Algorithm of the modelling process of catchment areas of potentially flooded contaminated areas, usage of HEC-GeoRAS and HEC-RAS software (authors Yuriy Starodub, Andrii Havrys).

Research results. The scope of the research aggregates collected by the authors and existing geological, geophysical, and chemical data for the dangerously affected areas and the results of the GIS exploration on the river flooding of the selected regions in Pre-Carpathians including small tributaries seen on the GIS modelled maps example.

The first step is defining the areas of interest. They are the following:

Sources of man-made influences. The most dangerous sources of technogenic influences on the territory of research are objects of oil and gas extraction, ozokerite mining, salt extraction, sulfur production, oil refining and oil and gas transportation industries. Somewhat smaller, but significant enough impact on the state of ecology and civil protection make objects of agriculture and processing industry, automotive and railways residential objects.

Oil and gas industry. The research area is confined to a number of oil and gas deposits of the Carpathian oil and gas region of the Carpathian oil and gas province. The Pre-Carpathian oil and gas region is divided into the Bilche-Volytsky oil and gas geological region (OGR), the oil and gas region of the Carpathian autochthon platform, the Boryslav-Pokutsky OGR, and the Sambir perspective area, where oil deposits dominate. In the Bilche-Volytsky OGR, there are mostly gas deposits, and in the Boryslav-Pokutsky OGR, the oil deposits (see Fig. 1).

The concentration of large (more than 100) hydrocarbon deposits within the Pre-Carpathian deflection facilitated the development of oil refining, and oil and gas transportation infrastructure. It should be noted that often complex drilling conditions within the research area required the use in the formation of drilling fluids such substances harmful to an environment as oil, carboxylmethylcellulose, concentrated sulfide alcohol, and others like that. In the course of wells drilling, oil sludge and reservoir water were raised to the surface. In the last century, there was a practice of building wells using temporary technological capacities of «barns», in which, after the completion of drilling operations, coal mining waste was often buried. This could not but affect the violation of the environmental safety of the region and lead to an increased risk of emergencies. The impact of drilling oil wells on ecological safety and emergencies is discussed in detail in the papers [Karabyn et al., 2019]. The most threatening influences are pollution of soils, surface and underground waters with hydrocarbon compounds and phenols. The consequences for people and the environment in case of flooding of drilling rigs, sites of operational wells, forbidden waste of oil production, etc., can be especially dangerous.

Extraction of ozocerite was concentrated in the Boryslav field. Because of the deposit exploitation on more than 20 hectares, there is located about 300 m^3 of waste. Sedimentation is not currently in use. Because mining operations were not conserved and the territory of the enterprise was not recultivated, from the territory of the deposit in excessive quantities, organic substances are supplied to the tributary of the Tysmenytsa River. From the territory of the deposit, there is a threat of contamination metals (Sr, Mn, V, Zn, Cr, Ni, Pb) [Tsaitler et al., 2010]. The ozocerite deposit is an extremely dangerous object in case of flooding on the territory.

The salt-mining industry was concentrated in the Carpathian region in Stara Sil, Sambir district, Lviv region, village Solotvyno of the Transcarpathian region, and on the territory of Boryslav-Pokutsky cover, Stebnyk and Kalush-Golin deposits of potassium salts. On the territory of the Solotvyno deposit of rock salt do to the severe floods of 1998 and 2001, processes of erosion and further subsidence of soils over salt mines intensified. On the place of sediment, salty lakes are formed by a large concentration of salt, which is absorbed into underground water and negatively affects soil fertility. On the territory of the Solotvyno deposit in the immediate vicinity of the mines, there is the Tysa River, which, as a result of approaching the industrial area, may be contaminated with ammoniacal nitrogen, nitrate, phosphorus orthophosphates, potassium nitrate, and calcium sulfate, which may lead to a state transboundary environmental disaster [National …, 2022].

Sulfur industry. In the Carpathian region, the mining and chemical industry includes Rozdil production association «Sirka», Kalush production association «Chlorvinil», and Stebnyk potash plant. Today, in the technogrades of the Pre-Carpathian sulfur deposits, the content of investigated chemical elements, except Mn and S, is at the level of Clark (averaged content) values for soils and clays [Vinogradov, 1962]. The highest concentrations of sulfur were found in insignificant areas (tailing ponds of flotation), where the sulfur ore was enriched by the underground melting of sulfur.

Potentially hazardous objects (PHO). The main part of the industrial potential of the Ivano-Frankivsk region is concentrated in the foothill zone (its central part), in the towns Kalush, Nadvirna, and Dolyna.

There are many refineries in the Drohobych district of the Lviv region, one of which is the refinery complex «Halychyna», with a capacity of almost 3.5 million tons of crude oil per year.

The danger of these objects flooding is the following: rising water levels in the rivers and flooding of territories take place, emergency of stopping of the dangerous technological processes is possible. This in turn can lead to an accident at the enterprises and create catastrophic situations.

Simulation of the emergency due to flooding. Various natural and artificial factors that cause the floods of the Pre-Carpathian rivers and adjacent territories are considered in the works.

For HEC-GeoRAS and HEC-RAS programs, the required calculation data are specified, and the required cross-sections of a river for further calculations are filtered. The initial flow parameters, which are experimentally determined or taken from standard fluid flow conditions, are then specified and the predicted flooded areas are being selected.

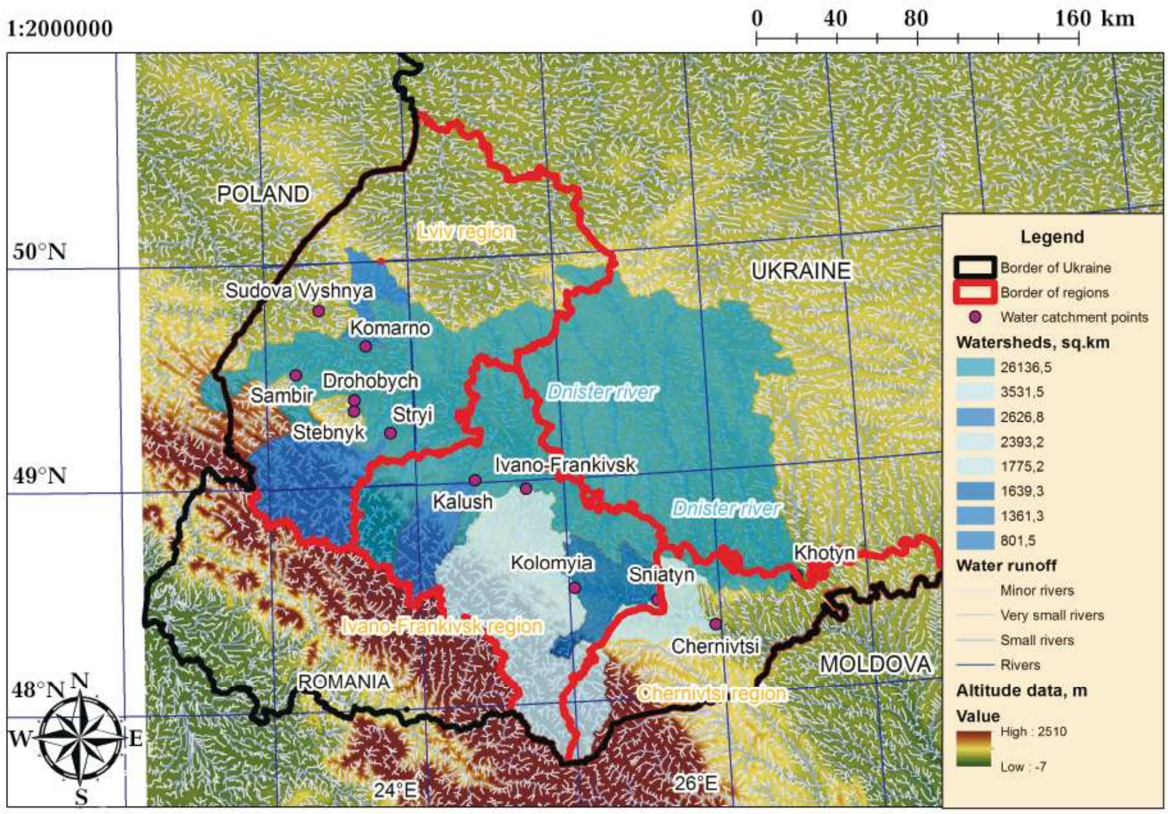

Fig. 3. Modeling of catchment areas for the potentially ecologically polluted territories of the Pre-Carpathian region to the East from the Carpathian arc, Western Ukraine. Watershed blue colors on the map separate areas of floodings (authors Yuriy Starodub, Vasyl Karabyn, Andrii Havrys).

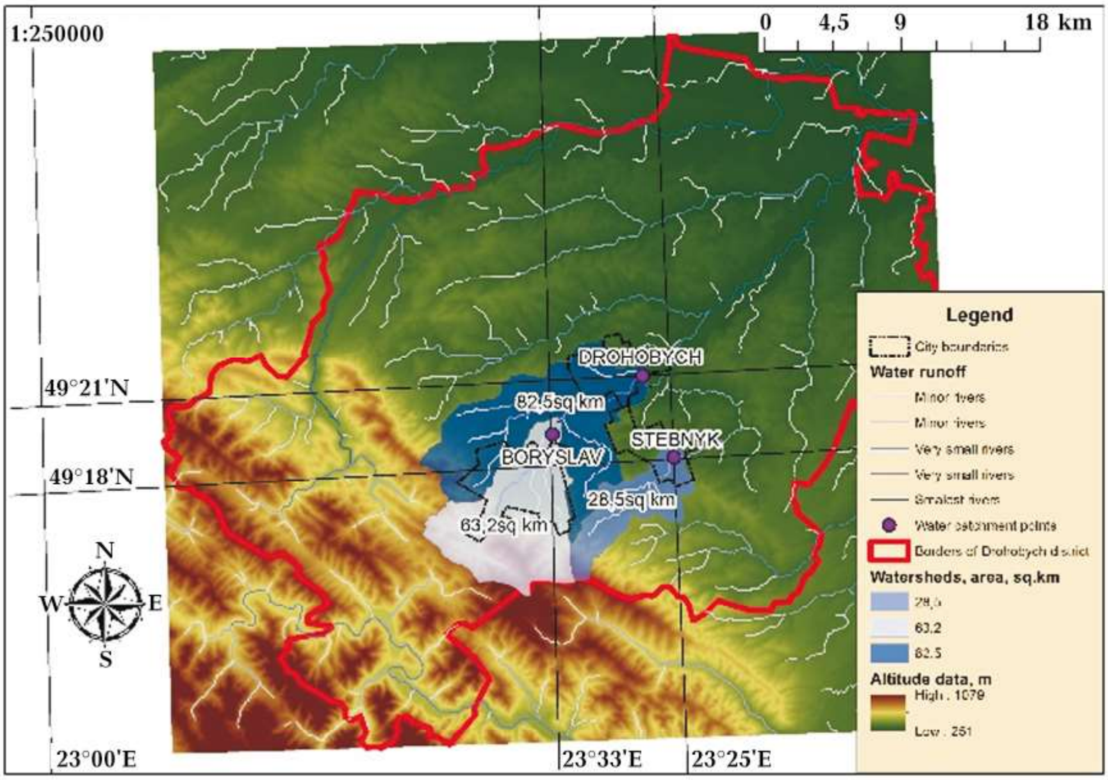

Fig. 4. Flooding model of the part of the territory of the Pre-Carpathian region, Lviv oblast — the regions of the towns Stebnyk, Boryslav, Drohobych (authors Yuriy Starodub, Vasyl Karabyn, Andrii Havrys).

Historical water elevation levels in these regions occur according to the Ukrainian Hydrometeorological Center, namely data from automatic hydrological stations.Input data in the studied region are as follows: at the post «Stryi (GIS) — Stryi» on 11.07.2017, the water level rose to a height of 1101 cm, and on 15.07.2016 at the post of Zalishchyky — Dnister, the automated hydrological station showed the water level of 1286 cm.

Watershed modeling tools were developed to model water catchment basins, which speeds up the task. The script (written in PYTHON language) is used to prepare the runoff analysis of the relief situation, the surface water state, and the creation of catchment areas of the selected territories. The amorphous property of water is used in the program ArcGIS/Model Builder. ArcGIS is used for the functions «Laundering», the determination of «Direction of runoff», «Stock accumulation», the tool of cutting of the digital model of relief on the allocated territory «Map Algebra» and creation of «Ranks of runoff» based on the functions used. Application codes save the source folders of newly created data [Starodub et al., 2019].

The following script (on PYTHON) is intended to create catchment points and beyond these points to create endangered catchment areas of the territory, with subsequent determination of the area of possible catchments and their ranking by size [Starodub et al., 2019]. The script contains Mouth Point Snap-in features, and the inputs are the results of runoff rank modeling when executing the first script. Next, the Raster to Points function is created, along with mouth points and possible catchments, which is the end result of this script execution.

The processing and interpretation of the results are as follows: the centerline of a river in a threatened area is applied, right and left river banks and, respectively, the axial line of the water stream are composited, then cross-sections of the river are applied. Before exporting the elaborated map into the HEC-RAS package, the correct application of all river cross-sections is interactively checked. Each of the cross-sections should be applied strictly perpendicularly to the river's central line and take into account their number and resolution of the map of the endangered area for the proper functioning of the terrain cover software.

The key element is that all four components of (the centerline of a river, right and left river banks) cross-sections use common geometric data and hydrological calculations of the routines used.

Next, the algorithm works as follows: after the estimations are carried out, the result is checked for geophysical correctness, which results in creating an output file (RAS GIS Export File). The result is imported into ArcGIS, where it is converted to an XML file using HEC-GeoRAS software. When opening the created file, a flooding map pre-generated by HEC-RAS, it is displayed along with a display of the flooding depths.

Due to the possible flooding of the territory of the Drohobych district of the Lviv region, catchment basins with the respective areas are formed, respectively: for Drohobych — 107.8 km^2, for Boryslav — 37.3 km^2, for the town Stebnyk — 28.6 km^2 (Fig. 3).

In the flood areas, there are many mining and chemical enterprises in Boryslav, Stebnyk, and Drohobych. The highest water levels in the watershed basins occur in Stebnyk and Drohobych potassium and salt deposits, marked by the darkest color. Plots of contouring the flood areas capture some small rivers on the map, which may be influenced by technological pollution and salt emissions of potassium salts in the area of Stebnyk and Drohobych. This aspect needs to be considered by flow of water from the catchment areas into the Dniester and the Black Sea Basin.

In Fig. 3 and 4, the Carpathian range is marked in brown on the geoinformation map with delaying water spills and catchment areas of the regions of possible flooding. Carpathian Range, in turn, is a watershed through the Carpathians and ensures the preservation of clean water resources in the southwest of the Carpathian region (see Fig. 3). The ecological status of the waters of small rivers shown in the scheme is important because they provide drinking water reservoirs to the region. A simulation of flooding in the area covering the Lviv, Ivano-Frankivsk, and Chernivtsi regions was carried out (see Fig. 3). The map presents the three major catchment areas along the Dniester River. These areas are sensitive to hazardous substances: mineral fertilizers and metallic magnesium.

In the direction of the river Dniester on the map (see Fig. 3), we see important small towns of the Carpathian region (Sudova Vyshnya, Sambir, Komarno in the West, and the abovementioned district of Drohobych). SE of the Lviv region, there are a lot of possible small floods of local rivers in the Ivano-Frankivsk region. Along the Dniester River, there are Kalush, Kolomyia, and Sniatyn, important for industrial and recreational considerations. On the Dniester to the East, in the Chernivtsi region, we meet the regional center Chernivtsi and the well-known tourist attraction Khotyn. In general, the water flows east, away from Poland, and from Romania, they are separated by the Carpathian Mountains. Dniester runs along the Moldova border. Due to the high level of water that is modelled in the district of Kalush, where one-third of industrial production in the Ivano-Frankivsk region is made, including mineral fertilizers, metallic magnesium, and polyethylene. There is a high threat of water source pollution all over Western Ukraine and additional research and strengthening of the riverbanks are necessary.

Fig. 4 shows the simulation results for some territories under the flooding of certain regions — the Carpathians, the Lviv region.

The highlands on the map are marked in brown; the lowlands outside the Carpathian arch are green. The scale is 2.25 km in one centimeter.

The situation with flooding of industrial-hazardous regions of the cities of Boryslav, Stebnyk, and Drohobych in the Drohobych district of the Lviv region was simulated. The study area is associated with the formation of catchment basins in the case of Boryslav oil field and Stebnyk and Kalush deposits of potassium salts. In figure 4, small rivers are classified according to the EU water framework directive [The EU Water …, 2012]: minor rivers — catchment area of 6.5 km^2; smallest rivers — 63.2 km^2; and very small ones — 82.5 km^2.

The approach allows planning detailed follow-up studies. In each case, it is necessary to conduct detailed field and cameral geophysical, geochemical studies in selected regions of the catchment areas of the Carpathian region in order to ensure a good and excellent ecological status of waters in the Carpathian region and the safety of the investigated territory in the event of a risk of possible flooding.

Conclusion. There should be carried out integrated geophysical and geochemical research of the hydrosphere in the industrial, recreational, and strategically important region of the Pre-Carpathians where intense natural and man-made factors can lead to a sharp deterioration of the environmental safety, and emergencies.

The novelty of the current study is that the methodology was developed by combining field experiments and theoretical modeling, comparitive analysis and synthesis of the results. The proposed method of the result's common interpretation also indicates the scientific novelty of the work.

The theoretical value of the work is the development of geoinformation technology. The method elaborated allows the complex geophysical and geochemical investigations in the management of ecological and geophysical protection of territories in order to reduce the risks of regional emergencies.

The provisions and conclusions of the work can be basis for applied research in the fields of ecology and geophysics and contribute to the improvement of the environmental situation in the region with the use of geological, chemical, and satellite data.

The practical significance of the obtained results lies in the method proposed by the authors of the complex regional forecast of floods on territories and ecological-geochemical changes, and the risk of emergencies caused by flooding. The results of the testing of the methodology on the territory of the Pre-Carpathian region can serve as the scientific basis for the practical interpretation of the results using geoinformation technologies' development and civil protection measures for investigating possible flooding of regions.

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Геофізичні дослідження обстановки Передкарпатської гідросфери для цілей цивільного захисту навколишнього середовища

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Об'єктом дослідження є розробка та вивчення методології дослідження екологічних регіональних змін Передкарпатської гідролітосфери в аварійному стані, спричиненому повенями. Метод досягнення мети передбачає отримання результатів шляхом інтеграції експериментальних, польових і теоретичних модельних досліджень, камерного наукового порівняння, аналізу та синтезу досягнення результатів. Дослідженою моделлю є затоплення в Карпатському регіоні на схід від Карпатської дуги в Україні, затоплення частин Передкарпаття Львівської області — важливих у промислово-рекреаційних регіонах: містах Стебник, Борислав та Дрогобич. Наукова новизна статті спрямована на розробку наукової методики комплексного підходу до вивчення території у питанні підтоплення через єдину інтерпретацію геофізичних, геологічних та хімічних даних при розгляді стратегічно важливого Передкарпатського регіону. Теоретичне та практичне значення отриманих результатів полягає в обґрунтуванні доцільності та можливості комплексного використання геофізичних, геологічних та хімічних даних у задачах практичної інтерпретації результатів із застосуванням геоінформаційних технологій. Результати роботи будуть використані в прикладних дослідженнях у галузі геофізики та екології та сприятимуть поліпшенню екологічної ситуації в окремих регіонах. Отримані результати сприяють розвитку геоінформаційних технологій у завданнях комплексних геофізико-геологічних та хімічних досліджень стосовно управління екологічною безпекою територій у разі надзвичайних ситуацій.

Ключові слова: розробка, дослідження, методологія, геофізика, екологія, надзвичайна ситуація, підтоплення.