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GEOLOGICAL AND ECONOMIC RISK ASSESSMENT FOR TERRITORIES OF HAZARDOUS GEOLOGICAL AND TECHNOGENIC PROCESSES (EXEMPLIFIED BY SOLOTVYNO TOWNSHIP)

Purpose. Assessing the risks of economic and social losses caused by the activization of hazardous natural geological and technogenic processes to establish the hazards of living in post-mining areas, with a view to developing strategies for their amelioration.

Methodology. Field observations were carried out to determine the state of the geological environment of the territory and individual engineering objects. The assessment of the territory stability was done relying on the mechanical and mathematical basics of engineering geology in conjunction with the approaches of system analysis and the theory of engineering and geological similarity. Methods of probability theory and mathematical statistics were used for the expert assessment and risk analysis. Cartographic materials were compiled using GIS and digital simulation methods implemented on the example of Solotvyno township. As the source material, the GIS database (geological, engineering-geological, hydrogeological, and so on), compiled at the Institute of Geological Sciences of the National Academy of Sciences of Ukraine for the territory of Solotvyno, was used alongside with the works assessing the occurrence of natural as well as man-induced processes.

Findings. It has been established that the most dangerous geological and technogenic hazards on the territory examined are karst-suffusion processes, whose probability in the central part of the territory is 1. At the object level, the economic risk ($4.35 \times \times 10^{-3}$ thousand UAH/$m^2 \cdot$ year) has been estimated, which shows the need for protective engineering measures due to an individual risk ($5.86 \cdot 10^{-4}$ people/person year). This is a significant value as compared with the average one for the territory of Ukraine. Integrated and differentiated economic risks have been calculated for the territory of Solotvyno, with the distribution of risks visualized on schematic maps.

Originality. The scheme for assessing the risk of hazardous geological and technogenic processes on the post-mining territory has been developed. The combined use of differentiated and integrated assessments of economic risks at the locality and object levels would optimize managerial decisions on protection against geological hazards and would permit the development of a high-quality system for settlement monitoring.

Practical value. The implementation of the S&T results obtained will enhance the efficiency of the monitoring and engineering protection systems developed for the territories with the possible occurrence of major emergencies.

Keywords: *karst-suffusion processes, landslides, post-mining territory, probability, risk*

Introduction. The following exogenous geological processes have been identified on the territory of Solotvyno township (Zakarpatska Oblast): karst-suffusion phenomena, ground surface deformations (collapses/man-induced sinkholes, subsidence, landslides), subsoil water logging; the hazards of seasonal floods and flash floods also exist.

Rock salt mining, territory undermining (the presence of abandoned mining and underground drainage workings), flooded salt mines cause the instability of the township's geologic environment, which is assessed as prone to high natural and technogenic hazards. Under the combination of geological and technogenic factors, the activization of hazardous geological processes (HGP) induces the risks of environmental consequences, material losses, and also endangers human lives.

Solotvyno township can exemplify post-mining territories, where such technogenic factors as salt mining, territory underworking (the presence of abandoned mines and drainage underground workings), flooded salt mines alongside with natural factors (floods, steep slopes, the presence of karstable rocks, extreme weather events) create risks of both material and human losses.

Since 2010 the emergency situation in Solotvyno township has grown to that of the national scale. Besides, ground surface deformations, irreversible landscape disturbances and degradation resulting from the uncontrolled karst development, the hazard of surface and ground water pollution give the neighboring countries certain reasons for concern about the risks of transboundary deterioration of the environmental characteristics of the Tisza River water body, in particular, on the background general climate change. Residents' safety, wealth preservation and further development of the township territory must be based on the strategy of reducing natural and technogenic hazards. The elaboration of such strategy for the region in question and relevant managerial decision-making are possible with reliance on the risk analysis of respective emergencies, the assessment of economic and social risks which would be based on comprehensive geological monitoring.

Literature review. The review of scientific publication shows that several approaches to risk assessment have been developed. In general, risk is understood as the danger of possible future losses or the danger of adverse consequences of an event, identifying the risk with the danger, a dangerous process [1].

Other authors consider risk as the possibility or probability of a dangerous event or process. The most commonly used concept is that of the risk as a probable measure of danger determined for a single object as possible losses over a certain period [2, 3].

The experience of developing national programs of risk management and counteracting emergencies in European countries shows that the analysis and comparison of a wide range of hazards with potential consequences should be made at the levels from the national to the object ones, including the concepts of multi-risk (the integrated value), the cascade-like development of hazardous processes and risk matrices [4, 5].

Purpose. The purpose of the research is to assess the risks of economic and social losses on the territory of Solotvyno township due to the activization of hazardous geological processes, with a view to determining the risk of living in the vicinity of the salt mine and elaborating the strategy of the territory amelioration.

The principal tasks of the research were: to identify the main HGPs on the territory examined; to provide the expert assessment of geological hazards caused by the development of karst-suffusion processes, subsidence, landslide development and flooding, with determining their probability; to assess possible economic and social losses (risks) over a 50-year period, which can occur due to the damage inflicted to the territory both by differentiated geological hazards (single-risks) and by the entire complex of the hazards identified (multi-risk); to provide the cartographic zoning of the Solotvyno township territory according to the level of economic risk.

Materials and methods. The study relies on the GIS-integrated database (covering geological, geological-engineering, hydrogeological and other information), which was compiled at the Institute of Geological Sciences of the NAS of Ukraine for the territory of Solotvyno township and the assessments of the occurrences of natural and natural-and-technologic processes [6].

In particular, it uses the results of identifying the principal hazardous natural and natural-technogenic processes within Solotvyno township, their description, parametrization, the space-time patterns of their distribution, territory zoning, geological maps of various scales, the data of the public cadastre map of Ukraine [7], the data of engineering geological explorations conducted in various periods, as well as historical and archival documents.

To determine the state of geological environment of the territory and individual engineering objects, field observations (sampling, measuring the level of ground waters, photofixation, population survey) were conducted [6].

Mechanical and mathematical foundations of engineering geology in conjunction with the approaches of system analysis and the theory of engineering geological similarity were used in the research.

In performing expert assessment and risk analysis, the methods of probability theory and mathematical statistics were employed.

In producing graphic materials, statistical and cartographic methods relying on geoinformation technologies and digital simulation were used.

Methodology of risk assessment. In this study, the risk is understood as the aggregate measure of the probability of HGPs and the losses due to their occurrence, which can have adverse impacts on people, buildings, objects of critical infrastructure and environment over a certain period of time, causing emergencies.

Hence, the risk assessment consists in identifying geological dangers (hazards) – HGPs and analyzing their possible consequences.

According to the scale of emergency consequences, the risk analysis for a settlement is to be performed at the locality and objects levels [8].

At the locality level of the assessment, the economic risks for the whole territory of Solotvyno township are determined – both integrated and differential ones.

Since the consequences could be the damage to or destruction of buildings, emergencies at infrastructure objects, as well as the deaths of or injuries to people, we separate the economic and social risks. Accordingly, at the object level of assessment (an individual building) those are the specific economic risk for the building and the individual risk for a representative of a certain population group (those who live in the building).

The risk has been quantified by the expression

$$R(H) = \{P(H),\ E(H),\ V(H),\ D\}, \qquad (1)$$

where $P(H)$ is the statistical probability of *HGP* occurrence (Hazard); $E(H)$ is the probability (geometric one – in space) of the occurrence (Exposure); $V(H)$ is vulnerability – the probability of the losses (economic or social) resulting from the vulnerability; D is the cost of tangible assets or the number of inhabitants.

The parameters involved in the formula are complex functions of multiple variables.

Depending on the risk type (economic or social), the parameters of (1) would have different dimensions and be calculated using different procedures.

Before calculating the risks for the post-mining territory of the township, a significant amount of input information was collected, which was analyzed and structured in the database.

Conditionally, it was divided into the natural and the technogenic units (Fig. 1).

The data of the natural unit are initial for HGP identification; relying on them the values of natural hazards have been obtained ($P(H)$ parameter).

Here, the main role belongs to geological data: structural and tectonic conditions, lithological composition, rock thickness, hydrogeological characteristics of the territory, and so on [9, 10].

The information concerning the territory seismicity, geodynamic activity has been obtained according to the results of respective geophysical and remote investigations and/or morphometric analysis, the geophysical model is specified and is tied to engineering geological conditions.

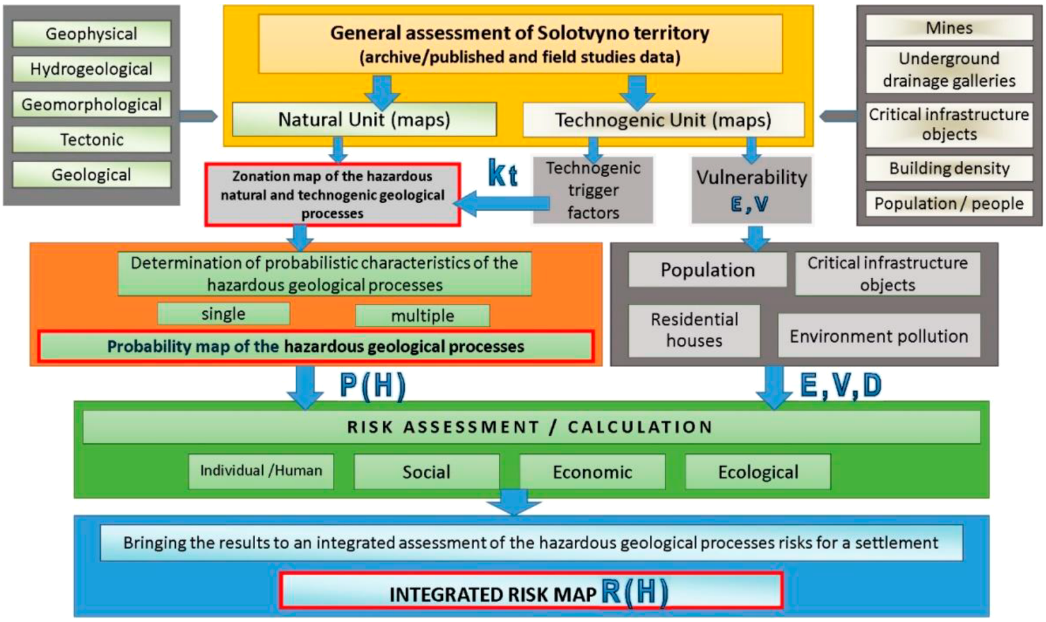


Fig. 1. The flowchart of assessing risks for a township

In determining the probability of some HGPs, the technogenic unit data on industrial objects are also used, in particular, those characterizing the underground space development and able to trigger the activation of natural hazards [11].

The technogenic unit data are used to determine $E(H)$, $V(H)$, D parameters, which characterize the vulnerability of the objects assessed (residential buildings, critical infrastructure, population) to some or other geological hazards.

When assessing the risks due to HGPs and building cartographic models, the geoinformation approach is used, which envisages the creation of database in the geoinformation system [12, 13].

The main purpose of its creation for Solotvyno township (as well as for other settlements) is to provide the most effective use of the information from the natural and technogenic units with reliance on the object-related data model.

The objects of risk analysis that are kept in the database are a part of the physical model. They also have their description in the logical data model, which permits not merely the support of geometrical connectivity of the objects but their connectivity at the object level as well.

The spatial information (the vector data that graphically describe the area in the map) is combined with the attributive one and is saved as files of various extensions.

Since the research object is the geological environment of a settlement, which is a complex dynamic system, the determination of risks is related to the presence of some uncertainties (temporal, structural, and metric ones). Temporal ones result in the uncertainty of the geological environment state in the future. Structural uncertainties are related to the complexity of geological structure. Metrical uncertainties are formed due to the lack of precision during field or laboratory measurements.

To reduce the impact of those uncertainties in the investigations, probabilistic methods were used in combination with the methods of the worst and the best scenarios in performing the expert assessment [6].

Results. ***Identification of hazardous geological processes and their expert assessment.*** HGP identification – the detection of geological hazards on the territory examined, which could cause risks in the case of their realization – is the initial stage of analyzing the risks.

It relies on the assessment of statistical data concerning hazardous natural and technogenic processes and phenomena, as well as the mechanisms of the possible impacts of their negative factors on people, buildings and facilities.

Among the methodological approaches to the HGP analysis and prediction, our investigation employed the expert approach that determined the probability of geological hazards by surveying experienced experts.

The results of surveying local inhabitants were taken into account indirectly. The data of the natural unit were used (Fig. 1).

The experts chosen were asked to answer a number of questions about the state of the geological environment, its possible changes and HGP activization (by which the HGP probability was quantified), in particular, by taking into account the abovementioned uncertainties and, on the other hand, possible impacts on infrastructure objects, people (scenarios of developments under geological hazards occurrence).

Geological hazards on the territory of Solotvyno township were characterized by main parameters that show the degree of the space-time danger of the processes, namely, the intensity and activity of their occurrence, their strength and rate.

The intensity was determined by the vulnerability coefficient, which shows the ratio of the area, length, the number of all forms of the process occurrence (irrespective of age) to the whole area of the site. The activity is expressed by the ratio of the active forms of a particular process on the site in question to the total number of those forms. The strength is determined by the dimensions of the process manifestation forms, most frequently those are their areas and volumes.

The patterns of natural and natural-and-technogenic processes occurred on the territory of Solotvyno township were described in detail in [10, 11].

Karst and karst-suffusion processes are observed across the entire part of the township that is situated over the core of the salt dome structure.

They occur most frequently in the central part of the territory examined (with the area of 2.05 km^2) and are directly related to the technogenic activities.

According to archival data, up to 150 karst occurrences of various scales have been recorded over the past 100 years.

The area of karst sinkholes was 3–155 m^2, with the average value of 6 m^2.

The areas of collapses are estimated in thousands of square meters: over the underground workings of mine No. 7 those are over 40,000 m^2, and over the developments of mine No. 8 they amount to 50,000 m^2 [6].

Karst formation processes are active in the vicinity of mines No. 7–9, within the western flank of mine No. 8 field and along the bed of the Hlod stream [6, 10].

According to expert analysis, the probability of karst occurrences on such sites is determined as 1.

Within the first floodplain terrace, in the central part of the salt deposit, the elevated area of salt-bearing clay occurrence is clearly distinguished.

In contrast to other parts of the deposit, this flat elevation (of absolute altitudes 294.37–295.5 m) with gradual slopes (0.2–3°) was not exposed to active surface karst.

The electrical substation of Solotvyno township, water utility facilities (water tower and wells), recreational buildings and residential houses of the total area 146,845 m^2 (5 % of the zone area) with high probability are situated in the zone affected by the development of karst processes.

On the sites with the probability of karst process occurrence of 0.1–0.5, the total area of buildings is 161,331 m^2 (7 % of the total area of such sites).

Active *landslides* are absent, small local mass movements of the areas 3,750–7,500 m^2 are recorded [6, 14]. Slopes take 25 % of the territory and consist of the *1st* and *2nd* floodplain terraces of the Tisza River (the probability of landslide occurrence on some sites is 0.2–0.3) and the southern slope of Mahura mountain (landslide probability is 0.1–0.15).

Subsoil waterlogging of Solotvyno territory is the result of unfavorable hydrogeological conditions and their deterioration over several decades of rock salt mining [6, 14].

The probability of *flood* was evaluated at the highest levels from 1 to 0.8 on the floodplain sites, the first and the second Tisza floodplain terraces and along the Hlod stream; the sites of local ground backwater, central flat sites and those of insignificant inclination have the probability values 0.3–0.6; that of the sloping part of the *2nd* floodplain terrace is 0.3.

Within sites with high probability of flooding, critical infrastructure objects are situated: railway, a sector of the H09 national highway, a sewage treatment plant.

Submergence during seasonal floods and flash floods. The highest probabilities of submergence were determined for the areas of the floodplain and the first floodplain terrace of the Tisza River – 0.5–0.75.

With reliance on the analysis of archive data and expert assessment, the second floodplain terrace is referred to sites with the probability of submergence equal to 0.03.

But, despite this low value, the presence of residential buildings in the southern and southeastern parts of the township territory increases the value of possible economic risk.

Subsidence. Cases of uneven subsidence and elevation are most common in the central part of the branch workings of salt mines and are caused by technogenic activities.

The recorded vertical deformations are in the range of 17–258 mm. In terms of process rate, three local zones of subsidence were distinguished over mine No. 8, with the average rate of 10–20 mm/year and that with the average rate 5–10 mm/year on the recreational territory on the site of old flooded mines [10, 14].

The probability of subsidence occurrence within those sites amounts to 0.5–1.0, that within the flooding zone near transport routes is 0.25–0.5.

The expert assessment performed took into account the indirect impact of technological activities in Solotvyno township on the intensity and probability of HGP activization (coefficient k_t, Fig. 1).

The underworking of the settlement territory with mine developments significantly increases the probability of damage (E) inflicted by geological hazards.

According to the expert assessment of natural and technogenic geological hazards, the entire territory was broken down into sites.

For each of them, the temporal probability of the specific geological hazard occurrence was established in the database compiled (Fig. 2).

Object level of assessing specific economic and individual risks. The assessment of karst collapse hazard (differentiated risk) was performed for a 5-storey panel frame house that, according to Fig. 2, is situated in zone 1.

The area of the building is 867.1 m^2, the area of the strip foundation is 203.4 m^2.

Karst sinkholes occurrence in this zone has the highest probability, but they all are of different sizes, therefore the calculations were carried out for the average (52.8 m^2) and the largest (95 m^2) sinkhole areas.

These values were taken into account in determining the building vulnerability $V_b(H)$. The medium and the maximum risks were calculated by the formula

$$R_b(H) = P(H) \cdot E_S(H) \cdot V_b(H) \cdot D_b.$$

P(H) is the space-time probability of karst sinkhole occurrence in time (100 years), which corresponds to the many-year average intensity of karst sinkhole formation for zone 1 over the past 100 years (Fig. 2).

$E_S(H)$ is the probability (geometrical) of damaging a building by a karst collapse.

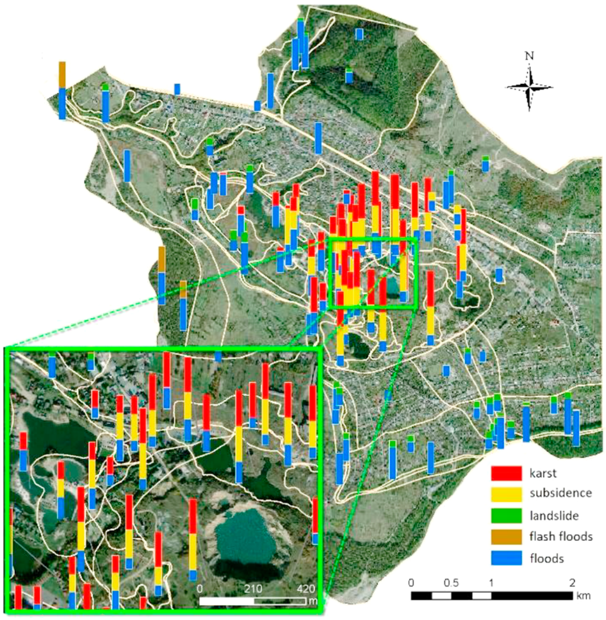


Fig. 2. Bar chart of the probability of emerging the main hazardous geological processes on Solotvyno township territory

This value characterizes the insecurity of an object when the geological hazard is realized; it is calculated by the formula

$$E_S(H) = S_b/S_Z,$$

where S_b is the area of the building, km^2; S_Z is the area of the whole zone 1, km^2.

$V_b(H)$ is vulnerability; the probability (economic) of the damage to building due to karst sinkhole formation was determined by the ratio of the sinkhole area to the area of building foundations, for the average and maximum sinkhole areas, respectively, in zone 1, according to appendix 6 of Guidelines [2].

The vulnerability value could be established by historical data, using the method of analogies for a similar building and HGP intensity.

D_b is the building value before the damage, UAH million.

The medium and maximum risks of the economic damage to the building (UAH/year) from karst sinkholes occurrence are

$$R_{bmid}(H) = 1 \cdot 304.25 \cdot 10^{-6} \cdot 0.35 \cdot 19.08 \cdot 10^{6} = 1976.9;$$

$$R_{bmax}(H) = 1 \cdot 304.25 \cdot 10^{-6} \cdot 0.65 \cdot 19.08 \cdot 10^{6} = 3773.31.$$

Taking into account the area of the building, the specific risks UAH thousand/m^2 · year) will be

$$R'_{bmid}(H) = 1976.9/867.1 = 2.28 \cdot 10^{-4};$$

$$R'_{bmax}(H) = 3773.31/867.1 = 4.35 \cdot 10^{-3}.$$

The analysis of the values obtained shows that specific risks are 2–5 times higher than the maximum permissible ones [15].

The calculated value of the economic (medium and maximum) risk is in the range $5 \cdot 10^{-6}$–$5 \cdot 10^{-5}$; according to the recommendations of the norms [16], the building requires that a system of measures be implemented to reduce it.

The risk of economic losses due to the damage to the building as a result of forming a karst sinkhole of the maximum area in zone 1 over 50 years is 0.98 % of the building value, which can be explained by an insignificant probability of the damage $E_s(H)$ to the house caused by the sinkhole – 0.000304, and by its being situated on the periphery of zone 1, but provided there are no sinkholes beneath the building itself at the moment.

The social risk of the loss of people living in the house due to karst sinkhole occurrence is

$$R_s(H) = P(H) \cdot V_S(H) \cdot D_p,$$

where $R_i(H)$ is the individual risk of dying for people who live in the house

$$R_i(H) = P(H) \cdot V_S(H),$$

where $V_S(H)$ is the social vulnerability of inhabitants in the house, depending on the economic vulnerability of the house $V_b(H)$, the social vulnerability of people in the building in time $V_{ST}(H)$ and the social vulnerability in space $V_{SS}(H)$ – the probability of death in the building when a karst collapse occurs

$$V_S(H) = V_b(H) \cdot V_{ST}(H) \cdot V_{SS}(H),$$

where D_p is the total number of people living in the building – 180.

Individual risks (pers./pers. per year) for house inhabitants when medium and maximum karst sinkholes occur beneath it are

$$R_{imid}(H) = 0.973 \cdot 0.000627 = 5.86 \cdot 10^{-4};$$

$$R_{imax}(H) = 1 \cdot 0.172 = 0.17.$$

The individual risk of human death in the building, considered as the result of a karst sinkhole formation beneath it, even that of an average diameter, is significant: $5.86 \cdot 10^{-4}$ pers./pers. year as compared with the background risk of death resulting from natural or technogenic emergencies, which, according to

[17], for the territory of Ukraine over the past 5 years is $0.067 \times \times 10^{-4}$ pers./pers.·year on the average.

According to the Concept of Risk Management [15], such value is much in excess of the maximum permissible risk $1 \cdot 10^{-4}$.

Integrated economic risk for the whole territory (locality level). The integrated economic risk for the objects of Solotvyno township territory was calculated for the aggregate of geologic hazards detected.

The data on the space-time probability of the identified HGPs were divided into geoinformation layers, separate for each HGP.

They contain spatially referenced polygons with attributive values of the probability of geological hazard realization. Individual layers were also created for various risk objects.

Material losses were calculated for three types of engineering objects on Solotvyno territory: residential buildings (for 1–3-storeyed and 5-storeyed ones separately), critical infrastructure objects (electrical substation, buildings of water pumping station, sewage treatment plant, natural gas distribution system), transport infrastructure objects (railway, national highway); as well as agricultural lands.

Attributive information consists of the following fields: geometric dimensions, area, the number of storeys, building category, the value of the object damaged by a particular HGP and its value before damaging.

The losses due to damaging by one or another hazard were determined for land plots according to the data of [18], for other objects – in accordance with current norms [19, 20].

The method for assessing by squares was used to produce cartographic materials.

The territory of Solotvyno township was broken down into equal-area unit squares of 50 × 50 m size. Such size correlated with the maximum dimensions of karst sinkholes; hence it was chosen for simplifying the calculations and high-quality mapping of zoning results.

Due to reliance on the geoinformation approach, the calculations were carried out in the automatic regime. By using the GIS spatial analysis means, for each unit square we collected a data array necessary for calculating the risk with the mathematical apparatus according to relation (1)

$$\sum_{k=1}^{l} R_k = \sum_{j=1}^{n}\sum_{i=1}^{m} P(H_i)\cdot E_{Sj}(H_i)\cdot V_j(H_i)\cdot D_j(H_i),$$

where R_k is the integrated economic risk of the k unit square of the territory for j objects affected by i geological hazards in it.

For the sites where, according to expert assessment, a concurrent HGP impact could occur, e.g., where flooding and karst, flooding and gravitational processes, flash flood and subsidence and others can take place concurrently, their preliminary specification was made by GIS means.

The coincidence (both in time and in space) of various hazard types leads to repeated harmful impacts on buildings and structures and to possible damage accumulation, which produces negative effects on the bearing capacity of structures and increases their physical vulnerability.

In accordance with probability theory, the probability of HGP activization on such sites was calculated and used for the integrated risk assessment as that for concurrent events by the formula

$$P(H_1 + H_2) = P(H_1) + P(H_1) - P(H_1 H_2).$$

Fig. 3 presents the schematic map of the integrated economic risk of the locality level, which under the necessity of making managerial decisions on minimizing material losses under the development of the worst scenario specifies the most dangerous sites on Solotvyno territory – those shown in red and dark red colors.

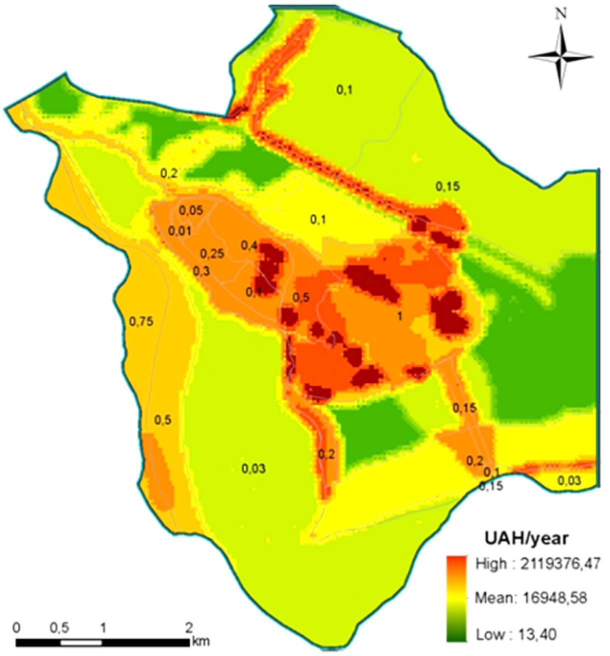


Fig. 3. The scheme of integrated economic risk of the locality level

The qualitative drawback of the integrated assessment is "disguising" the vulnerability of one type of objects by joint taking into account all types of objects within a unit square.

To itemize (specify) the objects suffering the heaviest losses within the worst scenario of HGP activization, e.g., housing buildings or railways, the maps of integrated risks for individual object types have been synthesized (Fig. 4). Fig. 4, *b* also presents the objects of critical and transport infrastructure since they are separated in space.

The graphic presentation of integrated economic risks for certain types of buildings does not allow the determination which of the identified HGPs would be superdangerous for an individual risk object.

It would be rational to construct maps of differentiated economic risks (from one or several necessary for HGP analysis) for the individual types of objects or for all (Fig. 5).

If the level of losses for critical infrastructure objects due to flash flood (Fig. 5, *a*) or seasonal flood (Fig. 5, *b*) is compared with losses in the worst scenario (Fig. 4, *b*), the losses resulting from flash flooding will be lower by 37.6 %, while the economic losses due to the activization of flooding processes will be 7.8 % of those possible as a result of the worst scenario development.

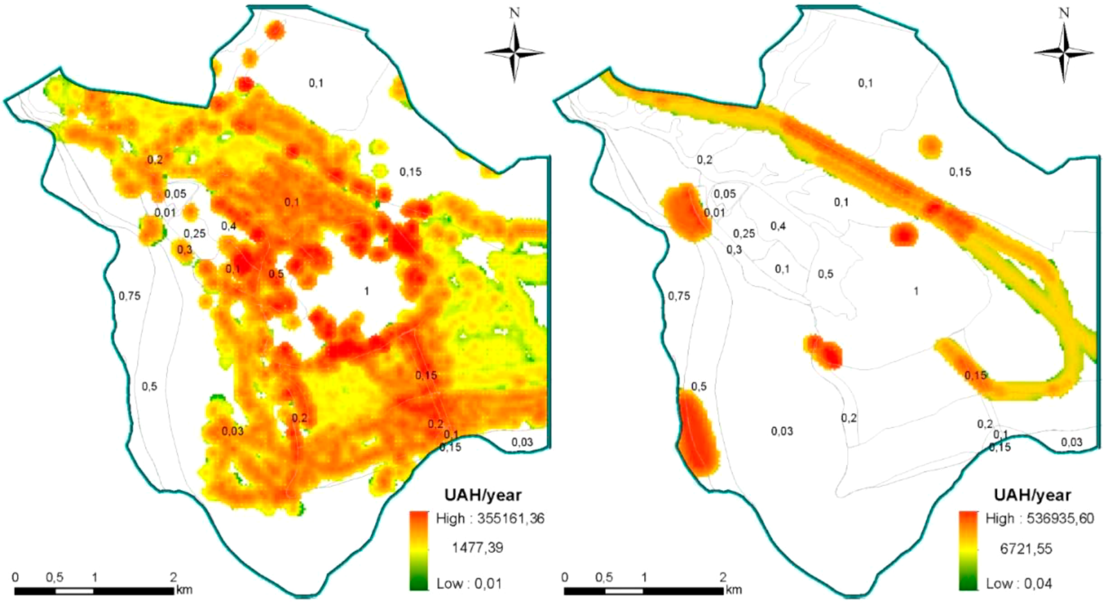
The cartographic presentation of social risks on the territory of Solotvyno township is of no special importance since it will vary within the unit squares, depending on the time of day and the season due to the spa and medicinal specialization of the region.

Conclusions. Risk analysis includes choosing the research scale, identifying hazardous geological processes, determining the probability of HGP occurrence, determining the vulnerability of risk elements, assessing the possible consequences of the process occurred and calculating the risk.

Risk analysis can be both quantitative, i.e., based on numerical values of probability, vulnerability and consequences, and qualitative (characterizing the process intensity, the losses expected and the probability of the event).

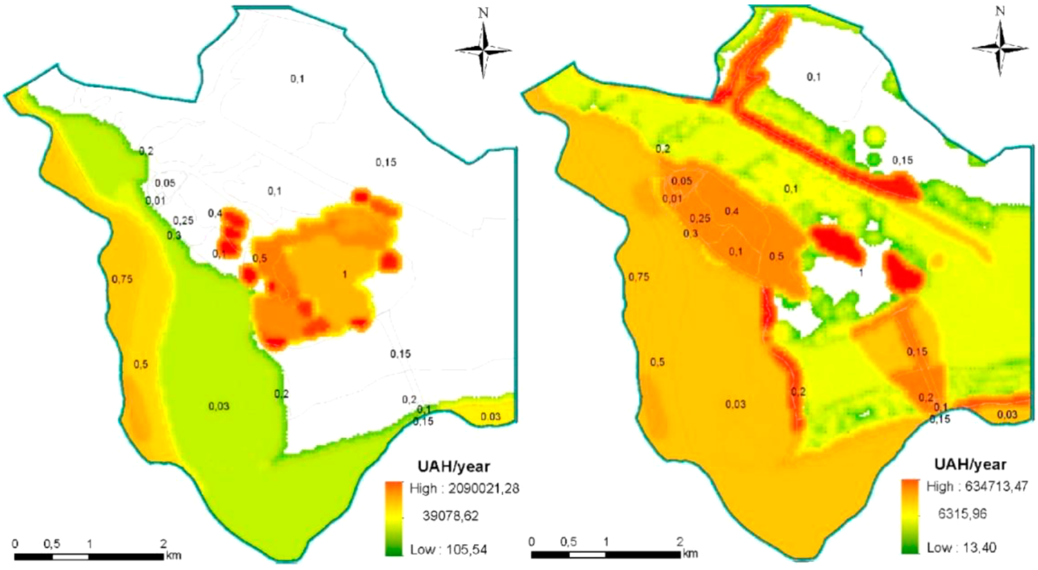
When assessing the territory, it would be proper to carry out both differentiated and integrated risk assessments on both the object and the locality levels.

The integrated risk assessment at the locality level permits the quantification of the risk under the worst scenarios, as well as the identification of the sites with the most probable degree of damage.



a *b*

Fig. 4. Integrated economic risk for residential buildings (*a*), *and objects of critical and transport infrastructure* (*b*)



a *b*

Fig. 5. Differentiated economic risk for all objects due to splash flooding and subsidence (a) and flooding (b)

Differentiated risk assessment at the locality level permits specifying the list of objects that could be damaged due to the occurrence of a single geological hazardous event.

Differentiated calculations of the risk due to various HGP types for a single object (the object level) specify their distribution and show the most detrimental of all hazards even at the equal probabilities of their occurrence.

The produced maps of geological hazard probabilities, as well as those of integrated and differentiated economic risks can be used for elaborating general recommendations, planning the investigations of hazardous natural processes, in particular, for organizing territory monitoring and providing protective measures.

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Геолого-економічна оцінка ризиків небезпечних техногенно-геологічних процесів (на прикладі смт Солотвино)

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Мета. Оцінка ризиків економічних і соціальних втрат при активізації небезпечних природних геологічних і техногенних процесів для встановлення рівня небезпеки проживання на постмайнінгових територіях з метою вироблення стратегій їх відновлення.

Методика. Для визначення стану геологічного середовища території та окремих інженерних об'єктів проводились натурні спостереження. При оцінці стійкості території населеного пункту використані механіко-математичні основи інженерної геології в комплексі з підходами системного аналізу та теорії інженерно-геологічної подібності. При проведені експертної оцінки й ризик-аналізу застосовані методи теорії ймовірностей і математичної статистики. Картографічні матеріали побудовано з використанням геоінформаційного підходу та методів цифрового моделювання, що реалізовано на прикладі смт Солотвино. Як вихідний матеріал використана створена в Інституті геологічних наук НАН України інтегрована у ГІС база даних (геологічних, інженерно-геологічних, гідрогеологічних та ін.) для території смт Солотвино та роботи з оцінки проявів природних і природно-техногенних процесів.

Результати. Встановлено, що найбільш загрозливою техногенно-геологічною небезпекою на території досліджень є карстово-суфозійні процеси, ймовірність яких у центральній частині території становить 1. На об'єктовому рівні оцінено економічний ($4{,}35 \cdot 10^{-3}$ тис. грн./м^2 · рік) ризик, що показує необхідність прийняття захисних інженерних заходів, та індивідуальний ($5{,}86 \times 10^{-4}$ люд./люд. · рік) ризик. Останній складає значну величину в порівнянні з середнім для території України. Для території смт Солотвино розраховані інтегральні й диференційовані економічні ризики, розподіл яких візуалізовано на картосхемах.

Наукова новизна. Розроблена схема оцінки ризиків від небезпечних техногенно-геологічних процесів для постмайнінгової території. Комбіноване використання диференційованих та інтегральних оцінок економічних ризиків на локальному та об'єктовому рівнях оптимізує прийняття управлінських рішень щодо захисту від геологічних небезпек і дозволить розробити якісну систему моніторингу населених пунктів.

Практична значимість. Упровадження отриманих науково-технічних результатів дозволить підвищити ефективність розроблення систем моніторингу та інженерного захисту на територіях із можливим виникненням значних надзвичайних ситуацій.

Ключові слова: *карстово-суфозійні процеси, зсуви, постмайнінгова територія, вірогідність, ризик*

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