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HAZARDOUS GAS-GEOCHEMICAL CONTAMINATION OF GEOLOGICAL ENVIROMENT FROM THE HORLIVKA CHEMICAL PLANT

The article deals with the issue of assessing the environmental hazards and risks of hazardous chemical contamination by the compounds of mononitrochlorobenzene and others hazardous chemicals sources of drinking water in the area of the Horlivka Mining and Urban Agglomeration. The analytical calculations concerning the potential area of pollution are presented and proposals are made regarding the composition of measures for the prevention of emergency ecological situations.

Key words: *technogenic-geological system, mining-urban agglomeration, highly toxic compounds, mines, flooding, flooding of the territory.*

В статті розглянуто питання щодо оцінки екологічних загроз і ризиків небезпечного хімічного забруднення сполуками мононітрохлорбензолу та інших небезпечних хімічних речовин джерел питно-господарського водопостачання у районі Горлівської гірничо-міської агломерації. Наведено аналітичні розрахунки можливої площі забруднення та розроблено пропозиції стосовно складу заходів з попередження надзвичайних екологічних ситуацій.

Ключові слова: *техногенно-геологічна система, гірничо-міська агломерація, високотоксичні сполуки, шахти, затоплення, підтоплення території.*

В статье рассмотрены вопросы оценки экологических угроз и рисков опасного химического загрязнения соединениями мононитрохлорбензола и других опасных химических веществ источников хозяйственно-питьевого водоснабжения в районе Горловской горно-городской агломерации. Приведены аналитические расчеты о возможной площади загрязнения и разработаны предложения по составу мероприятий по предупреждению чрезвычайных экологических ситуаций.

Ключевые слова: *техногенно-геологическая система, горно-городская агломерация, высокотоксичные соединения, шахты, затопление, подтопление территории.*

The problem in general

The town of Horlivka, with a population of over 350,000 people (as of 2005), remains one of the largest industrial centres of Donetsk oblast. There are many industrial enterprises concentrated in the town’s area, based on coal, chemicals, metallurgy and machine-building [1]. These enterprises used to produce and accumulate significant volumes of aerial, liquid and solid wastes, contaminating the lower atmosphere, soil and surface and ground water. As a result, the ecological state of the area is characterised by significant tensions and instability.

In recent years, the threat of regional degradation of surface and ground water used for domestic water supply in the adjacent territory on both sides of the ATO has increased [1]. This is driven by an undetermined state of mine workings contaminated with highly toxic compounds from the Horlivka Chemical Plant, as well as risk of an accelerated migration of contaminants into the surface and underground hydrosphere and operating sources of domestic water in the absence of territorial monitoring. We should note contamination from the Horlivka Chemical Plant manifested itself in mine workings as early as the beginning of the 2000 s at a distance of up to 12–15 km.

Under conditions of mine exploitation and closure, the local environment is characterised by an appearance of a significant set of natural and anthropogenic geological processes, including those that result in the degradation of rock massif stability, an increase in rock permeability and a reduction of the protective ability of upper zone of the geological environment. In the context of mine closure and a further partial or full flooding of closed mines, some of these processes may be qualified as auto-rehabilitation processes, i.e. processes that develop on the basis of effects of regional factors of the geological environment (fig. 1) [2].

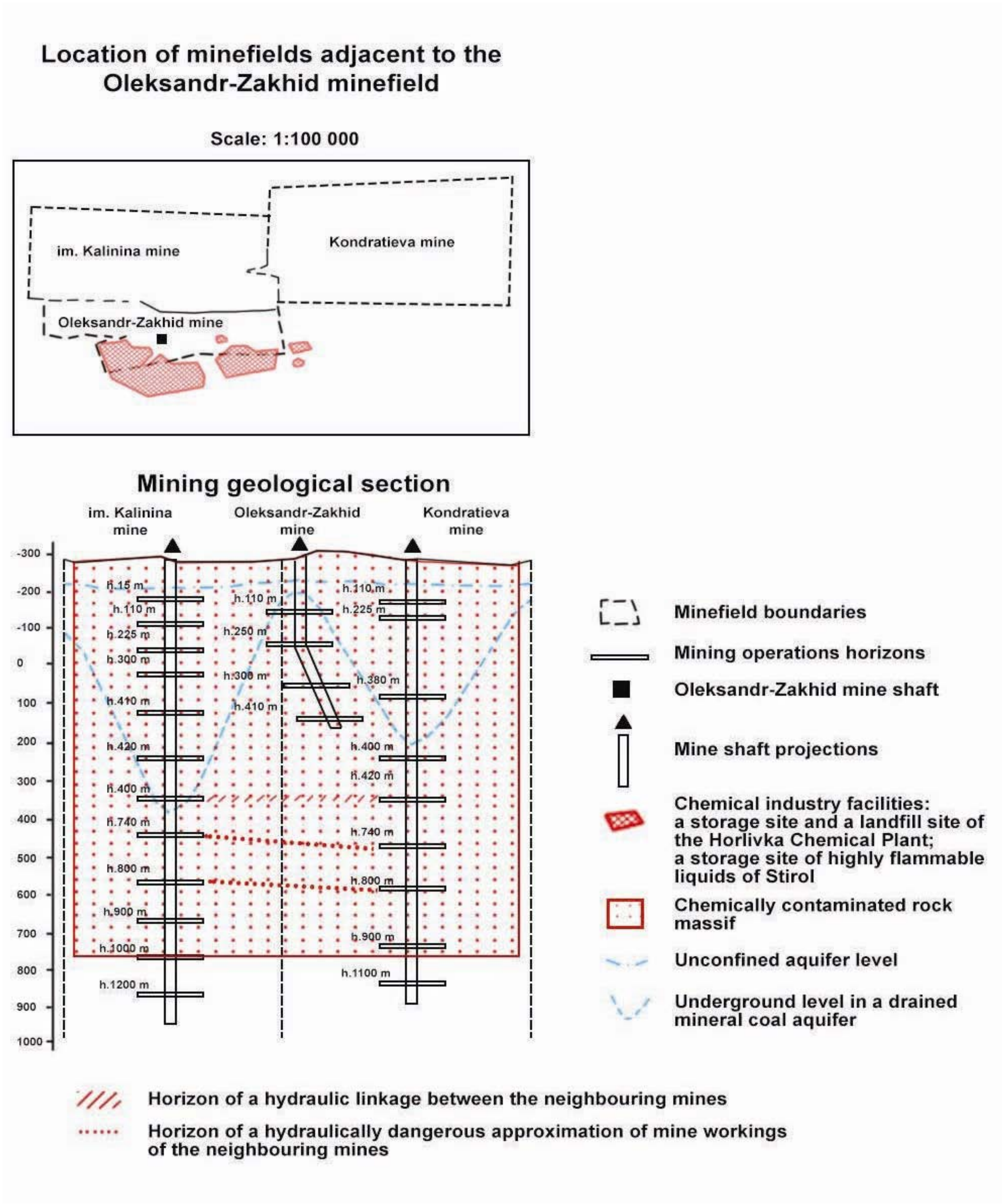

Fig. 1. Gas-geochemical Contamination of the industrial site of the Horlivka Chemical Plant

Key processes significantly influencing the formation of ecological-geological conditions of urban mining agglomerations of coalmining districts of Donbas may include the following:

1. A regional rise in groundwater levels, reaching pre-industrial marks within the boundaries of the catchment area.
2. Development of water-conducting cracks in the undermined areas and an increase in groundwater-quality vulnerability due to an accelerated migration of anthropogenic contamination.
3. Intensification of water exchange in the zones of aeration (also known as unsaturated zones or zones of suspended water), expansion of waterlogged and flooded areas and geochemically contaminated sites of urban mining agglomerations, as well as emergence of groundwater contamination sites.

Regional assessments of groundwater-quality vulnerability conducted during the first implementation phase [2] demonstrate that the areas of mining operations belong to the territories with an accelerated migration of contaminants located in underground workings, semi-underground sites and surface burial (storage) sites of industrial wastes.

In 1989–1990, mine-atmosphere contamination with chlorobenzene and other highly toxic compounds, whose concentrations reached lethal levels, was detected in the Vuhlehorska, Oleksandr-Zakhid and other mines in the Donetsk oblast. A key factor responsible for the arrival of compounds in mine workings was the undermining of the industrial site of the Horlivka Chemical Plant and Stirol Chemical Plant. The area of the industrial site is *8.6 km²*, including the undermined area of *2 km²*.

Ecological-hydrological assessments conducted during project implementation demonstrated that a potential closure of a mine or a group of hydraulically connected mines of the Tsentralnyi coalmining district, including the mines of the Horlivka urban mining agglomeration and the Yunkom mine (see Section 2.2 above), creates a risk of ecological emergencies in the most densely populated part of Donbas. In making these assessments, the authors primarily used data from a simulation of groundwater levels in the setting of the closure of mines of the Donetsko-Makiivsko-Horlivsko- Yenakiievska urban mining agglomeration [2, 3].

Global practice lacks experience in the waterlogging and flooding of sites of an industrial urban agglomeration with a high level of aeration-zone soil contamination with highly toxic compounds. In this connection, individual ecological- geological assessments have been made of potential impacts of the industrial site of the Horlivka Chemical Plant and Stirol under the conditions of an uncontrolled (passive) and controlled (active) flooding of mines of the Horlivka mining urban agglomeration.

Undoubtedly, the generated assessments are preliminary, since the development of a set of mining-engineering and ecological-geological changes in the Horlivka urban mining agglomeration may significantly depend on changes in the conditions of hydraulically connected mines (Oleksandr- Zakhid, Vuhlehorska, im. Kalinina, Kondratievska, among others). This is in addition to the geo-mechanical state of rock massif in the area of multi-year mining activities and lasting exploitation of chemical, machine-building, and other industrial facilities, which have their own complexes of factors affecting the upper level of the geological environment (thermal, mechanical and other).

Considering the above, and the long-term geochemical contamination of the site of the Horlivka Chemical Plant and Stirol, as well as the residential area of the Horlivka mining agglomeration, with highly toxic wastes, the authors have taken an approach based on factoring in the protective (stabilising) ability of the geological environment. Analysis of the ecological structure of the mine environment has demonstrated that such a protective ability may develop only under the conditions of a stable state or limited deformations of the top zone of rock massif, which excludes the development of water-transmitting cracks. This may be achieved through implementation of the following package of safeguarding measures:

– ensuring hydro-geo-mechanical stability of rock massif by slowly raising the groundwater level in a controlled manner, which excludes unequal deformations of rock and the development of seepage tensions zones;

– backfilling mine workings (possibly with the creation of seepage and sorption barriers), which are adjacent to the industrial sites of the Horlivka Chemical Plant and Stirol to exclude additional rock subsidence and displacement within their boundaries;

– implementing a package of measures to compact and neutralise highly toxic waste, as well as to hydro-isolate the sites of waste burial (storage);

– utility of such safeguarding measures is substantiated on the basis of a conservative scheme of the formation of an ecological-hydro-geological risk of impacts by highly toxic compounds accumulated in the industrial site of the Horlivka Chemical Plant and Stirol within the confines of the Horlivka urban mining agglomeration, if flooding occurs, given high quality-vulnerability of groundwater formed in the area of undermined territories.

Anthropogenic pressures on the environment of the Horlivka mining agglomeration

Ecological impacts of anthropogenic facilities (hot spots) within the confines of the Horlivka urban mining agglomeration depend largely on their location relative to regionally developed anthropogenic jointing, tectonic faults and a system of depression cones caused by mine drainage. Increased infiltration of saline mine water, geochemical landscape contamination and disturbance of regional water-confining layers has resulted in a practically complete replacement of fresh water (up to 1.0–1.5 g/dm³) and slightly saline water (1.5–3.0 g/dm³) with water of salinity of 3–5 g/dm³ (in around 70 % of the research area).

There is currently a drastic difference between permeability and the level of infiltration recharge of covering and coal deposits in a majority of urban mining agglomerations of Donbas. This has resulted in a two-tier structure of hydro- geo-filtration (seepage), as follows.

1. Lateral development of the anthropogenic unconfined (water-table) aquifer, which has a natural–anthropogenic recharge mode.
2. Planar groups of local depressions of groundwater levels within the confines of minefields and the sites of geological structures associated with the areas of an increased drainage impact of mining operations (including layers of permeable sandstone, coal, tectonic faults and hydraulic linkages of workings).

The performed analysis demonstrates that, after the closure of mines when groundwater levels rise again and depression decreases, an uprising (in-depth) recharge of groundwater will become more intensive. Waterlogging and flooding processes develop, as well as water saturation and a decline in rock strength in the lower horizons with the appearance of highly gradient sediments and rock disintegration. According to the simulation data, for 50 % of the area of the Horlivka urban mining agglomeration, an estimated depth of groundwater in mineral coal aquifers does not exceed 20 m. Consequently, this territory will be prone to local minor flooding of anthropogenic facilities (hot spots), the development of existing and the emergence of new focuses of groundwater contamination.

According to the available data, the Horlivka urban mining agglomeration and the adjacent territory contain over 70 ecologically hazardous facilities, including chemical and metallurgical enterprises, waste ponds and sludge depositories. These are likely to have negative water-ecological impacts such as an accelerated migration of contaminants into surface and ground water bodies. A water-divide location of the industrial site of the Horlivka Plant, as well as the Horlivka urban mining agglomeration at large, a hydro- geological openness of its territory, including anthropogenic splitting zones in the territories undermined by mine workings and the exposure of permeable sandstone, increase the risk of a spatial migration of chemical contaminants.

If mines in the territory of the Horlivka agglomeration become flooded partially or fully, without a preliminary implementation of engineering safeguards and measures to protect the environment, there may be damage to the waterproofing of waste-storage facilities and a disastrous arrival of contamination in mine workings, aquifers and surface water flows. An upsetting of the current equilibrium of the system may lead to an emergency within the confines of both the Horlivka urban mining agglomeration and the southeastern part of the Tsentralnyi coalmining district of Donbas.

Hydraulic links between mines and a rise in groundwater vulnerability

Many mines of the south-eastern part of the Tsentralnyi coalmining district have been operating for 50–70 years. Therefore, their depth primarily exceeds 1,000 m. A steep dipping of coal seams (an angle of 55 ° and above) and a significant quantity of such seams in the minefields (up to 11–18) are responsible for the linear form of the minefields and the approximation of permanent workings and breakage faces of the adjacent mines.

Linearly expanded zones of processing of steeply dipping coal seams are accompanied by the extraction of significant volumes of coal and rock in each mine (up to 1 million m^3 per year). This results in the upsetting of the geo-mechanical balance of the rock massif and the development of a complex of changes in the environment, as follows:

1. Development of anthropogenic cracking, an increase in rock massif permeability, and the development of routes of accelerated migration of surface contaminants into mine workings and groundwater.
2. Development of rock subsidence and displacement zones, as well as their short-term local deformations, accompanied by relevant movements of the land surface (local anthropogenic earthquakes).
3. Activation of interconnection between ground and surface water, accompanied by an enhanced infiltration of surface water within the confines of minefields.
4. Emergence of new migration routes for explosive gases including coal-bed methane, oxidation products of pyrite compounds, and anthropogenic compounds.

Presently, practically all mines in the territory of the Horlivka urban mining agglomeration, in the Southern and Northern Flanks of the Major Anticline, are hydraulically interconnected at a depth of 230–1,080 m. The largest hydraulic contact density is recorded in mines adjacent to the industrial site of the Horlivka Chemical Plant and Stirol.

Analysis has been carried out of the geological structure and hydro-geological conditions of the Oleksandr-Zakhid, Kondratievska, Vuhlehorska, im. Karla Marksa, im. Haievoho, Kocheharka, im. Rumiantseva and im. Kalinina mines. This shows that these mines, interacting with the anthropogenic- geological system, create a unitary hydraulic geo-filtration system with a high level of anthropogenic vulnerability of groundwater.

According to the available data, there are around 14 direct hydraulic linkages of the above mines and up to 10 zones of coal-mining operations (given a normative decline of pillars between the mines) with a total length of around 1.5–2.0 km. In our opinion, the distribution of non-normative pillars practically throughout the entire depth interval (0.2–0.9 km) may result in the activation of deformations of the rock massif due to a decline in rock strength during full or partial flooding of workings, as well as the development of additional accelerated migration routes of contaminants, explosive and toxic gases.

The Horlivka urban mining agglomeration is characterised by a high level of chemical contamination of the uppermost zone of the geological environment. Forecasts demonstrate that, in the event of a partial or full flooding of mines in the area, it is possible that the following processes will contribute to long-term emergencies:

1. A decline in rock strength and additional deformations of rock in the foundations of ecologically hazardous facilities such as oil-product pipelines and toxic waste ponds.
2. Emergency long-term migration of contaminants from external sources into surface and ground water bodies, and contamination of water intakes for domestic water supply.
3. Synergistic reactions and a risk of atmospheric contamination in mine workings and other facilities with highly toxic unstable compounds in liquid and gaseous forms.
4. Entry into food chains of highly toxic compounds during their emergency arrival in the environment, including on the surface of the ground and in agricultural crops.

The vulnerability of groundwater quality in the Horlivka industrial agglomeration

A regional assessment of groundwater quality vulnerability in the Tsentralnyi coalmining district of Donbas was conducted within the framework of [5]. In their research, the authors attempt to connect assessments of groundwater-quality vulnerability with a predominant impact of mining operations upon a decrease in the protective ability of geological environments in Horlivka. There are large waste ponds filled with highly toxic compounds: some 325,300 tonnes while the area of the industrial site is approximately 8.6 km². Of this quantity, only approximately 11,600 m³ or 20,000 tonnes (i.e. 6 %) is located in semi-underground poorly isolated storage facilities with a total area of 2,500 m².

Having analysed factors affecting groundwater-quality vulnerability, the effects of which are presently obvious in the industrial sites of Horlivka, the authors identify the following key factors:

1. Affectedness of 30 % of the territory by undermining operations of the Oleksand-Zakhid mine (2.3–3.0 km²).
2. Active infiltration of contaminated groundwater that originates in the area of the Horlivka urban mining agglomeration in connection with increasing jointing of undermined rock and active anthropogenic rock deformations.
3. Formation of an anthropogenic hydro-geo-filtration system, uniting the hydraulically connected mines (Oleksandr- Zakhid, Vuhlehorska, Kondratievska, im. Kalinina, and im. Rumiantseva) in the Horlivka agglomeration. A system of crossing and longitudinal faults in the central zone of the Major Anticline is a factor in possible expansion of the anthropogenic hydro-geo-filtration system when mine drainage is reduced in the direction of the Kocheharka, im. Haievoho and im. K. Marks mines, which are hydraulically interconnected.

The factors affecting groundwater-quality vulnerability within the confines of the Horlivka urban mining agglomeration are distinguished as follows:

1. The industrial site of the Horlivka Chemical Plant and Stirol has a reduced density of tectonic faults, while such density value increases by 10–15 times in the Southern Flank of the Major Anticline (fields of the adjacent Kocheharka, im. Haiovoho, and im. K. Marksa mines).
2. A water-divide location of the territory is responsible for minimal density values of the drainage network but under the conditions of the formation of an anthropogenic hydro-geo-filtration system it may contribute to an active migration of contaminants in the direction of the river basin of the Siverskyi Donets, as well as rivers flowing into the Azov Sea (the Krynka, the Mius and others).
3. Mining operations have a leading impact on a decline in the protective ability of the uppermost zone of the geological system due to the development of anthropogenic jointing and a reduction in the time taken for anthropogenic contamination to migrate from the surface to the groundwater level. (According to computations, an estimated time for a contaminant to reach the groundwater level within the confines of the industrial site of the Horlivka Chemical Plant and Stirol is less than 20 days.).

An integral assessment within the confines of the Horlivka urban mining agglomeration demonstrates that around 45 %, 30 % and 25 % of its area have high, increased and minor levels of groundwater vulnerability, respectively. We should note that the obtained assessments of groundwater-quality vulnerability are inclusive of the current quasi-stationary state of mine depressions at the groundwater level within the confines Horlivka mining agglomeration and in the region in general. Projections concerning the impact of mine closure involving full or partial mine flooding Tsentralnyi coal mining district are indicative of a potential development of additional rock subsidence and displacement. This may result in additional fracturing, an increase in the permeability of undermined rock and a decline in the protective ability of the uppermost zone of the geological environment. Filtration losses from industrial waste ponds, product pipelines, and other facilities containing highly toxic waste increase the vulnerability of groundwater quality within the confines of the Horlivka agglomeration.

Ecological risks associated with waste from the Horlivka Chemical Plant

It was noted in Chapter 3 of the Information Bulletin [5] that, according to the conducted assessments, areas with a high level (45 %) and an increased level (30 %) of groundwater- quality vulnerability prevail within the confines of the Horlivka urban mining agglomeration. This is primarily a result of the impact of mining operations on a decline in the protective ability of the uppermost zone of the geological system.

The assessment of an ecological-geological risk associated with impacts of waste from the Horlivka Chemical Plant and Stirol is based on the following:

1. Real effects of an extreme contamination of the mine atmosphere in the workings of the Vuhlehorska and other mines (1990).
2. A stable decline in the protective ability of the geological system while mining operations develop laterally and in depth in the territory of the Horlivka urban mining agglomeration and adjacent land.
3. Presence of a significant quantity of hydraulic linkages and lengthy non-normative approximations of mine workings in the territory of the Horlivka urban mining agglomeration, including those that are filtration-interconnected with the anthropogenic-geological system.

This permits us to consider, in our estimates, a risk of migration of highly toxic compounds into the anthropogenic- geological system, which consists of two connected blocks: within the confines of the industrial site's projection to the depth of mining operations (an area of $S_1=8.6\ km^2$, a depth of $H=1\ km$) and the territories of minefields of the adjacent Vuhlehorska, im. K. Marksa, im. Haiovoho, Kocheharka, im. Rumiantseva, im. Kalinina, and Kondratievska mines (an area of $S_2=86\ km^2$, a depth of $H=1\ km$).

Analysis of the migration of highly toxic water-gaseous aerosols into mine workings and the layer of the atmosphere closest to the surface (the Horlivska urban mining agglomeration, 1990, Pershotravnevy raion of Mykolaiivska oblast, 2000) suggests that such aerosols have a sizable distribution in the pore space, in a synergy with organic-mineral compounds of rock (coal tart, sulphide compounds of pyrites and pyrrhotite), and that such aerosols may arrive along with mine-water vapour. In addition, the evaporation temperature of many toxic compounds (nitrous, chlorobenzene, etc.) is 7–700 °C. In connection with this, their local concentration in a liquid form (as the temperature falls) and gaseous form (during heating) is possible.

Considering a significant quantity of highly toxic waste in the industrial site of the Horlivka Chemical Plant and Stirol and a low level of such waste hydro-isolation, the authors have made a conservative (harsh) projection, which envisages two developmental phases for an emergency long-term migration of toxic water-aerial aerosols into an undermined rock massif.

1. A downward migration of water-aerial aerosols within the confines of the industrial site in an area of $S_1=8.6\ km^2$. The depth of migration is estimated to reach the lowest horizon of mining operations, namely $H=1\ km$.
2. A lateral migration of water-aerial aerosols into mine workings of the adjacent mines, which creates an anthropogenic-hydro-geological system with a total area of $S_2=86\ km^2$.

In connection with a high migration ability of water-aerial aerosols, the authors expect that such aerosols will fully saturate a porous and fractured area of undermined and disturbed rock (porosity of μ=0.1) to the depth of mining operations, namely $H=1\ km$.

At the same time, the authors have accepted generalised maximum and minimum values for toxicity of chemical compounds in the atmosphere of the working area and population centres, which are presented in Table 1 according to the data mentioned in an order of the Ministry of Healthcare of the USSR (1991) and Letter # 603 of the Ministry of Healthcare of Ukraine of 21 September 2000, clarifying the parameters of atmosphere contamination [classified, referenced in 5].

When a porous and fractured area of rock massif within the confines of the industrial site becomes fully contaminated, contamination weight G_1 will be equal to the following:

$$G_1=(0.01\div10.0)\times S_1\times H\times \mu\approx(0.01\div10.0)\times8.6\times10^6 m^2\times10^3 m\times0.1\approx(0.86\times10^7\div8.6\times10^9)\ mg = (0.0086\div8.6)\ tonnes$$

Table 1

Values of permissible limited concentrations of highly toxic contamination

№ пп	Permissible limited concentration of highly toxic contamination	
	Atmosphere in the working area	**Atmosphere in population centres**
1	Minimum – 0.1 mg/m^3	Minimum – 0.0001 mg/m^3
2	Maximum – 10 mg/m^3	Maximum – 0.1 mg/m^3

If we take into account that the total volume of waste from the Horlivka Chemical Plant and Stirol amounts to 325,296 tonnes, including an organic component of 37.4 %, the total volume of highly toxic contamination (G_{tox}) will amount to:

$$G_{токс} = P \times \frac{37,4}{100} = 325296 \times 0,374 \approx 11500\,ton$$

It is interesting to look at an estimate of a relative fraction of highly toxic contamination capable of marginally contaminating mine workings in the form of aerosols to the rock massif within the confines of the industrial site:

$$E_1 = \frac{(0,0086 \div 8,6)}{121500} \times 100 = \left(7 \times 10^{06} \div 7 \times 10^{-3}\right)$$

The above calculations demonstrate that the transfer of the smallest fraction of highly toxic contamination in the form of water-aerial aerosols may result in a marginal contamination of the mine workings' atmosphere and a porous and fractured area of rock massif within the confines of the industrial site of the Horlivka Chemical Plant and Stirol.

According to simulation data, a hydraulic connection between workings of mines immediately adjacent to the Horlivka Chemical Plant and Stirol, which form an anthropogenic hydro-geo-filtration system, may bring about a lateral movement of toxic water-aerial aerosols. Their marginal estimated quantity, G_2 in the event of a peak contamination will amount to the ratio of the area of the industrial site (S_1=8.6 km^2) to the area of the anthropogenic-geo-filtration system ($S_2 \approx 86\ km^2$):

$$G_2 = {G_1 \times S_2}/{S_1} = (0,0086 \div 8,6) \times 88,0/8,6 \approx (0,086 \div 86,0)\,tonnes$$

A relative efflux of highly toxic contamination r_2 will amount to:

$$r_2 = r_1 \times \frac{S_2}{S_1} \approx \left(70 \times 10^{-6} \div 70 \times 10^{-3}\right)$$

As noted above, these computations of ecologically marginal quantities of the intake of highly toxic contaminants through aerosols, which have accumulated in the industrial site of the Horlivka Chemical Plant and Stirol, into adjacent mine workings are extremely inherently conservative, since they envisage a peak discharge and arrival of toxic aerosols and lack a record of sorption-protective effects of porous rock solutions. At the same time, a failed miners rescue operation of 1990 and the estimates demonstrate that there is a high risk of water-migration and atom-aerosol intake into restricted volumes of mine workings and land surfaces of highly toxic contaminants, which have accumulated in the industrial site of the Horlivka Plant.

To a significant extent, this may be associated with the specificity of the geodynamic behaviour of rock massif in flooded mines, the balance of which has been upset through the treatment of steeply inclined coal seams (>55 °). The mining of such seams results in the disintegration of rock massif into separate linearly extended blocks, whose strength during mine flooding begins to decline from the bottom. Consequently, under the weight of the overlying non-flooded section of the interbedded block, crushing and squeezing of rock in the block's foundation occurs, while the foundation is saturated with water to such an extent that the rock becomes plastic. This leads to further subsidence of the weakened rock. The process finally results in extremely unequal deformations of the surface and the emergence of tear splits in building foundations and structures. At the same time, these splits serve as routes of "rapid" contamination filtration and upward migration of explosive or toxic gases.

The simulation data of regional rises of groundwater levels due to the closure of some mines and a decline in the volume of water drainage can be combined with assessments of groundwater-quality vulnerability made within the framework of the project. Together, these indicate a possibility that new factors may have an impact on a decline in the protective ability and strength of the uppermost part of the geological environment.

According to our assessments, the most hazardous factors are as follows:

1. An increase in the area of land with geo-mechanical rock balance upset due to a growth in the depth and in area.
2. Of mining operations within the confines of the Horlivka urban mining agglomeration.
3. A risk of the effects of local hydro-geo-mechanical movements (seismic hydro-deformations) caused by short-term rises in the hydrostatic pressure in isolated volumes of mine workings or by water flows of significant volumes.
4. Degradation of physical-mechanical (water-physical) qualities of the foundations of industrial and residential buildings, including toxic waste ponds, due to the effects of a chemical landscape contamination of the Horlivka urban mining agglomeration and a rise in soil and groundwater aggressiveness.

In general, the estimates demonstrate that the uppermost zone of the geological environment of the Horlivka agglomeration will change if the complex of anthropogenic factors continues affecting the environment. These factors include mining operations, anthropogenic water saturation, and thermal and chemical pollution. Such change will entail a decline in the protective ability and an increase in vulnerability of groundwater quality. The latter factor may become a source of atmo-hydro-geochemical contamination of mine workings within the confines of both Horlivka and other urban mining agglomerations of Donbas.

Preliminary study proposals to prevent ecological emergencies in Horlivka

Cooperation with the Geological Survey of Denmark and Greenland (GEUS) within the framework of [5] has revealed sufficient effectiveness of using computer technologies and methods to assess ecological changes in the geological environment arising from an accelerated closure of numerous mines.

During the research period, the team established an auto- rehabilitation nature of a number of regional processes of the geological environment. These include the reduction of groundwater levels within catchment areas, acceleration of the migration of anthropogenic contaminants, and additional land subsidence resulting from undermining. In general, this lays the groundwork for a further complication of ecological- geological conditions during the closure of mines.

The Horlivka urban mining agglomeration is connected with the axis zone of the Major Anticline, which has contributed to steep coal seam dipping and proneness of underworked rock to gradient deformations of the land surface. The latter circumstance is a factor contributing to the progressive worsening of engineering-geological conditions in the Horlivka urban mining agglomeration and a risk of disastrous destruction of residential and industrial facilities, including ecologically hazardous ones.

In view of the above, it would be reasonable to take the following steps to mitigate the risk of hazardous changes in the geological environment and ecological emergencies in the territory of the Horlivka urban mining agglomeration:

1. Conducting an assessment of the completeness and composition of ecological information from the regional (public) and facility-based monitoring systems.
2. Conducting a comprehensive ecological-geological survey, including assessments of chemical soil contamination, gas-geochemical composition of the porous ground atmosphere and an analysis of structural changes on the basis of satellite images and topographic maps for various time periods.
3. Developing a map of anthropogenic pressures and disturbances in natural parameters of the geological environment within the Horlivka urban mining agglomeration, identifying zones with different levels of ecological-geological risks.
4. Developing a permanently functioning model of the Horlivka urban mining agglomeration, which will ensure efficient forecasting of groundwater levels and the selection of ecologically safe options for partial of full mine closure.
5. Extending the system of ecological monitoring to the geological environment, including observation of the migration of explosive and toxic gases and compounds, land surface deformation and the state of ecologically hazardous facilities.

Mine workings and toxic waste of the Mykytivsky Mercury Integrated Plant are located in the potentially affected area of mine flooding accompanied by the contamination of mine workings adjacent to the industrial site of the Horlivka Chemical Plant. In addition, according to the Defence Ministry of Ukraine, in Horlivka, insurgents have started dismantling and removing for scrap the equipment of the 2-bis mine, where waste from the former Mykytivsky Mercury Integrated Plant is buried.

Tentatively, the mine is in the “dry abandonment” mode and special pumps continuously remove water from the mine. If the equipment stops pumping water out of the facility, the adjacent territory may become waterlogged and there may be a breakdown of the water supply system. This in turn could result in the termination of the supply of drinking water to a major part of Donetsk oblast, contamination with mercury compounds and the flooding of nearby villages such as Rtutne, Michurine and Bessarabka.

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