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Ecological Threats in Donbas, Ukraine

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Assessment of ecological hazards in Donbas impacted by the armed conflict in eastern Ukraine

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Credits

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The Centre for Humanitarian Dialogue (HD) is a private diplomacy organisation founded on the principles of humanity, impartiality and independence. Its mission is to help prevent, mitigate, and resolve armed conflict through dialogue and mediation.

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Executive summary

The Donbas is a region dominated by heavy industry, in particular coal mining, chemical processing sites and metallurgy. Intensive mining and steel smelting led to substantial environmental damage prior to the armed conflict. The fighting in eastern Ukraine has exacerbated an already fragile ecological situation, introducing a range of new risks – of stray munitions hitting large chemical and industrial facilities, or interconnected mines being flooded and poisoning the water throughout the region. Ongoing hostilities have made systematic ecological monitoring extremely difficult, and insufficient attention is being paid to an increasingly precarious environment for human life and economic activity. The presence of over 4,000 potentially hazardous sites in a heavily urbanised area (which, prior to the conflict, was home to some 7 million people) means that a looming environmental catastrophe could be virtually impossible to control, given the amplifying power of winds, water flows, and the interconnectedness of mines. A failure to take urgent preventive measures presents a lose-lose scenario for all sides, with the humanitarian and economic consequences in Donbas (and surrounding areas in Ukraine and Russia) to be felt for generations.

One of the most pressing environmental concerns in Donbas is the contamination of ground water and centralised water supply. The Siverskyi Donets River and its tributaries provide 80–85% of the water used by the Donbas Water Company, the region's main water provider. The vast majority of this water is drawn from the surface runoff of rivers in the area, however continuing hostilities around the Siverskyi Donets basin are damaging the water supply infrastructure, and uncontrolled leakage of contaminated water from flooded mines and damaged industrial sites are tainting river beds, canals, and water reservoirs. Critical water supply is thus often reduced or suspended. As a result residents of Donbas are increasingly making use of unprotected shaft wells, boreholes and springs, which are at high risk of contamination. The population of the region is thus exposed to potential epidemics, infection and non-infectious diseases.

Under the auspices of the Centre for Humanitarian Dialogue (HD), a Geneva-based peacemaking organisation, a scientific assessment was undertaken in October and November 2016 by ecological experts on both sides of the line of contact, with a view to assessing the impact of the conflict on vulnerable sites in Donbas. A total of 61 water and soil samples were analysed (23 sampling sites in Donetsk Oblast, 12 in Luhansk Oblast within government-controlled territory; and 26 sites in the Donetsk oblast of non-government controlled territory). Water sample points included shaft wells,

“Ongoing fighting runs the risk of mines being seriously damaged, causing uncontrolled flooding and the leakage of toxic and/or radioactive substances.

bore holes, spring and surface water. Assessments were conducted based on current Ukrainian sanitary norms and corresponding international standards.

This assessment found that, within government controlled areas, 100% of the sampled surface water sources and around 75% of the underground water sources were contaminated with chemical-synthetic and mineral components. Meanwhile, in non-government controlled areas, around 85% of the sampled surface water and underground water sources were contaminated. The main chemical contaminants found were chlorine, sulphates, nitrates, iron, and manganese, with additional industrial contaminants such as mercury, arsenic, cooper, lead, and various hydro carbonates. Flooded coal mines, many of which are hydraulically interconnected throughout the region, caused the contamination of underground water sources. Ecological assessments conducted prior to the conflict found the same sources to have been suitable for potable water.

Furthermore, unstable or damaged water-treatment facilities throughout many cities and villages in Donbas have led to the contamination of surface water due to increased household and industrial waste discarded into rivers. Further destruction of waste treatment facilities will result in accelerated contamination of drinking water reservoirs across the Siverskiy Donets River and its tributaries.

On top of an already precarious ecological balance in Donbas there are several other looming risks. Coal mines throughout Donbas continue to be abandoned and flooded (rather than systematically pumped in a controlled manner), leading to further underground water and soil contamination affecting both the access to potable water and the area's suitability for agricultural activities. Ongoing fighting runs the risk of mines being seriously damaged, causing uncontrolled flooding and the leakage of toxic and/or radioactive substances. Unchecked and unfiltered industrial waste is increasingly accumulating in many of the riverbeds of Donbas, creating large-scale health hazards for local inhabitants. Finally, the armed conflict introduces the serious risk that an exchange of shells or mortars may hit sites across the dense concentration of chemical and steel-processing industrial facilities along both sides of the line of contact. This could cause toxic fumes and leachate to contaminate the water, air, and soil in the region.

The ecological experts who conducted the study suggest a series of measures to ensure the ecological safety and quality of human life and health in Donbas. Firstly, periodic ecological monitoring should be conducted in the area where the armed conflict continues, including through the use of remote-sensing technologies. Secondly, an assessment of additional ecological threats should be conducted, in particular regarding the impact of uncontrolled mine flooding on surface areas (towns, villages, agricultural sites), potential migration of contaminated waters beyond the Donbas region (in both Ukraine and Russia), and the growing impact of contaminated waters on the Siverskyi Donets due to the destruction of dams and hydraulic structures. Thirdly, further studies should be conducted to identify the precise sources of contamination and radiation as well as their respective health hazards. Finally, critical infrastructure which has been damaged or neglected as a result of the conflict should be restored. In this regard, particular attention should be paid to water supply systems, sewage corridors, and industrial waste treatment facilities across Donbas. It is in the general interest of all sides to address this pressing problem, in order to forestall the potentially catastrophic and long-term humanitarian and economic consequences for Donbas and the wider region.

Introduction

Military conflict continues in southeastern Ukraine, posing unprecedented and severe hazards to people and the environment. The Donbas, or Donetz basin (around the River Donetz), is a region of 20,000 square kilometres featuring coalmining and other industry with a high density of potentially hazardous industrial facilities. There are some 7 million people living in this territory, and over 4,000 potentially hazardous facilities in the urban agglomerations within it.

Increasingly, as a result of disruption caused by the conflict, local people are using water from shaft wells, boreholes and springs, as well as water supplied through the central system of the Donbas Water Company. This report is based on an assessment of the ecological state of reserve sources of domestic water supply for the population of Donetsk and Luhansk oblasts (provinces) in the territory. It covers water supplies from both uncontrolled sources and sources controlled by the Government of Ukraine.

The Donbas Water Company uses water from the Siverskyi Donets river basin: 80–85% drawn from surface runoff and 15-20% from groundwater. Hostilities around the Siverskyi Donets basin is damaging the water-supply infrastructure, while uncontrolled leakage of contaminated water and toxic chemicals are tainting river beds, canals and water reservoirs. This leads to reduction or complete suspension of the centralised water supply, which, in turn, triggers emergencies at water-supply facilities. Clearly, these are key elements of critical infrastructure required to support health and life of the local population.

As a result of the effects of the war, local people are increasingly dependent on alternative and informal water sources such as shaft wells, individual boreholes and capped springs. These are unprotected from surface contamination, with sanitary-hygienic conditions that are often unknown or hazardous. Such war-related anthropogenic vulnerability of domestic water supply sources creates a high risk of water-ecology emergencies, including epidemic, infectious and non-infectious diseases, which may arise from the consumption of contaminated drinking water.

There is also, in this area, increasing contamination of both surface and underground sources of domestic water during mine flooding and uncontrolled leakage of saline and contaminated water. While the system of ecological monitoring of water sources remains fragmented due to the ATO, and funding is insufficient, there is a mounting threat of contamination through leakage of toxic leachate from many hundreds of industrial and household-waste landfills, spoil heaps and filtering waste ponds.

> “. . . war-related anthropogenic vulnerability of domestic water supply sources creates a high risk of water-ecology emergencies, including epidemic, infectious and non-infectious diseases, which may arise from the consumption of contaminated drinking water.

Taking into consideration recommendations of local offices of the State Emergency Service of Ukraine, the Health Ministry and oblast military-civil administrations, this group of experts identified 35 locations for the inspection of drinking water supply sources in challenging ecological and anthropogenic conditions. As well as sampling the water, we also took samples of nearby soil, and measured background radiation levels. There were 23 sampling sites in Donetsk oblast and 12 in Luhansk oblast, in the government controlled territory. In addition, we sampled drinking water supply sources and soil at 26 locations in the territory beyond the control of Ukrainian authorities (all 26 sampling sites in Donetsk oblast).[a]

When deciding on the number of samples for each oblast, the mission bore in mind the primary use of groundwater in domestic water supply systems in Luhansk oblast. These sources are protected to a greater extent from the impacts of anthropogenic contamination and have stable chemical composition indicators and physical water parameters (such as temperature, turbidity and taste). Taking into account local conditions, the mission developed an indicative scheme of instant testing, to assess the factors critical for ensuring ecological safety, as well as human health and life in this region.

1. Natural and anthropogenic conditions affecting water supply in Donbas

Since Soviet times, Donbas has been a region of heavy industry with the highest levels of anthropogenic impacts on the environment. Such impacts include emissions of hazardous substances into the atmosphere, discharge of untreated wastewater into natural water bodies, and waste disposal. This was associated both with the local industry – notably coalmining, production of chemicals, coal metallurgy and machine-building.

For 200 years, people have been intensively extracting coal in Donbas in a relatively small territory of 15,000 square kilometres. Some 20 billion tonnes of rock were removed from the Earth's interior during this period, including 15 billion tonnes of coal. In an area of 8,000 square kilometres, the surface of the Earth has subsided on average by 1.5–2 metres; 600 cubic kilometres of the rock massif have suffered from deformation.

The anthropogenic hazard level in Donbas is primarily caused by the presence of potentially hazardous facilities in the territory. In 2009, operating in Donetsk oblast alone, there were 157 coal mines, 108 hydraulic engineering facilities, 537 petrol stations and 12 open-pit (or opencast) mines. There were also 11 railway stations, 115 bridges and crossovers, 1 tunnel for land transportation, and 13 major pipelines and branch pipes. In Luhansk oblast, there were 69 coal mines, 66 hydraulic engineering facilities, 247 petrol stations, 3 open-pit mines, 2 railway stations, 13 bridges, 5 major pipelines and branch pipes, and 4 oil deposits.

At the beginning of 2013, in Donetsk oblast, there were 3,020 potentially hazardous facilities. This is approximately 13% of the total number in Ukraine, or 114 facilities per 1,000 square kilometres of land. Of the potentially hazardous facilities in Donetsk oblast:

- 1,443 were explosive
- 17 were radiation-hazardous
- 522 were flammable
- 111 were hydro-dynamically hazardous
- 22 were bio-hazardous
- 17 were assigned the first degree of chemical hazard
- 63 were assigned the second degree of chemical hazard
- 91 were assigned the third degree of chemical hazard
- 69 were assigned the fourth degree of chemical hazard.

In Luhansk oblast in 2013, there were 1,220 potentially hazardous facilities (5% of the total number in Ukraine, or 46 facilities per 1,000 square kilometres of land). Of these:

- 717 were explosive
- 7 were radiation-hazardous
- 798 were flammable
- 65 were hydro-dynamically hazardous
- 12 were bio-hazardous
- 6 were assigned the first degree of chemical hazard
- 29 were assigned the second degree of chemical hazard
- 43 were assigned the third degree of chemical hazard
- 6 were assigned the fourth degree of chemical hazard.

1.1 Conditions affecting water supply in Donbas

The literature surveyed, available in the list of references (page 59), provides a detailed description of the hydrogeological conditions of the Donbas region. Therefore, the literature and publications have been used to profile the territory in which this assessment of reserve sources of domestic water supply has been conducted. In this section, we cover only the singularities of the basin's geological structure and hydro-geological conditions which are connected with a dominant influence of coalmining and other economic activities, as well as the armed conflict, upon the environment.

Natural factors

There are two key singularities of natural conditions in the territory of Donbas.

The structural geology creates a variety of forms and sizes of folded basin structures. In terms of form, these are both synclinal (dipping) and anticlinal (rising) structures of folded rock layers. These range from linear to batchy folds[b] with rock bedding ranging from horizontal to vertical. Coal mines occur in areas of particular landforms, and water catchment areas form over minefields, which creates a geologically non-homogenous environment. A non-homogenous environment is an upper layer of the lithosphere (rigid outermost shell of the earth's surface) which presents a mixed structure of rocks.

The geology (structures and positions of rocks) affects water supplies in terms of quantity, volume and quality of underground aquifers and surface water sources. The area of underground fresh and low-salt water depends on the position of different geological layers and the interstratifications of more and less permeable rock. (The recent flooding of unprofitable mines has reduced the number of areas containing fresh water.)

Human factors

There are three particular anthropogenic conditions in Donbas affecting water quality.

1. **Extensive coalmining**: there is an extremely elaborate system of mine workings at broad-ranging depths, with a large number of closed-down and flooded mines. There is considerable horizontal expansion of the field of operations and a long duration of mine exploitation.
2. **Unstable groundwater movement** within operating and closed mines. There are regional 'cones of depression' (areas of lowered groundwater levels) spreading far beyond minefields, as well as local cones of depression migrating along breakage faces. Recharge is increasing through the infiltration of atmospheric precipitation falling over the minefields due to the growth of jointing after the collapse of roofs over worn-out treatment facilities. There is also a rise in rock permeability where roofs have collapsed over mine workings, plus absorption and penetration of surface water into mine workings where solid rock massif under streams and water ponds has been disturbed.
3. **Land subsidence and compaction**. Troughs of land have subsided over minefields, to a depth of 3–4 metres in some cases, where waterlogged areas and wetlands have developed. After collapse of mine workings, rock compaction can occur, plus dehydration compression of soil. There is intensive industrial and urban pressure on most coalmining complexes, with additional anthropogenic recharge of groundwater.

1.2 Resources of surface water in Donbas

Mining operations over more than two centuries in Donbas have extremely adversely affected the quality of surface water and the mode of surface streams. The overall resource of surface water in Donbas is formed by the basins of the Dniper, the Siverskyi Donets and small rivers of Pryazovia (Figure 1).

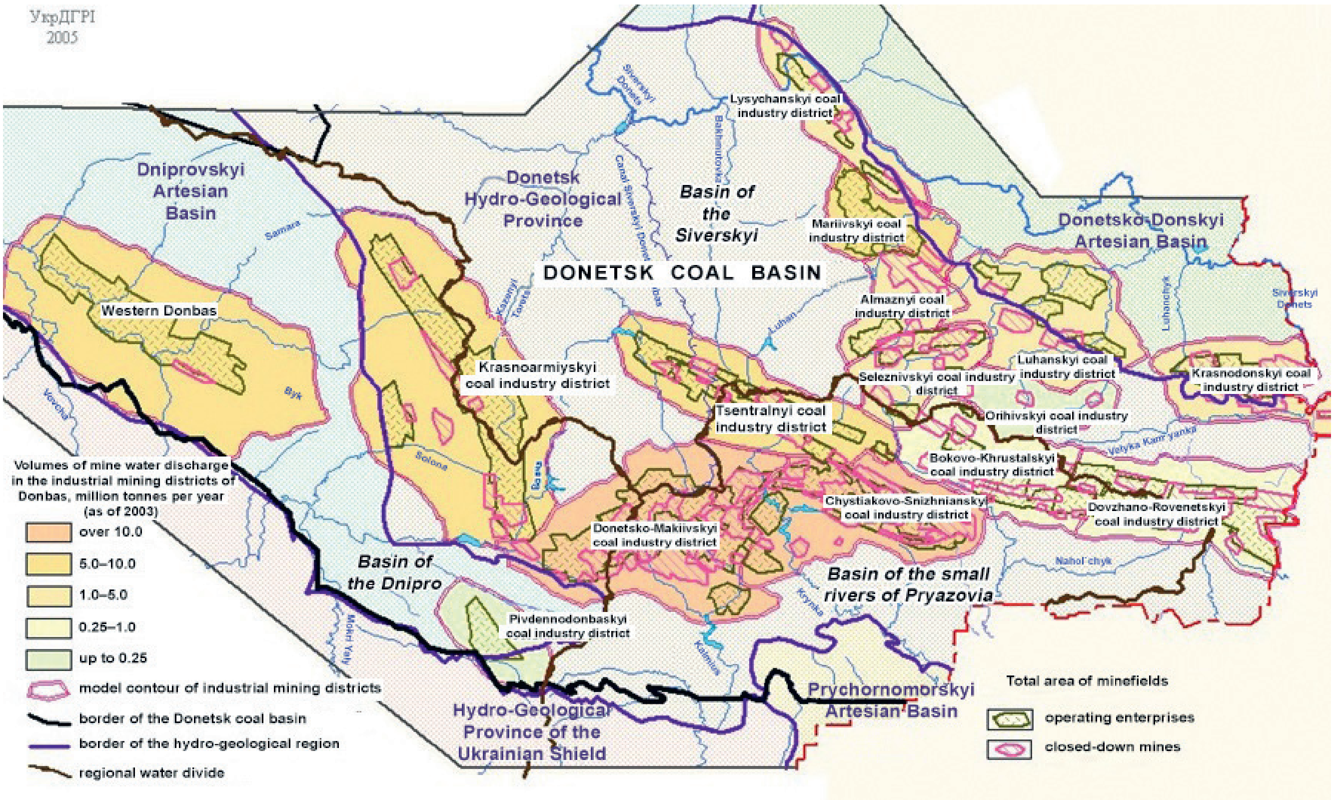
In natural conditions, the rivers of Donbas are primarily fed from atmospheric precipitation and especially the spring melting of snow, which delivers 40–80% of their runoff. Feeding from groundwater is significant only within the confines of the Donetsk Range where, due to down-cutting, river valleys drain aquifers in mineral coal deposits and covering deposits.

Mine drainage water (mine water) plays a significant role in the recharge of river runoff. The total discharge of mine water into surface streams in 1995 was approximately 25m^3 per second [1]. Now, according to the authors' estimates, it amounts to 24.2m^3 per second or 87,000m^3 per hour (Table 1). Industrial facilities in Donbas discharge approximately 70m^3 per second (252m^3 per hour). For domestic and industrial use, approximately 39m^3 per second (140,000m^3 per hour) of water are taken from the rivers according to the available data [2].

Measuring the impact of coalmining on the formation of ecological and resource-related parameters of the surface runoff was based on comparing natural indicators of the river mode in an undisturbed state and under the influence of human activities. However, the following circumstances complicated the task.

1. The development of coal deposits in Donbas, followed by the dewatering of solid rock massif and a large-scale discharge of mine drainage water into surface streams, began over 130 years ago. However, a systematic study of the hydrological regime of the rivers of Donbas started only in the second half of the 1940s, when significant human influence already existed – and no attempts were made to define and assess this.
2. Long-term systematic data concerning the quantity of mine water discharge in rivers are not available. The rivers of Donbas are characterised by an extremely broad range of river discharge values in different time periods. With such a range, a comparison is challenging since during flooding the impact of mine water discharge may be insignificant, while it may be a decisive factor in the dry-weather period. Therefore, for comparison, we can use only the river discharge calculated as an average over many years.

Figure 1. Map of Donbas river basins: surface water resources and mine-water discharge



3. A natural broad range of the content of soluble salts is typical for the rivers of Donbas, particularly Pryazovia. Water salinity ranges from 0.2–0.3g/dm^3 at the time of seasonal flooding to 3.5–5.0g/dm^3 in the dry season. With mine-water salinity primarily at the level of 2.0–4.0g/dm^3, mine-water discharge into surface streams may have both a negative and a positive impact.

In Donbas, there is a large number of enterprises applying water-use technologies and having a substantial volume of discharge. In total, this is three times greater than the volume of mine-water discharge: up to 70m^3 per second or 252,000m^3 per hour were discharged by urban industrial agglomerations recorded up until 2010.

To satisfy household needs, since 1958 the Siverskyi Donets-Donbas Canal has supplied water at the rate of up to 35m^3 per second. Since the beginning of the 1980s, the Dnipro-Donbas Canal has supplied up to 45m^3 per second. After such water use and irreversible technological losses, a significant portion of this water is discharged into rivers, thus entirely changing the river discharge. Unfortunately, not all existing hydrological reference works take this into consideration [2, 3]. They reference only results of a study of multi-year materials without distinguishing the anthropogenic component.

The above-mentioned circumstances reduce the accuracy of the conducted assessments to some extent. However, even given their implications, in many cases the impact of coalmining enterprises upon surface-runoff formation is illustrative.

1.3 Resources of groundwater in Donbas

Regionally, there are complex and varied conditions for accumulating groundwater resources and determining its quality. The specific hydro-geological conditions of various zones of Donetsk and Luhansk oblasts arise from a complex interplay of geological factors. These include the composition of water-bearing rock (notably its solubility), physical-geographical factors (such as precipitation volumes, development of river networks and climate) and, in past decades, anthropogenic factors (such as drainage by mines, open-pit mines, water-intake facilities and infiltration of anthropogenic contamination).

Table 1. Scale of coalmining operations by Donbas river basins, 2012/13

Donbas river basins of the 1st order		Minefield impact areas, thousand km²	Mine-water discharge volume (for 2012), thousand m³/hour	Coal extraction (for 2013), million tonnes/year	Total number of mines with water pumping: operating / closed	Mine-water discharge rate, m³/hour per km²
Basin of the Dnipro-Samara		1.59	14.70	18.17	31 / 4	0.8
Basin of the Siverskyi Donets		2.29	30.18	18.09	65 / 29	1.1
Small rivers of Pryazovia	The Kalmius	0.64	11.63	6.04	18 / 9	1.7
	The Mius	1.50	30.46	9.67	69 / 18	1.8
Total for Donbas		**6.02**	**86.97**	**51.96**	**183 / 61**	**1.3**

At the same time, there are distinct regional features in groundwater distribution, resources and quality. For instance, the zones of shallow and open coal seams ('Open Donbas' – the central and eastern parts of Donetsk oblast and the south-western part of Luhansk oblast) are characterised by the development of porous cracks with an active water exchange in the water-bearing rock up to the depth of 100–200 metres. Northern regions of Donetsk and Luhansk oblasts have the hydro-geological structure of an artesian basin with a storey development of aquifers in soft sedimentary rock. Lower aquifers (the third and fourth, counting down from the surface) contain saline (salty) water, which accounts for a higher concentration of salts in mine water and its contaminating impact on rivers, springs, wells and the top groundwater layer.

Groundwater runs in all kinds of stratigraphic units of rock. The Dniprovskyi Artesian Basin and the Dniprovsko-Donetskyi Artesian Basin (along with the Donetsko-Donskyi Artesian Basin) are abundant with fresh groundwater originating in Meso-Cenozoic deposits. In the Donetsk hydro-geological folded province in the area of the Palaeozoic folded unit of metamorphosed sedimentary rock (from the Devonian period until the beginning of the Mesozoic age), groundwater reserves are confined to aquifer units of Jurassic, Triassic, Lower Permian and mineral coal deposits (see Figure 1, Table 2).

There are several key natural and anthropogenic factors in the formation of fresh groundwater resources within the Donbas groundwater basins. These factors also affect the interaction between groundwater and surface runoff. They include: specific features of the tectonic structure; relief fragmentation for active water-exchange zones with due account taken of water catchment areas and the boundaries of geological structures for slow water exchange zones; and the

Table 2. Mining and population in hydro-geological areas, 1 January 2014

Hydro-geological provinces, artesian basins	Area, km²			
	Region	Minefields	Towns, urban settlements	Towns, urban settlements over mines
Donetsk Folded Province	22,963	4,219	2,272	963.9
Dniprovskyi Artesian Basin	8,743	649	114.9	14.3
Dniprovsko-Donskyi Artesian Basin	311	–	–	–
Donetsko-Donskyi Artesian Basin	4,343	28	281.5	21.9
Hydro-Geological Province of the Ukrainian Shield	3,931	–	48.5	–
Prychornomorskyi Artesian Basin	789	–	12.2	–
Total	**41,080**	**4,896**	**2,729**	**1,000.1**

impact of mine drainage (water pumping) on the formation of cones of depression and discharges into the runoff of the Siverskyi Donets, the Luhan, the Kalmius and other rivers.

Prognosed resources[c] of drinking groundwater in Donetsk oblast total 2.4 million m^3 per day, including explored resources with approved reserves of 1.1 million m^3 per day (115 sites). Presently, the aggregate groundwater intake amounts to 0.34 million m^3 per day or 14% of the total quantity of inferred resources. In 2015, episodic contaminations by natural compounds were registered at 34 water intake facilities (an increase in dry residue, hardness, the content of sulphates, chlorides, iron, and manganese).

Luhansk oblast is mostly provided with inferred resources of fresh groundwater (4.8 million m^3 per day) and has a high level of exploration (98 sites with reserves of 1.9 million m^3 per day or 40%). In 2015, contamination was recorded at 12 water intake facilities (dry residue, hardness, the content of iron, manganese, nitrates, phenols, and ammonium). A lower level of contamination is attributed to a greater degree of protection by regional water-confining strata (poorly permeable layers).

In general, a majority of raions (districts) of Donetsk and Luhansk oblasts (provinces) have a substantial reserve of explored and prospective sites of drinking groundwater. It is reasonable to prepare such sites for exploitation as back-up or basic water supply points for when there are disturbances in water supply by the Donbas Water Company from surface sources. Such surface sources are primarily unprotected from contamination due to adverse effects of military activity and the leakage of contaminated water from flooded mines. Sources of surface water are also unprotected from and the possible influx of contaminants from waterlogged and flooded landfill sites during spring flooding or times of increased precipitation, and from unauthorised discharges into domestic water reservoirs and other surface water bodies in the river basin of the Siverskyi Donets and its tributaries.

2. Current threats to domestic water supply

The current domestic water supply in Donbas and its development occur under special conditions due to the following factors related to technologies, resources and the environment.

1. Up to 80– 90% of water in Donetsk oblast is supplied from unprotected surface runoff of the Siverskyi Donets through a hydraulic engineering complex of water reservoirs, canals and water pipes, which drastically diminishes sustainability and safety of domestic water supply systems.
2. The surface runoff of the Siverskyi Donets is characterised by significant seasonal fluctuations, with quality dependent on precipitation per year.
3. The water catchment area of the Siverskyi Donets in the Russian Federation, and in Kharkiv, Donetsk and Luhansk oblasts of Ukraine has a high level of plough disturbance (up to 65%) and contamination of water-collecting spots in the relief, great volumes of influx of industrial (mine) waste and a low degree of conservation of water protection zones.

In general, the domestic water supply in Donbas is seriously endangered by the armed conflict, which have caused destruction of water treatment facilities, hydraulic engineering structures and power supply systems. Dangerous repair and reconstruction works have led to deaths among professionals. This has required introducing restrictions on water supply, for the drinking water quality to cause minimum damage to the health of the local population and military personnel. At present, control of drinking water quality is primarily connected with Donbas Water Company's systems. Meanwhile, there are many scattered shaft wells, springs and local boreholes without a systematic water quality control. Their usage rate rises significantly when Donbas Water Company's facilities are damaged.

In addition to the direct effects of the ATO, there is a growing threat of unauthorised discharges in surface runoff of the Siverskyi Donets basin. The assessment conducted for this study has demonstrated that enhancement of technological sustainability and ecological safety of domestic water supply in Donbas may be achieved through diversification of drinking water sources on the basis of the resources of explored groundwater intakes and individual boreholes. Groundwater sources of domestic water have a high degree of protection from contamination, stability of chemical composition and independence from annual precipitation.

> “There is a need for exploration of reserve water sources suitable for human consumption in these regions, as termination of centralised drinking water supply in the above-mentioned towns will result in a humanitarian crisis.

Concerning the enhancement of ecological resource-related safety of domestic water supply, a gradual increase in the number of operating boreholes could mitigate risks of water-ecological emergencies and reduce consequent social tensions. Findings of the HD mission's ecological survey of reserve water supply sources in Donetsk and Luhansk oblasts (carried out from 23 October to 4 November 2016) demonstrate that this gives room for manoeuvre for local administrations to ensure stable and ecologically safe operation of domestic water supply systems.

There are two broad implementation stages preliminarily identified in the diversification procedure for domestic water supply. The first stage entails a comprehensive ecological anthropogenic inspection of all available reserve sources of domestic water supply that are not part of the Donbas Water Company's complex. The second stage involves identification of locations for the first regular equipping of operating water boreholes and approval of operational regulations.

In general, increasing the use of contamination-protected groundwater will help to mitigate risks of ecological water emergencies affecting public health. The surface water resources of the Siverskyi Donets are now formed in the increasingly deteriorating ecological condition of the catchment area.

In this report, the authors talk about increasing the number of operating boreholes 'from the perspective of enhancing ecological resource-related safety of drinking water supply'. Some towns in Donetsk oblast in territory uncontrolled by the Government of Ukraine, such as Donetsk, Horlivka, Torez and Khartsyzk, as well as Pokrovsk, have no underground sources of drinking water supply. Presently, drinking water may be supplied to the population and the municipal infrastructure in these towns only from surface sources. There is a need for exploration of reserve water sources suitable for human consumption in these regions, as termination of centralised drinking water supply in the above-mentioned towns will result in a humanitarian crisis.

Furthermore, even the availability of centralised drinking water supply in towns of the oblast having their own groundwater sources will not resolve the problem since, in all large towns of the oblast, groundwater sources have played only an auxiliary role, complementing water from surface sources. The use of surface water sources to meet consumer needs is dangerous and alternative (underground) sources which are protected from contamination. Facilities with high epidemic risks (pre-school educational institutions and healthcare facilities, community dining facilities, and industrial facilities) will not be able to operate with a drastic decline in the volume of drinking water and should be the first to receive clear drinking water form alternative sources. Generally, clear water is delivered to the population by special-purpose vehicles, which have a limited volume capacity.

2.1 Coalmining impacts on the geological environment of Donbas

The geological environment in coalmining districts

Commercial development of mineral coal, occurring in the Donetsk basin for over 150 years, has resulted in the extraction of over 10 billion cubic metres of coal rock massif. This has been accompanied by regional disturbance of the geodynamic and hydrodynamic environment and ecological–geological conditions of the basin. Coalmining has been carried out at around 900 mines and 180 coal seams. In total, there are close to 2,250 extraction sites. Management of the roofs of worked-out coal seams by collapsing them entirely was applied practically universally. The volume of disturbed rock amounted to approximately 600km^3, or 14.3% of the total volume of rock massif within the confines of minefields.

Coal production reached its peak in the 1980s and 1990s when there were 254 mines operating in Donbas, extracting 180 million tonnes of coal per year (Figure 2). The impact of mining upon the geological environment was supplemented with those of production activities included in the mining complex. Specifically, there were 65 preparation plants, 9 coke plants, 17 chemical complexes and 9 metallurgical plants built and operated in Donbas. As a result of large-scale mining operations, the undermined areas make up approximately 8.2% and 7.8% of the territory of Luhansk and Donetsk oblasts, respectively.

During field development, a large volume of rock undergoes mine dewatering – a process of pumping water from an underground part of a coal-mine. A fall in the groundwater level within the technical boundaries of mines can reach 300–1,000 metres. Regional ‘cones of depression’ then emerge as a result of falling groundwater levels at the sites adjacent to mine boundaries, reaching up to 30–100 metres (Figures 2 and 3). With the current annual volume of coal extraction at the level of approximately 50 million tonnes, up to 450 million cubic metres per year of contaminated saline water (rough estimates) is pumped out. This water primarily has high levels of salinity (2.0–4.0g/dm^2). A decline in the volume of pumped-out water by nearly 300 million cubic metres per year brings about acceleration of mine flooding and an increase in the migration of contaminated saline mine water into aquifers and surface runoff into rivers, which are major sources of domestic water supply.

Densely populated coalmining areas, including processing, metallurgical, machine-building, chemical and other industries

Figure 2. Scale of coalmining operations in Donbas, 1990–2005

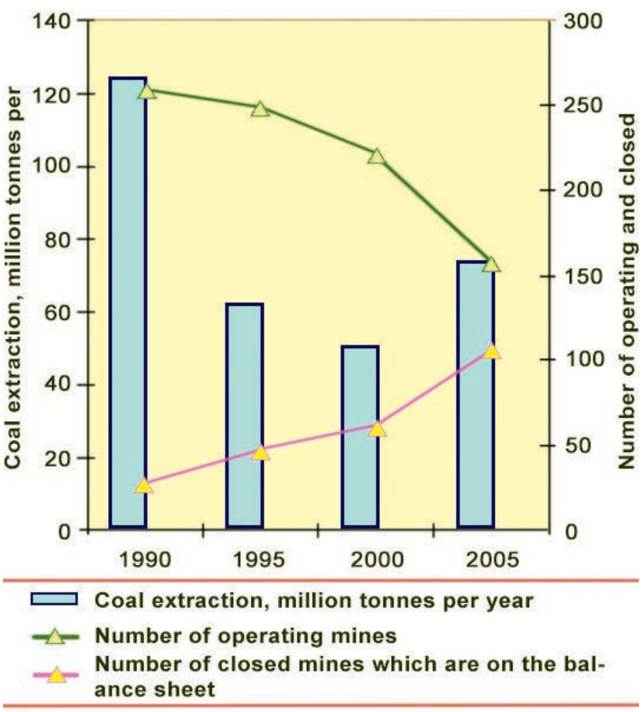
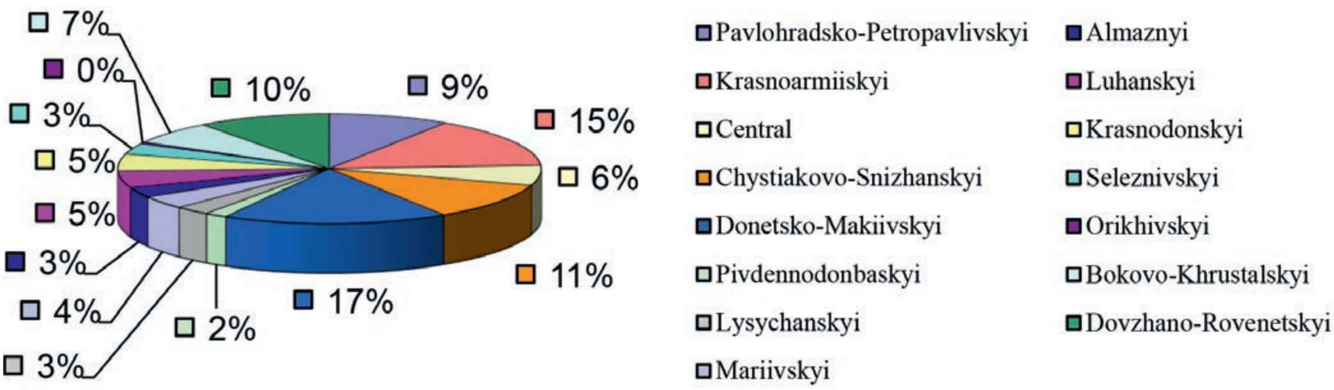


Figure 3. Comparison of minefield areas by geological industrial districts of Donbas



as well as the mines, have undergone the greatest environmental changes. The pressure from mining on the geological environment has formed in the Donetsko-Makiivskyi, Chystiakovo-Snizhnianskyi and Tsentralnyi geological industrial districts. There is less severe pressure on the Dovzhano-Rovenetskyi and Krasnoarmiiskyi geological industrial districts (Table 3).

The deepest mines are located in the Donetsko-Makiivskyi (1,420m), Chystiakovo-Snizhnianskyi (1,260–1,300m), Tsentralnyi and Dovzhano-Rovenetskyi (1,200m) geological industrial districts. The largest volume of disturbed rock is in the Bokovo-Khrustalnyi (102km^3) and Donetsko-Makiivskyi (99km^3) districts. Presently, the most productive mines (in terms of volumes of coal) in Donetsk oblast are Krasnoarmiiska Zakhidna #1, Komsomolets Donbasu and Im. Stakhanova. The most productive mine in Luhansk oblast is Dovzhanska Kapitalna, with a total yield of 8.7 million tonnes per year.

A critical aggravation of ecological conditions for the safety of human life and health and a decline in the reliability of domestic water supply systems are associated with the fact that 18% of minefields are located beneath built-up areas. In Donbas, 63 towns and 91 urban-type settlements, with a total area of 1,000 square kilometres, stand over minefields. On average, 25% of the area of the towns and 51% of the area of the other settlements are undermined (Table 4). In certain locations, coal extraction operations in old mining areas are performed in the same territory simultaneously by several mines at different depths. This significantly increases the risk of destruction of above-ground technological complexes and contamination of surface sources of domestic water, as the number of uncontrollably flooded mines grows with the duration of the armed conflict.

The ecological state of surface sources of domestic water is significantly worsened by disturbance of undermined rock massif and further land-surface subsidence. This leads to a rise in groundwater levels along with soil waterlogging, formation of additional wetlands and minor flooding of buildings in industrial zones and population centres. There is contamination of surface water and groundwater with mine water, seepage of toxic and explosive gases from mine workings, and activation of anthropogenic micro-seismic phenomena.

Coalmining impacts on river runoff in Donbas

Mining activities have had extremely adverse effects on the quality of surface water and the regime of surface water flows in Donbas. Rivers in the Ukrainian part of Donbas belong to three river basins: the Siverskyi Donets, the Dniper and the Azov Sea. In natural conditions, the rivers of Donbas are primarily fed from atmospheric precipitation and, first and foremost, spring snowmelt, which supplies 40–80% of their runoff. Recharge from groundwater is significant only within the confines of the Donetsk Range where, due to down-cutting, river valleys drain aquifers in coal deposits and covering deposits.

Mine drainage water (mine water) plays a significant role in the recharge of river runoff. The volume of such water discharge into surface water flows in 1995 was about 25m^3 per second. According to the authors' calculations, it is presently 15m^3 per second or 550 million m^3 per year. For domestic and industrial use, up to 40m^3 per second (144,000m^3 per

Table 3. Areas affected by coal mines, by administrative units of Donbas

Number, in the Donbas Water system	Towns of oblast subordination, administrative raion within the boundaries of the coalmining district	Area of the administrative unit (within the boundaries of the Donbas Water system), km²	Areas affected by coal mines		
			Total area of minefields, km²	Potentially waterlogged lands	Waterlogged land in towns and urban settlements, hectares
1	2	3	4	5	6
1. Donetsk oblast			2,664	65	5,369
1	Dobropollia, Bilozerske, Biletske	17.37	14.31	–	175
	Dzerzhynsk, Artemovo	14.39	13.87	–	–
	Dymytriv, town	18.91	18.61	–	–
	Oleksandrivskyi raion	1,005.04	64.59	–	175
	Dobropilskyi raion	940.07	189.60	–	–
	Kostiantynivskyi raion	1,340.83	65.38	–	–
	Krasnoarmiiskyi raion	1,463.19	434.64		570
	Mariinskyi raion	1,366.63	223.88	–	22
2	Horlivka, town	127.0	71.40	–	–
	Yenakiieve, Vuhlehirsk, Yunokomunarivsk, towns	39.57	13.56	–	27
	Avdiivka, town	11.33	2.24	65	–
	Yasynuvata, town	12.67	12.62	–	480
	Zhdanivka, town	3.87	2.30	–	–
	Kirovske, town	4.24	2.89	–	73
	Khartsyzk, Ilovaisk, Zuhres, towns	128.29	104.80	–	342
	Shakhtarsk, town	39.05	35.00	–	–
	Torez, town	49.65	46.70	–	–
	Snizhne, town	29.99	26.39	–	–
	Makiivka, town	75.21	75.21	–	–
3	Donetsk, Mospyne, towns	194.67	179.49		2,973
	Vuhledar, town	1.04	0.11	–	532
	Dokuchaivsk, town	9.80	–	–	–
	Artemivskyi raion	2,041.81	33.36	–	–
	Yasynuvatskyi raion	1,098.70	155.50	–	–
	Shakhtarskyi raion	2,234.38	889.81	–	–
	Volnovaskyi raion*	1,380.08	31.94	–	–
	Amvrosiiyevskyi raion	1,485.56	40.87	–	–

Number, in the Donbas Water system	Towns of oblast subordination, administrative raion within the boundaries of the coalmining district	Area of the administrative unit (within the boundaries of the Donbas Water system), km²	Areas affected by coal mines		
			Total area of minefields, km²	Potentially waterlogged lands	Waterlogged land in towns and urban settlements, hectares
1	2	3	4	5	6
2. Luhansk oblast			2,189	10	7,222
4.	Rubizhne, town	16.90	–	–	–
	Severodonetsk, town	16.81	–	–	–
	Lysychansk, Novodruzhesk, Pryvillia, towns	54.99	23.75	–	255
	Pervomaisk, Zolote, Hirske, towns	45.89	37.90	–	2,581
	Kirovsk, town	5.14	0.02	–	3
	Stakhanov, Almazna, Teplohirsk, towns	69.32	53.44	10	8
	Luhansk, Oleksandrivsk, Shchastia, towns	119.33	4.57	–	4,115
	Brianka, town	38.82	29.46	–	–
	Alchevsk, town	21.75	0.73	–	46
	Krasnodon, Molodohvardiisk, Sukhodilsk, towns	27.47	23.72	–	40
	Krasnyi Luch, Vakhrusheve, Miusynsk, towns	68.49	50.56	–	155
	Antratsyt, town	24.01	9.23	–	–
	Rovenky, town	26.46	24.70	–	–
	Sverdlovsk, Chervonopartyzansk, towns	45.04	36.03	–	–
	Kremenskyi raion*	1,023.44	21.53	–	–
	Popasnianskyi raion	1,439.61	233.17	–	–
	Slavianoserbskyi raion*	1,087.16	100.59	–	–
	Stanychno-Luhanskyi raion*	578.37	3.67	–	–
5.	Perevalskyi raion	868.48	271.59	–	–
	Lutuhynskyi raion	1,069.91	194.63	–	19
	Krasnodonskyi raion	1,422.91	247.79	–	–
	Antratsytovskyi raion	1,823.89	512.19	–	–
	Sverdlovskyi raion	1,310.52	318.17	–	–

Table 4. Towns of Donbas developed over minefields, by territory of coalmining districts

No.	Town within the confines of a coal industry district	Names of operating mines and coal preparation plants operating within the confines of the town	Names of closed plants located beneath a built-up territory, year of mine closure	Town area by coal industry districts		
				Total area, km²	Percentage of area over minefields	Including waterlogged area, hectares
1	2	3	4	5	6	7
1. Donetsk oblast						
1.1 Krasnoarmiyskyi coal industry district				**80.15**		**745**
4	Bilozerske	Bilozerska	–	2.40	100	165
5	Dobropillia	Almazna, Dobropilska	–	12.78	60	10
6	Biletske	Bilytska, Ordynska, VZF Zhovtneva *(Zhovtneva Coal Preparation Plant)*	–	2.18	100	–
7	Rodynske	Rodynska, Krasnolymanska, Tsentralnaya, Im. Stakhanova, TsZF Krasnolymanska *(Krasnolymanska Central Coal Preparation Plant)*	Zaporizka, 1972	4.07	100	–
8	Dymytrov	Tsentralna, Im. Dymytrova, Im. Stakhanova	–	18.19	95	–
9	Pokrovsk	–	Im. Shevchenka, 1991	21.24	15	570
10	Novohrodivka	Novohrodivska #2		4.29	100	–
11	Selydove	Im. Korotchenko, TsZF Selydivska *(Selydivska Central Coal Preparation Plant)*	Selydivska, 1995	8.36	40	–
12	Ukrainsk	Ukraina, TsZF Ukraina *(Ukraina Central Coal Preparation Plant)*	–	2.03	100	–
13	Hirnyk	Kurakhivska	Hirnyk, 1999	4.61	100	
1.2 Tsentralnyi coal industry district				**195.08**		**27**
14	Dzerzhynsk	Novodzerzhynska, Toretska, Im. Dzerzhynskoho, Nova, Pivnichna, TsZF Im. Dzerzhynskoho *(Central Coal Preparation Plant Named after Dzerzhynskyi)*	Im. Artema, 2001	10.79	100	–
15	Horlivka	Im. Haharina, Komsomolets, Im. Lenina, Im. Rumiantseva, Im. Kalinina, Oleksandr-Zakhid, Im. Haievoho, Im. K. Marksa, Ts.ZF Kalininska *(Kalininska Central Coal Preparation Plant)*, Vuzlova	Im. Izotov, 1997; Kocheharka, 1997; Kindrativka, 1999; #19–20, 1994; Rtutna #3, 1984	127.0	70	–
16	Yenakiive	–	Krasnyi Profinter, 2001; Krasnyi Oktiabr, 1997	24.89	30	27
17	Vuhlehirsk	TsZF Vuhlehirska *(Central Coal Preparation Plant)*	–	12.1	–	–
18	Yunokomunarivsk	–	Krasnyi Oktiabr 1997, Yunyi Komunar 2001	20.3	70	–
1.3 Chystiakovo-Snizhnianskyi coal industry district				**153.09**		**415**
19	Zhdanivka	Zhdanivska, Vinnytska, Im. Shestydesiatyrichchia VZhSR	Krymska, 1996	3.87	60	–

No.	Town within the confines of a coal industry district	Names of operating mines and coal preparation plants operating within the confines of the town	Names of closed plants located beneath a built-up territory, year of mine closure	Town area by coal industry districts		
				Total area, km²	Percentage of area over minefields	Including waterlogged area, hectares
1	2	3	4	5	6	7
20	Shakhtarsk	Postnykivska, #17, Im. 17 Partzizdu, Shakhtarska-Hlyboka, TOV ‘Shakhtovuhleservis’, Fominska mining site	Shakhtarska, 2001; Fomynska, 2001; Obiednana, 2001; #43, 2000; Im. Chapaieva, 1995; #1-6, 1993; Kyivska, 1987; #2- 2-bis, 1985	39.05	80	–
21	Torez	Zoria, Im. Lutuhina, Prohres, Im. Kyselova, Udarnik, Postnykivska, Torvuhillia PP, Enerhovuhillia	Obiednana, 2001; Miuska, 2001; Chervona Zirka, 2000; Udarnik #24, 1993	49.65	90	–
22	Snizhne	Im. Kyselova, Udarnik, Ahroprom *(Avanhard mining site)*	Miuska, 2001; Skhid, 2001; Snizhnianska, 2001; Udarnik #24, 1993	29.99	40	–
23	Kirovske	Komsomolets Donbasu, Zhdanivvuhillia *(field of the Rassviet Mine)*	–	4.24	70	73
24	Khartsyzk*	Komunist *(80% of the town area is in the Donetsko-Makiivskyi Coal Industry District)*	–	10.2 *	20	50
25	Zuhres	–	Khartsyzka, 1996	5.72	7	92
26	Ilovaisk	Ilovaiska	–	9.33	7	200
1.4 Donetsko-Makiivskyi coal industry district				**1,323.0**		**3,775**
27	Krasnohorivka	Im. Cheliuskintsiv	–	7.13	20	–
28	Avdiivka	Butivka-Donetska, Butivska	–	11.33	20	22
29	Yasynuvata	Butivska, Im. Zasiadko, Chaikine	–	12.67	100	480
30	Khartsyzk*	Chaikine, Im. V.M. Bazhanova, Hlyboka, Im. Lenina, Kalynivska-Skhidna, #13-bis, Yasynivska Hlyboka, Im. Kirova *(20% of the town area is in the Chystiakovo-Snizhnianskyi Coal Industry District)*	Sovietska, 2001; Im. Batova, 2000; #21, 2000; Im. Pochenkova, 2001; Makiivska-Tsentralna, 1999; Im. Ordzhonikidze, 1998; Hanzivka #2, 1991; Hruzka Pokhyla, 1996; Kirovska Zakhidna, 1994; Novokalynovo, 1986	103.05	95	300
31	Makiivka	Zhovtnevyi Rudnik, Im. Skochynskoho, Im. Zasiadko, Zaperevalna #2, Im. Horkoho, Im. Kalinina	Im. Pochenkova, 2001; Zhovtneva, 2000; Im. Ordzhonikidze, 1998; Chervonohvardiyska, 1998; Panfilivska, 1996	75.21	100	n/a
32	Donetsk	Im. Skochynskoho, Lidiivka, Im. Cheliuskintsiv, Trudivska, Im. Abakumova, Kuibyshevska, Im. Horkoho, Im. Kalinina, #20, #17-17 bis DP, Pivnichna, Zaperevalna #2	Kirovska, 2002; #9 Kapitalna, 2001; Skhid, 2001; #6 Chervona Zirka, 2001; #11 bis, 1998; ZF Trudivska *(Preparation Plant)*, 1998; #12-18, 1997; #2, 1996; Mushketivska, 1996; #29, 1993; #6 Kapitalna, 1991; #8 Pokhyla, 1988; Livenska Zaperevalna, 1993; VZF Abakumivska *(Coal Preparation Plant)*, 1989; #19, 1977; #11-21, 1968; #3-18, 1961	1,101.8	90	2,973

No.	Town within the confines of a coal industry district	Names of operating mines and coal preparation plants operating within the confines of the town	Names of closed plants located beneath a built-up territory, year of mine closure	Town area by coal industry districts		
				Total area, km^2	Percentage of area over minefields	Including waterlogged area, hectares
1	2	3	4	5	6	7
33	Mospyne	Mospynska	–	11.80	90	–
1.5 Pivdennodonbaskyi coal industry district				**1.04**		**532**
34	Vuhledar	Pivdennodonbaska #1	–	1.04	12	532
Total per oblast: 31 towns				**1,741.36**		**5,494**
2. Luhansk oblast						
2.1 Lysychanskyi coal industry district				**73.96**		**258**
35	Kreminna	–	Kreminna, 2000	13.48	30	–
36	Pryvillia	Im. Kapustina, Pryvilnianska	–	5.25	20	–
37	Novodruzhesk	Novodruzheska	Tomashivska, 1975	5.33	95	–
38	Lysychansk	Im. Mielnikova, Matroska	Chornomorka, 2002; Im. Voykova, 1984	44.42	40	255
39	Kirovsk*	*50% of the town area is in the Mariivskyi Coal Industry District*	Luhanska *(a hydraulic mine)*, 1997	5.48	5	3
2.2 Almazno-Mariivskyi coal industry district				**154.04**		**2,581**
40	Hirske*	Hirska, Karbonit, Hirska DZF *(Crushing and Preparation Plant) (15% of the town area is in the Lysychanskyi Coal Industry District)*	Raiduha, 2000	11.95	95	–
41	Zolote	Zolote, Rodina, Hirska, Karbonit, Pervomaiska	–	18.15	95	–
39	Pervomaisk	Pervomaiska, Mariia Hlyboka, Mykhailivska VZF *(Coal Preparation Plant)*	–	15.79	70	2,581
40	Teplohirsk	Holubivska, Im. Kirova	Maksymivska, 1997; Tsentralna Irmino, 1995; #100, 1986; #77, 1986; #6 Im. Kirova, 1978	33.25	100	–
41	Stakhanov	Stakhanivskyi VZK *(Coal Preparation Plant)*	Maksymivska, 1997; Im. Chesnokova, 1998; Im. Illicha, 1996	30.95	50	–
42	Almazna	*Presently, no mines*	–	5.14	2	–
43	Brianka	TOV 'Karat' (from Krasnopolivska), VZF Briankivska *(Coal Preparation Plant)*, and Kryvorizka	Krasnopolivska, 2002; Annenska, 2000; Im. Kosiora, 2000; Kryvorizka, 1999; Briankivska, 1995; Im.Dzerzhynskoho, 1995	38.82	60	–
2.3 Seleznivskyi coal industry district					**56.42**	**46**
44	Zorynsk	Nykanor-Nova	Nykanor, 1995	4.90	100	–
45	Alchevsk*	Romanivska, Komunarskyi VZK *(Coal Preparation Plant)*	Ukraina, 2003	21.75	5	46

No.	Town within the confines of a coal industry district	Names of operating mines and coal preparation plants operating within the confines of the town	Names of closed plants located beneath a built-up territory, year of mine closure	Town area by coal industry districts		
				Total area, km²	Percentage of area over minefields	Including waterlogged area, hectares
1	2	3	4	5	6	7
46	Artemivsk	Im. Artema	Ukraina, 2003; Zaperevalna, 1960	11.41	95	–
46	Perevalsk	Perevalska, Romanivska	Ukraina, 2003	18.36	70	–
2.4 Luhanskyi coal industry district				**123.8**		**4,134**
47	Lutuhyne	Lutuhinska	–	5.31	25	19
48	Luhansk	Mine Administration 'Luhanske'	–	116.74	5	4,115
49	Oleksandrivsk	Mine Administration 'Luhanske'	–	1.78	5	–
2.5 Krasnodonskyi coal industry district				**27.47**		**40**
50	Molodohvardiisk	Orikhivska, Talivska, Im. Piatdesiatyrichchia SRSR	–	2.42	100	–
51	Sukhodilsk	Duvanna, Im. Barakova, Sukhodilska-Skhidna, Talivska, Duvanska TsZF (Central Preparation Plant)	–	5.07	100	–
52	Krasnodon	Im. Barakova	Im. S. Tiulenina, 1995; Im. Molodoi Hvardii, 1990; Im. Koshevoho, 1975	19.98	80	40
2.6 Bokovo-Khrustalskyi coal industry district				**84.7**		**155**
53	Vakhrusheve	Olvin-Treid, Kniahinynska, Krasnokutska, Khrustalska	Almazna, 2000; Yelizavetivska, 1999; Yanivska #3, 1997	18.48	90	90
54	Krasnyi Luch	Krasnolutska, Im. Hazety Izvestia, Kniahinynska, Miusynska, DZF Im. Hazety 'Izvestia' *(Crushing and Preparation Plant)* and Krasnolutska	Miusynska #3-4, 1997; #4-bis, 1967; #162, 1964	34.57	92	–
55	Miusynsk	Miusynska	Miusynska #3-4, 1997	7.62	8	65
56	Antratsyt	Partyzanska, Koil A.S, Im. Piatdesiatyrichchia Radianskoi Ukrainy, Komsomolska	Tsentralna, 1996; #15, 1962	24.01	50	
2.7 Dovzhano-Rovenetskyi coal industry district				**71.5**		
57	Rovenky	No 1 Rovenkivska, #2 Luhanska, #81 Kyivska, #71 Industria, Voroshylivska, Im. Kosmonavtiv, #2 Im. Dzerzhynskoho	Kyivska Komsomolska #2, 1982; No 3 Im.Dzerzhynskoho, 1997; #54, 1994	26.46	80	–
58	Sverdlovsk	Kharkivska, Tsentrospilka, Im. Sverdlova, Sverdlovska DZF *(Crushing and Preparation Plant)*	Im. Voikova, 2002; Maiska, 2000; Sverdlovska, 1995	36.57	75	–
59	Chervonopartyzansk	Chervonyi Partyzan	Maiska, 2000	8.47	100	
Total per oblast: 31 towns				**591.89**		**7,214**

hour) are withdrawn from the rivers according to the 2013 approximate data.

The runoff system of river basins and local groundwater basins undergoes comprehensive changes caused by a rise in the scattered runoff of contaminated water from mines that are being flooded. Determining the projected impact of coalmining enterprises on surface runoff, especially in the Siverskyi Donets basin, which will remain the key source of domestic water supply for a long time, is complicated. This is because of a decline in the level of regional ecological water monitoring, including the following factors.

1. There is a lack of multi-year systematic data concerning the amount of mining water discharged into rivers.
2. The rivers of Donbas demonstrate a substantial variability of river discharge in different seasons. This increases the relative share of mine water, industrial waste inflows and contamination levels of surface water, as a source of domestic water supply.
3. A natural broad range of the content of soluble salts is typical for Donbas, particularly for Pryazovia. Water salinity levels range from 0.2–0.3g/dm^3 during seasonal flooding to 3.5–5.0g/dm^3 in the dry season. With mine water salinity primarily at the level of 2–4g/dm^3, its discharge into surface water flows may have a predominantly negative impact, given the reduced surface runoff during dry-weather periods of summer–autumn and winter.
4. Even under the current conditions in Donbas, there are many enterprises applying water-use technologies and having significant volumes of discharges, which according to estimates may exceed the volumes of mine water discharge. This creates substantial risks of water-ecological emergencies.

Under the current water-use schemes, wastewater from mines, industrial plants and households is discharged into rivers, completely changing resource-related and hydro-chemical indicators of the river runoff. Unfortunately, due to the destruction of the surface- and ground-water monitoring system, the existing present-day hydrological data do not permit accurate calculations concerning the impact of these factors.

2.2 Potential radiation impact of burial of the Klivazh facility in Yunkom mine

Amid the closure of mines in Donbas, the ecological and geological environment responds with ‘auto-rehabilitation processes’. These have considerable effects on conditions affecting urban mining agglomerations. Key processes include a regional rise in groundwater levels within affected river basins. There is also an accelerated migration of anthropogenic contamination due to an intensified water exchange in the zones of aeration (also known as unsaturated zones or zones of suspended water). There is an expansion of waterlogged and flooded areas of geochemically contaminated sites, both under and above ground.

In addition to the above, in our opinion, additional rock subsidence during rock saturation with water and the development of new migration routes for explosive gases may to a great extent be qualified as auto rehabilitation processes. These are also occurring in connection with the closing of mines in coalmining districts of Donbas.

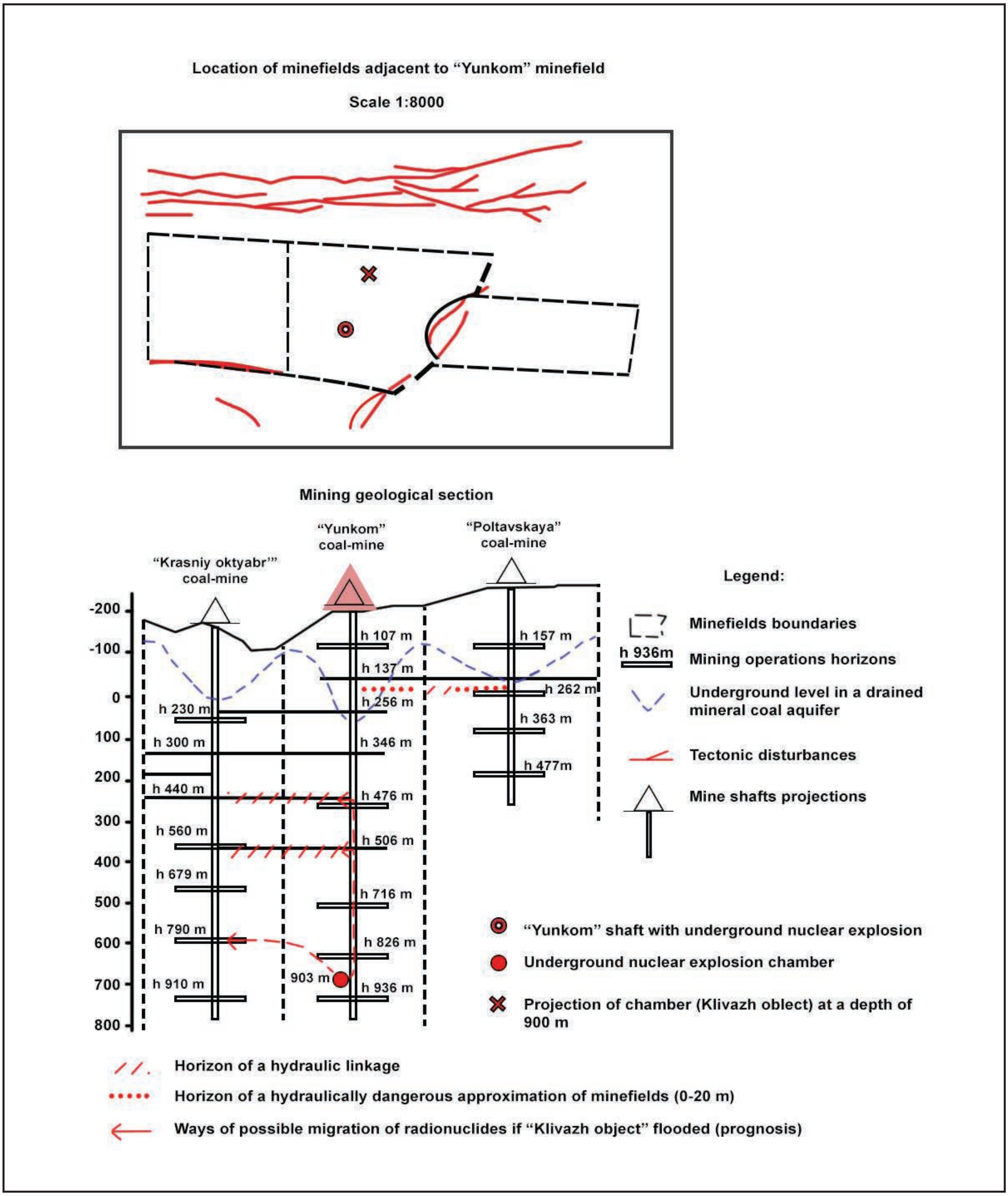
In 1979, an industrial underground nuclear explosion with a TNT energy equivalent yield of 200–300 tonnes (0.2–0.3kt) was produced at the Yunkom mine. This mine is in Yunokommunarovsk town, on the southeastern periphery of the Tsentralnyi coalmining district in Donetsk oblast. This happened for the first time in the world and in a densely populated and intensively exploited coalmining district. The purpose of the underground nuclear explosion was to assess its effectiveness for reducing the frequency of sudden coal and gas outbursts in the process of coal bed workings. A code name for the section of the geological environment containing the chamber of the underground nuclear explosion and an adjacent jointing zone is the Klivazh facility (Figure 4).

In the opinions of the researchers of the present report, the planned closure of a group of hydraulically interconnected mines of the Tsentralnyi coalmining district, including the Yunkom mine, given insufficient physical and technological coherence of measures, creates a risk of practically uncontrolled flooding of the Klivazh facility. The consequences of this are difficult to predict precisely but may include the contamination of groundwater and the wider geological environment with anthropogenic radionuclides. This may lead to a risk from radiation to human health and life.

Groundwater contamination from the Yunkom mine

The Yunkom mine is a hydraulically interconnected area of the geological environments of the adjacent Chervonyi Zhovten and Poltavska mines. Groundwater contamination has been persistent here for the past 50 years, extending as mining operations have extended in depth and area. Key impacts

Figure 4. The Yunkom mine area: adjacent minefields and a geological section



include the enhanced infiltration of saline mine water, geochemical contamination of landscapes, and destruction of regional low-permeability layers. This has resulted in a practically complete replacement of fresh water (up to 1.0–1.5g/dm^3) and slightly saline water (1.5–3.0g/dm^3) with saline water containing concentrations of dissolved salts in the range of 3–5g/dm^3 in up to 70% of the research area.

Various previous project studies demonstrate that accelerated groundwater contamination during the development of mining operations was caused by an increasing impact of the following factors.

- A rise in rock massif permeability due to the development of anthropogenic jointing in the areas where rock balance has been upset by mining operations.
- A rise in the infiltration of anthropogenic water and contamination caused by a more active interplay of surface and ground water, including due to the undermining of river beds.
- An increase in the area of landscapes contaminated through human activity, as well as in the number of filtering waste ponds with industrial and mine water.
- Development of poor drainage areas and non-contributing areas where land subsides over mine workings.

The vulnerability of groundwater has been assessed in quasi-stationary conditions when it is affected by mine water drainage, tectonic structures, a hydrographic network and a zone of aeration (groundwater depth levels). These assessments have demonstrated the prevalence of areas with a high level (60%) and an elevated level (30%) of proneness for aquifer contamination amid landscapes creation and changes induced by industrial activities.

Presently, in the area of declined groundwater levels of the Yunkom minefield within the confines of finished coal layers and the surrounding permeable sandstone, there is a possibility of an accelerated upward migration of saline mine water, including radionuclides of caesium-137 and strontium-90, during the flooding of mine workings. This may happen if there is a passive flooding and a partial decline in the level of hydro-isolation of the Klivazh facility while preliminary safeguarding measures to stabilise the adjacent rock massif are not implemented.

An analysis of the mining-geological conditions of the Chervonyi Zhovten and Poltavska mines, which are adjacent to the Yunkom mine, demonstrates that the presence of hydraulic linkages may be a contributing factor for the acceleration of upward and planned radionuclide migration processes. Key links are the horizons of 476m and 596m, and the hydraulically hazardous approaching of mine workings (the horizon of 262m of the Poltavska mine – the Yunkom).

The explosion chamber of the Klivazh facility is located in the central area of mining operations of the Yunkom mine, which is characterised by an utmost disturbance of coal-bearing rock massif and a significant depth of mine workings (up to 1 km). Thus, if there is an accelerated hydro-geo-mechanical destruction of the Klivazh facility and the facility is upwardly flooded, there will be an increased risk of the manifestation of all groundwater vulnerability factors, as well as local contamination of surface watercourses (see Figures 1–3).

On the other hand, the explosion chamber of the Klivazh facility is located at a substantial depth (903m) and characterised by the local evolution of jointing and the absence of hydraulic linkages and hazardous geotechnical approximations with mine workings of the adjacent mines (the Chervonyi Zhovten mine and the Poltavska mine). There is also a slow rock deformation and low rates of the migration of water-soluble forms of radionuclide, namely caesium-137 and strontium-90, through a relatively solid layer of rock capable of absorption.

In addition, the flooding of a stabilised rock massif, provided there is a steady filtering saturation of the explosion chamber of the Klivazh facility with water, may lead to the establishment of a practically stagnant regime. This may result in decelerated sorption and migration processes in the enclosing rock.

The underground nuclear explosion at the Yunkom mine

The Yunkom mine (within the Tsentralnyi coalmining district) in Donbas was distinguished by high levels of sudden outbursts of coal and explosive gases during mining operations. Between 1959 and 1979, there were up to 235 gas-related geodynamic phenomena at the Yunkom mine, including 28 cases involving the death of workers.

The geological conditions of the Yunkom minefield feature an intensive tectonic disturbance of rock by four large thrusts and a dense network of local deformations of coal seams and enclosing rock. On average, there is one disturbance per 243m of the minefield. At the horizon of 823m, up to 42% of coal beds that are worked are located in the areas of geological faults. High gas saturation levels of coal-bearing rock under conditions of significant tectonic disturbance is a factor contributing to the continuous emergence of gas and coal outbursts and a growing insecurity of mining operations.

The nuclear explosion with a yield of 200-300 tonnes (0.2-0.3 kt) was conducted at a depth of 903m between the Deviatka and the Kyrpychivka coal seams, 45m and 31m away, respectively. The chamber for the placement of the nuclear explosive charge was constructed in an inclined working, which had been driven from the level of 826m through enclosing sandstone. The place of the explosion chamber in sandstone was selected on the basis of expectations for the formation of a vitreous water-insoluble melt capable of containing up to 95% of the explosion products, according to estimates. In addition, to prevent the migration of gaseous explosion products, the explosion chamber was isolated by concrete bulkheads with a width of 6–10m.

Justifying the explosion's yield, the designers factored in seismic safety of mine shafts, permanent mine workings, and industrial and residential buildings located on the surface in the area close to the Yunkom mine and the town of Yenakiieve. After the explosion, up to 1,260 buildings were examined on the surface, within a radius of 1.6km from the explosion epicentre. Of the examined buildings, 22 (1.8%) demonstrated the emergence of hairline cracks, the deformation of chimneys and the falling-off of whitewash. Practically no disturbances were identified in mine workings, apart from the falling-off of small fragments in a long wall working from the roof and side surfaces of individual nearby workings.

The examination results demonstrated that gaseous explosion products had not migrated beyond the confines of the isolating bulkheads, since the traces of strontium-90 and caesium-137 emerged in mine water only after the opening of the isolation-complex material in 1991. Between 1979 and 1992, there was no registration of any accident associated with a sudden outburst of coal and explosive gases.

Mining operations in the area of potential gas-geodynamic impact of the nuclear explosion were conducted in accordance with a special project. The project envisaged a procedure for preparing and working with coal seams, as well as measures concerning radioactive safety and environmental protection. According to agency-level data for 1992–2001, radiation pollution levels of the workings and the surface corresponded to the natural background level, while radionuclide concentrations of strontium-90, caesium-137 and tritium in mine water were lower than acceptable levels for drinking water by a factor of hundreds.

Preliminary ecological-geological assessment of the nuclear explosion chamber and the adjacent rock massif

An ecological-geological singularity of the formation of the nuclear explosion's affected area is the presence of an explosion chamber (a camouflet chamber), i.e. a chamber that has evolved without an explosion-driven outburst of rock. Field assessments have showed that vitreous sandstone melt may contain concentrations of up to 95% of radioactive explosion products (Semypalatynsk, Nova Zemlia, and other nuclear test sites).

Data obtained through probing boreholes and an inspection of the 936-metre horizon on 17 October 2001 indicate the following radio-ecological conditions in the explosion chamber of the Klivazh facility.

- Partial downward filtration of groundwater into mine workings at the horizon of 936m (33m below the explosion epicentre).
- Destructive deformations of the explosion chamber and water admission (according to the data obtained through a probing borehole, which opened the chamber in September 1991).
- A small horizontal radius of the explosion chamber – up to 5.0m (diameter up to 10.0m), with the formation of up to 100 tonnes (according to estimates) of a vitreous molten mass where 95% of radioactive explosion products are concentrated.
- Formation of an area of crushed (entirely ruined) rock, within the confines of which such rock is transformed into sand fractions and gravel fractions, with a radius of up to 8.0m from the explosion epicentre, i.e. with a stable area thickness of (8.0-5.0)≈3.0m.
- Development of a radial jointing area at a distance of up to 15m from the explosion epicentre or in the adjacent rock massif with a thickness of (15-8.0) ≈ 7.0m.

It is estimated that individual activated (formed) hidden fractures may appear at a distance of up to 20–25m from the explosion epicentre. Meanwhile, according to the data obtained through 23 probing boreholes, no radioactive melt residues have been detected in the radial jointing area.

Estimated radiation contamination in the explosion chamber and adjacent rock massif

Studies conducted in the process of underground nuclear explosions have established that one hour after an explosion (t=1 hour) the volume of radioactive contamination (R_t) depends on the yield of such explosion (TNT equivalent in kilotons) q:

$$R_{t=1h} = 4.5\ 10^8 q = 4.5\ 10^8\ 0.3 = 1.35\ 10^8 Ci$$

Generally, the quantity of radioactive products R_t changes over the course of time and is a function of the following:

$$R_t = R_{t=1\ h}\ t^{-1.2}$$

Within the period of 1979–2001, the residual quantity of radioactive products may be estimated at the following level:

$$R_{t(2001)} = \frac{R_{t=1\ ч}}{[(2001 - 1979)] \times 365 \times 24]^{1.2}} = \frac{1.35 \times 10^8}{(1.93 \times 10^5)^{1.2}} = 60Ci$$

Certain estimations imply that, depending on the composition of a nuclear explosion substance, the volume of produced radioactive products may amount to the following: $R_0 = 2\ 10^6 Ci$ when $q = 1\ kt$. This means that, at the initial stage for the conditions of the Yunkom mine this could amount to:

$$R_0 \cong 2\ 10^6\ 0.3 \cong 0.6\ 10^6 Ci$$

In this case, the residual volume of radioactive residues in the explosion chamber as of 2001 may amount to the following:

$$R_{(2001)} = \frac{R_0}{t^{1.2}} = \frac{0.6 \times 10^6}{(1.93 \times 10^5)^{1.2}} = 0.3Ci$$

A control calculation of residual radio activeness associated with the presence of caesium-137 and strontium-90 in the vitreous melt ($P \cong 10^5 kg \cong 100$ *tonnes* with the chamber volume of $V = 500m^3$) produces the following result (according to the data of the Russian Design and Research Institute of Industrial Technology of the Atomic Energy Ministry of the Russian Federation, 1992).

- Specific activity of the vitreous melt in the explosion chamber of the Klivazh facility for strontium-90 amounts to:

  $R_{90} \cong 6.2\ 10^{-5}\ Ci/kg\ (2.3\ 10^6\ Bq/kg)$.

- Specific activity for caesium-137 amounts to:

  $R_{137} \cong 4.6\ 10^{-5}\ Ci/kg\ (1.7\ 10^6\ Bq/kg)$.

- The total volume of radioactive contamination for caesium-137 and strontium-90 will amount to:

  $R_{(90)+(137)} \cong (6.2 + 4.6)\ 10^{-5}\ Ci/kg \times 10^5 kg \cong 10.8\ Ci$

The presence of other long-lived radioactive explosion products in the explosion chamber (plutonium-239, americium-241 and others) demonstrates that the estimation of residual contamination at the level of $R_{2001} \cong 60Ci$ is realistic.

In conclusion:

1. The available data suggest that the ecological-geological state of the Klivazh facility under current conditions is characterised by relative stability and probability of a slow filtration transition of the solid (continuous) stream of groundwater through the area of the explosion chamber, crushed and radially jointed rock in the direction of the 936-metre horizon.
2. Prevalence of permeable sandstone in the geo-mechanical impact area of the nuclear explosion (up to 75.4% in 135m of rock massif) diminishes the hydro-isolation capacity of the rock massif as further deformations develop and the rock massif becomes fully saturated with water during mine flooding.
3. The affected area of the Klivazh facility is characterised (under the current conditions of incomplete water saturation of the rock massif) by a limited migration of radioactive explosion products due to their predominant concentration in vitreous formations of low solubility in the explosion chamber and the sorption impact of low-permeability coal-bearing rock.

Migration of radionuclides during the Yunkom mine closure, 'dry' and 'wet' abandonment

Key factors contributing to environmental vulnerability under different mine-closing scenarios

In our opinion, the following key factors may account for a decline in the protective ability of the geological environment.

- Hydraulic linkages of the Yunkom mine with the adjacent Chervonyi Zhovten mine (the horizons of 476m and 596m) and the Poltavska mine (the horizon of 262m), as well as the presence of horizons where mine workings approach each other, creating geo-technical hazards.
- Great tectonic disturbances on the border of the Yunkom mine, which are characterised by reduced geo-mechanical rock stability, and accelerated migration of groundwater;

- Abutting of the Yunokomunarivska industrial urban agglomeration to the technical borders of the Yunkom mine. In our opinion, this may contribute to the emergence of additional factors of geological environmental vulnerability: the presence of waterlogged areas with reduced rock stability, increased groundwater aggressiveness, and other factors.

High spatial and temporal variability of regional groundwater levels during mine closure brings about a possibility for a stochastic development of the affected area of the Klivazh facility of the Yunkom mine. Therefore, below we consider major characteristics of ‘wet’ and ‘dry’ abandonment conditions for the Klivazh facility in the mining space of the Yunkom mine.

Risk estimates for ‘dry’ abandonment of the Yunkom mine

The explosion chamber at the Klivazh facility is centred at a depth of 903m in a layer of sandstone. As estimated by use of boreholes, the nuclear explosion chamber has a radius of 5m and a total capacity of approximately 500m^3. It holds 100 tonnes of vitreous melt containing 6.2 curies (Ci) of strontium-90 and 4.6 Ci of caesium-137 while potential maximum contents of radiation products total up to 60 Ci (see Figure 4).

Strontium-90 is the most mobile radionuclide and thus it is reasonable to compare the balance of strontium migration distribution with mine water contamination levels in 1989 (4.0 10^{-13} Ci/l) and 2001 (5.1–9.4 10^{-13} Ci/l). The level of sludge contamination in the mine pond (as the final destination) is (0.58–3.3) 10^{-10} Ci/l. The level of caesium-137 contamination during this time remained practically unchanged: 8.0 10^{-13} Ci/l in 1989, and (7.6–9.7) 10^{-13} Ci/l in 2001.

Unfortunately, there are no assessments of the levels of radiation contamination of mine water and sludge in direct outflows from the explosion epicentre area. Therefore, we assume that there is a complete efflux (with a minor rise in the period of 1989–2001) of the water-soluble phase of strontium-90 along with mine drainage water (for the period of 1979–2001, or 22 years with an average yield of 450m^3 per hour) and that its sorption concentration occurs in the sludge layer with a width of up to 200mm (with an accumulation speed of 10mm per year).

With the help of the above data, we may make the following rough calculations concerning the strontium-90 balance and distribution. Assuming strontium-90 has been arriving in the mine pond steadily, we may calculate the total efflux of strontium-90 in 22 years as follows (an average concentration of 7 10^{-13} Ci/l):

$$R_{90} = 450 \times 24 \times 365 \times 22 \times (7\ 10^{-13} Ci/l) \approx 0.06\ Ci$$

Calculation results demonstrate that the migration efflux amounts to (0.06/6.2) 100% ≅ 1.0% of the initial amount of strontium-90 in the explosion chamber. In the same period, resulting from a radioactive decay, the amount of strontium in the chamber has fallen by (lg22/lg28) 50% ≈ 37% or nearly by one third. With the help of the above estimates, we may also conclude that the radioactively contaminated explosion chamber is sufficiently isolated and that the efflux of strontium-90, which is the most capable of migration, is very slow, at nearly 100 times less than its physical decay.

With conditional strontium-90 accumulation in the bottom sludge layer with a width of 200mm (0.20m) and an average concentration of 2 × 10^{-10} Ci/kg, the level of contamination of a conditional area with a size of 1km^2 will amount to the following (given sludge density of 1.1kg/dm^3 = 1,100 kg/m^3):

$$R_{90/1km^2} = 10^6 m^2 \times 0.20\ m \times 1.1 \times 10^3\ kg/m^3 \times 2 \times 10^{-10} Ci/kg = 4.4 \times 10^{-2}\ Ci/km^2$$

The estimated level of strontium-90 contamination density is nearly twice as large as the average global level of strontium-90 distribution in the topsoil as of 1986 (0.02 Ci/km^2).

The ratio of strontium-90 concentrations in the mine pond and in the sludge may be regarded as an indication of their even distribution, which amounts to the following:

$$K_p = \frac{(0.58 - 3.3) \times 10^{-10}}{(5.1 - 9.4) \times 10^{-13}} = (1.1 - 3.5) \times 10^2$$

This means that it corresponds to the values whose distribution is known from literary sources ($n\ 10^0 - n\ 10^2$).

The below rough calculation of a potential seepage-water contamination level (4m^3 per hour) as a proportion of its mixture with the general mine drainage water (450m^3 per hour) may be indicative of the current relative stabilisation of radio-ecological and hydro-geological parameters for radionuclides migration and sorption in the rock massif of the affected area of the explosion chamber:

$$R_{поц} = R_ш \frac{(450.0)}{4.0} \equiv 10^2 R_ш$$

Given the above data, the level of potential radioactive contamination of seepage water at the edge of leakage from the affected area of the explosion chamber may reach the following amounts:

- for strontium-90 – (5.1–9.4) 10^{-11} Ci/l
- for caesium-137 – (7.6–9.7) 10^{-11} Ci/l.

Compared to acceptable concentrations of these two radionuclides in drinking water (allowable concentration for the population) according to the 97 Radiation Safety Standards for Ukraine (the NRBU-97) [4], the initial contamination may amount to the following:

- for strontium-90 – (5.1–9.4) 10^{-11} Ci/l: 2.7 10^{-11} = 1.9–3.5 times
- for caesium-137 – (7.6–9.7) 10^{-11} Ci/l: 2.7 10^{-9} = 0.03–0.04 times.

A tritium contamination level at the beginning of tritium arrival in mine water may be estimated according to the data for 1991 obtained through probing boreholes #1 and #2 (1×10^3 and 8.5×10^3 Bq/l, or 2.7 10^{-8} Ci/l and 2.1 10^{-7} Ci/l). Comparing it to an allowable concentration according to the NRBU-97, (30,000 Bq/l or 8 10^{-7} Ci/l), we obtain the following values:

(0.27-2.1) 10^{-} : 8 10^{-7} = 0.03–-0.26 times

The above estimates imply that, even when compared to more stringent standards of the NRBU-97, the level of initial contamination of seepage water in the explosion chamber with the most toxic radionuclides in the area of their arrival in the general mine drainage water does not exceed acceptable values. A certain increase in strontium-90 concentrations in seepage water may have a very limited duration due to rapid dilution in increasing volumes of water drainage, which at a horizon of 936m (deeper than the explosion chamber) grows by 8–10 times (up to 40–45m^3 per hour).

Conclusions for 'dry' abandonment conditions

1. The data obtained from various sources[d] indicate a relatively balanced current state of the explosion chamber of the Klivazh facility at the Yunkom mine and virtually a lack of preconditions for an increase in its radio-ecological hazard level.
2. According to the estimates, application of the 'dry' abandonment scheme for the Klivazh facility, given its location in a relatively stable massif of monolithic sandstone, will help to maintain the achieved balance and will contribute to the sorption containment of a predominant part of radiotoxic nuclides of caesium-137, strontium-90 and tritium, as well as hydro-geo-mechanical strength of the explosion chamber. Under the given conditions, the speed of radionuclides' physical decay exceeds their migration efflux by nearly two orders of magnitude. When necessary, as a supplementary safeguard measure, it may be proposed to fill the space of the explosion chamber with zeolite gravel or perlite, as a mechanically stable filler and sorbent.
3. There is a possibility of the emergence of additional deformations in the explosion chamber resulting from stress re-distribution in the adjacent finished coal seams. This brings about a need for expanding the radio-ecological monitoring system, developing a set of the Klivazh facility models (nuclear-physical, geo-mechanical and sorption-filtration) and urgently conducting a comprehensive radio-ecological inspection of potential radionuclide migration routes with balance calculations of radionuclide distribution in the environment.

Risk estimates for 'wet' abandonment of the Yunkom mine

A transition of the Klivazh facility into the 'wet' abandonment condition may be associated with the following changes affecting radio-ecological safety.

- Gradual, complete saturation with water of the rock massif adjacent to the explosion chamber and a possible increase in the rate of vitreous melt dissolution, reaching maximum values.
- Decline in rock strength resulting from complete water saturation of such rock with a possibility of a further destruction of the explosion chamber with a volume of up to 500m^3, as well as hydraulic migration of the initial volumes of radioactively contaminated water (on the margin of maximum known concentrations of strontium-90 (~ 10^{-7} Ci/l) and caesium-137 (10^{-8} Ci/l) in the underground stream.
- Manifestation of a protective impact of the sorption capacity of the surrounding rock massif, a substantial share of which is porous rock with a high concentration of clay matter. (According to estimates at underground explosion sites under similar conditions, the sorption capacity of moderately metamorphosed rock amounts to 1–150 g-eq/100g). Considering the significant depth of the explosion and a high geostatic pressure (rock pressure) (200kgf/cm^2 or 20MPa), which will limit migration routes for radiation-contaminated water from the explosion

chamber, we will decrease the rock sorption capacity by four orders of magnitudes to equal 0.1mg-eq/100 kg (S=0.001mg-eq/1 kg).

Over 95% of radioactive explosion products are concentrated in the form of a lens at the bottom of the explosion chamber, which occupies 5–10% of the chamber's volume. The absence of fusion products and an abnormal increase in the background radiation in the shaft of probing borehole #1, which opened up sandstone at a distance of 5.0m from the boundary of the chamber, bears witness to a low risk of an essential escape of radioactive explosion products beyond the confines of the explosion chamber.

According to experimental data, up to 10^6 mg-eq of radioactive decay products are produced during a nuclear explosion with a yield of 1 megaton (1Mt). Therefore, the explosion chamber area of the Klivazh facility at the beginning of its creation could contain up to $R_0=1\times10^6(0.3\times 10^3/10^6)=300$ mg-eq of radioactive contamination.

Radioactive contamination solubility parameters under the conditions of water saturation of explosion chambers (apart from salt ones) are characterised by limited variety. Therefore, at the first stage of making estimations, we accept a rather conservative scheme of the dissolution of radioactive residues in the explosion chamber – simultaneously with a complete flooding of such chamber and a gradual rise of the groundwater level.

Additionally, to establish an engineering safety factor in calculations, we will assume that there is no lateral outflow of water, which will seep through the area of the chamber's circular projection:

$(r_o = 5.0\mu$; $Fk = \prod r_o^2 = 3.14\times5^2=78.5m^2)$

Proceeding from a minimum sorption capacity of rock at the level of S=1.0 mg-eq/1,000 kg=0.001 mg-eq/kg and the presence of a layer of sorption rock 'h' on the surface of the explosion chamber,

$R_0 = \prod r_o^2 S h \delta_w$,

where h is an average length of a path of a continuous migration of contaminants until full sorption by rock, which accommodates (without a lateral outflow):

δ_w is rock density, $\delta_w \approx 2{,}000$ kg/m^3

$h = R_0/\prod r_o^2 = 300/3.14 \times 5^2\, 0.001 \times 2{,}000 \cong 2.0\ m$

However, migration within a stream whose form resembles a hemisphere may be a more realistic option in connection with a possibility of a partial outflow in the direction of jointing areas, which emerged during the undermining of adjacent seams. In this case, an estimated dependence of a migration route r_x will look as follows:

$R_0 = 2/3 \times \prod \times (R_x^3 - r_o^3)\ S\ \delta_w \cong 2(R_x^3 - r_o^3)\ S\ \delta_w$

The calculations imply that $R_x \approx 6.1$ m. This means that even with an essential decline in the known minimal values of the ion-exchange (sorption) capacity of rock, additional rock contamination under the conditions of a complete dilution of radioactive residues and a radial migration will be insignificant and will amount to approximately 1m (contamination will not go beyond the crushing and jointing zones).

This bears witness to the fact that even when the sorption capacity of low-volume rock is utilised, a route of radioactive-contamination migration under the conditions of a continuous seepage flow will be insignificant. Given that, in the area affected by the explosion geo-mechanically (beyond the boundaries of the explosion chamber where solid rock melt has formed), the enclosing rock is intensively broken, we should expect a sufficient implementation of the sorption process and a rise in sorption values (an increase in the sorptive-protective ability of rock).

In our opinion, the key factor of radio-ecological safety of the Klivazh facility under the 'wet' abandonment conditions is the establishment of an extremely decelerated mode of leaching and hydro-geo-filtration migration of toxic radionuclides of strontium-90, caesium-137 and tritium. To meet this condition reliably, when necessary, it may be reasonable to fill the explosion chamber with mechanically stable and sorption-active zeolite gravel and to fill the adjacent mine workings with absorptive and seepage-proof materials (zeolite, bentonite, perlite and others) to essentially reduce active deformations of rock between the horizons of 826m and 936m and to exclude a hydraulically accelerated displacement of radioactive contamination through fractures and fragments of mine workings.

Calculations based on a maximum speed of the dissolution of radiation-contaminated glass, which begins to have structure destructions (R=350Ci/kg, leaching under the conditions of a stream of 10^{-5}–10^{-7}g/cm^2 per day), also imply that the migration of radionuclides of strontium-90, caesium-137 and tritium is possible at the level of current values (n 10^{-13}

Bq/l). That is, at the level of practically equilibrium background concentrations in the setting of a full-scale development of sorption processes.

Conclusions for 'wet' abandonment conditions

1. A potential risk that the 'wet' abandonment of the Yunkom mine will affect the degradation of the ecological state of the explosion chamber of the Klivazh facility may be connected with an accelerated upsetting of rock balance and a geo-mechanical destruction of the explosion chamber of the Klivazh facility. The latter may require express assessments of the solidity of the surrounding rock massif (through non-destructive methods such as electromagnetic sounding).
2. When the current hydro-geo-mechanical conditions of the explosion chamber are maintained, a decelerated hydro-geo-migration of radioactive contamination (if the sorption capacity of rock stays at its current level) and a very insignificant conditionally continuous migration of contaminants (1–2m) will occur within the confines of the adjacent rock massif.
3. Under the 'wet' abandonment conditions, preconditions develop for a decelerated change of downward seepage (from the horizon of 826m to that of 936m and adjacent coal seams located below stopping zones) into upward seepage. This may involve a predominant influx of dissolved radioactive contaminants into the areas of radio-geo-chemically unsaturated (uncontaminated) rock. In general, this will contribute to the restriction of their migration and reduction of the radio-ecological risk of groundwater and surface water contamination.
4. Implementation of the Yunkom mine 'wet' abandonment scheme must be conditional upon a comprehensive assessment of the mining-geological and geo-mechanical state of the explosion chamber of the Klivazh facility and the adjacent rock massif. This should include an analysis of the reliability (equal safety margin levels) of safeguard measures to stabilise rock massif, when required. Anticipating probable behaviour of the Klivazh facility in the mining space of the Yunkom mine requires accurately establishing the radioactive contamination balance, developing nuclear-physical, geo-mechanical and hydrogeological models, which must be reconciled with general parameters, as well as establishing a system of comprehensive radio-ecological monitoring for the environment, as a precautionary measure.

General conclusions on effects of closing the Yunkom mine

The assessment provided here is based on the previous geological examinations, both public [5] and confidential.[e]

The materials and recommendations used by the authors of this report explicitly state that from the ecological-geological perspective the closing of mines has a complicated and random (stochastic) nature with respect to the performance of a number of factors. In addition, the mine closure process generally entails an increasing impact of a substantial group of natural auto-rehabilitation processes. Such processes appear as regional factors of boundary conditions, such as a rise in groundwater levels and activation of the migration of surface contaminants.

The forecasts presented in the above analysis of the Klivazh facility, which has no analogue in mine closure practice, have been primarily made as conservative assessments. At the same time, the authors have factored in the following provisions associated with the initial lessons learned from the process of the closing of mines in Donbas.

- There are limited possibilities for restoring and managing the environment at the raion level (a group of mines) and at the regional level (a geological structure, an urban mining agglomeration) where a balance in the depth of the earth has been irreversibly upset. There is a lack of domestic and foreign experience and enterprises regarding the burial of radioactive waste in a nuclear explosion chamber located in a mining space.
- There is insufficient and incomplete information about the state of the geological environment and mining space in a majority of mines or hydraulically connected groups of mines.
- There are shortcomings in the existing normative-legal, methodological, technological and other provisions concerning the validation of ecological, socio-economic and other parameters of mine closure.

There is a growing imbalance between the facility-level of mines closure and progressing territorial changes in ecological and associated socio-economic conditions of urban mining agglomerations. It appears that the lack of complete records concerning ecological and economic impacts of a rise in regional groundwater levels and the distribution of such groundwater inflow among the remaining operating mines is a key factor responsible for this imbalance.

The Yunkom mine currently has outdated equipment, is excluded from the list of operating mines and has virtually no funding for restructuring measures (i.e. 'dry' or 'wet' abandonment). Therefore, self-destruction of the mine may occur following a long-term power-cut, thermal deformations of the top end of the mine shaft involving deformation of the shaft's structures and consequent breakdown of the lifting, pumping, ventilating and other equipment. This may become a precondition for a direct and poorly managed physical burial of the Klivazh facility with radionuclides and highly radioactively contaminated water (with a volume of up to 500m^3) remaining in its explosion chamber. This water may be driven into mine water as a result of a piston-like displacement. Furthermore, such developments may aggravate socio-economic conditions and complicate the implementation of safeguarding measures, as well as reducing effectiveness of environmental monitoring.

Preliminary recommendations to mitigate risk associated with the Klivazh Facility

A significant uncertainty associated with the present mining-geological state of the Klivazh facility dictates a need to validate assessments of the geological environment's protective ability. These assessments will be crucial when a decision is made about the final burial of nuclear explosion products under any scheme of the Yunkom mine closure. Therefore, based on the above analysis, the authors make the following preliminary recommendations for necessary measures regarding further treatment of the Klivazh facility.

1. Conduct a comprehensive radio-ecological survey of the Yunkom mine and the affected area to identity locations where radiotoxic nuclides, including strontium-90, caesium-137, tritium and radon, accumulate, as well as paths of their distribution and migration.
2. Harmonise parameters of nuclear-physical, geo-mechanical and geo-hydro-filtration models of the potential radio-ecological impact area of the Yunkom mine.
3. Expand and reconstruct the monitoring system, enhancing system comprehensiveness for the conditions of 'dry' or 'wet' abandonment of the Yunkom mine and the adjacent mining-industry facilities (at facility and regional levels).
4. Assess a need for taking measures to maintain and enhance a hydro-geo-mechanical durability of the explosion chamber of the Klivazh facility and the rock massif in the affected area (including filling in with absorptive materials) for both dry and wet abandonment options for the Yunkom mine.
5. Ensure the implementation of the following in the process of a controlled final burial of the Klivazh facility, as a deep-seated local storage of long-lived radioactive waste, without further administrative oversight:
   a. classifying the Klivazh facility and radioactive waste located in it according to the provisions of the Laws of Ukraine 'On the Treatment of Radioactive Waste' (of 30 June 1995 #256/95-VR) and 'On the Use of Nuclear Power and Radiation Safety' (of 08 February 1995 #39/95-VR);
   b. ensuring an equal safety level in the models with respect to an assessment of a change of the Klivazh facility's state and the speed of migration of anthropogenic radionuclides in the environment.

2.3 Hazardous chemical contamination from the Horlivka Chemical Plant

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. These enterprises used to produce and accumulate significant volumes of aerial, liquid and solid waste, 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. 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 2000s at a distance of up to 12–15km.

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 stability, an increase in rock permeability and a reduction of the protective ability of rock. 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.

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

- A regional rise in groundwater levels, reaching pre-industrial marks within the boundaries of the catchment area.
- Development of water-conducting cracks in the undermined areas and an increase in groundwater-quality vulnerability due to an accelerated migration of anthropogenic contamination.
- 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 [5] 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 waste.

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 8.6km^2, including the undermined area of 2km^2.

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 [5, and other non-public sources]

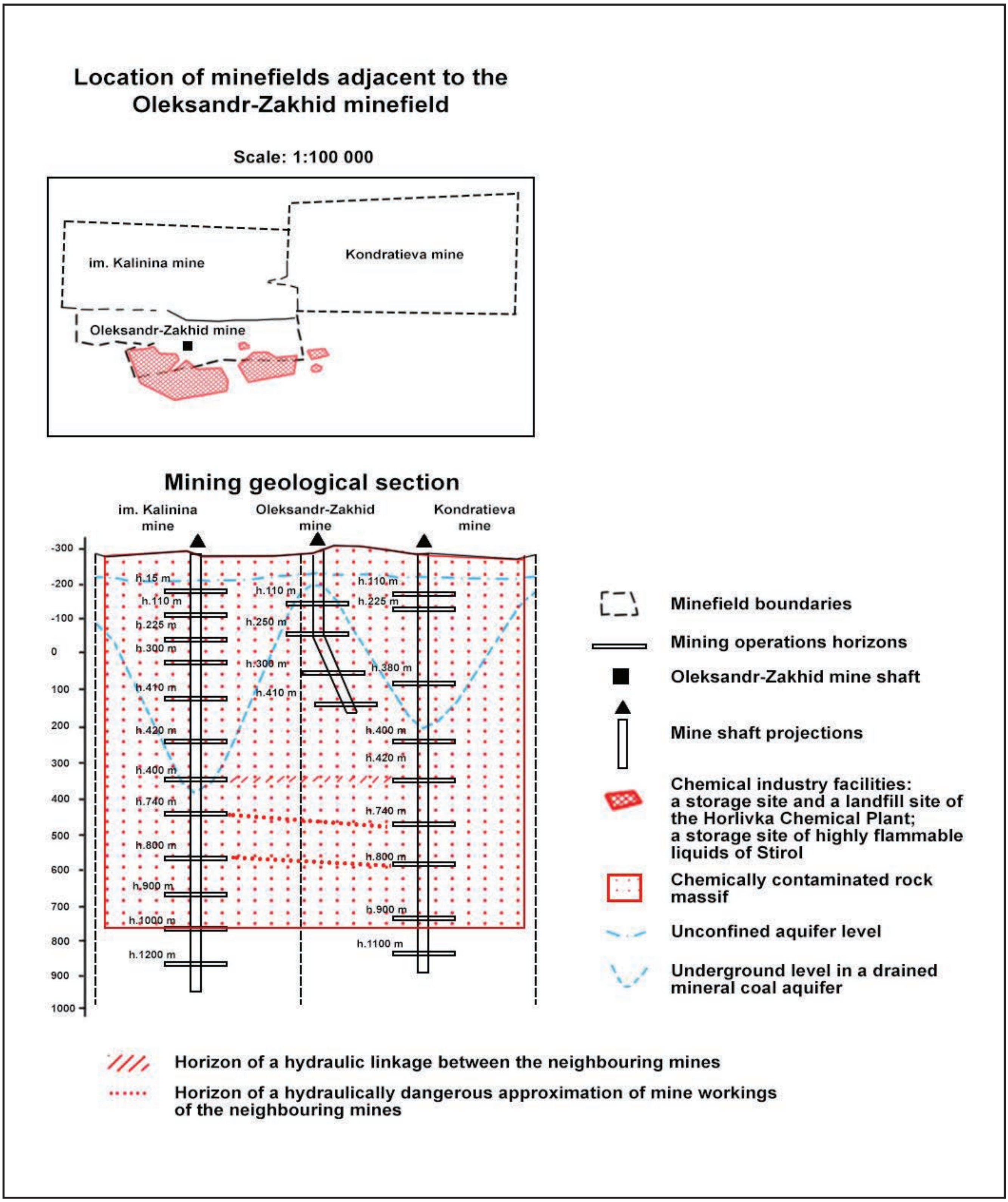
Global practice lacks experience in the waterlogging and flooding of sites of an industrial urban agglomeration with a high level of aeration-zone soil contamination with highly toxic compounds. In this connection, individual ecological-geological assessments have been made of potential impacts of the 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 waste, 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.

Figure 5. Contamination of the industrial site of the Horlivka Chemical Plant



- 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 1.0–1.5g/dm^3) and slightly saline water (1.5–3.0g/dm^3) with water of salinity of 3–5g/dm^3 (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 20m. 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 hydrogeological 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 1,000m. 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.

- 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.
- 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).
- Activation of interconnection between ground and surface water, accompanied by an enhanced infiltration of surface water within the confines of minefields.
- 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 230–1,080m. 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 1.5–2.0km. In our opinion, the distribution of non-normative pillars practically throughout the entire depth interval (0.2–0.9km) 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.

- 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.
- Emergency long-term migration of contaminants from external sources into surface and ground water bodies, and contamination of water intakes for domestic water supply.
- Synergistic reactions and a risk of atmospheric contamination in mine workings and other facilities with highly toxic unstable compounds in liquid and gaseous forms.
- 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 8.6km^2. Of this quantity, only approximately 11,600m^3 or 20,000 tonnes (i.e. 6%) is located in semi-underground poorly isolated storage facilities with a total area of 2,500m^2.

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.

- Affectedness of 30% of the territory by undermining operations of the Oleksand-Zakhid mine (2.3–3.0km^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.
- 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. Marksa mines, which are hydraulically interconnected.

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

- 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).
- 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).
- 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 risk 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.

- Real effects of an extreme contamination of the mine atmosphere in the workings of the Vuhlehorska and other mines (1990).
- 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.
- 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=8.6km^2, a depth of H=1km) 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=86km^2, a depth of H=1km).

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 $S1=8.6km^2$. The depth of migration is estimated to reach the lowest horizon of mining operations, namely H=1km.
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 $S2=86km^2$.

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 $\mu=0.1$) to the depth of mining operations, namely H=1km.

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 5 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 G1 will be equal to the following:

Table 5. Values of permissible limited concentrations of highly toxic contamination

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

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

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:

$$G_{tox}=\frac{P\times37.4}{100}=325{,}296\times0.374\approx11{,}500\textit{ tonnes}$$

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:

$$E_1=\frac{(0.0086\div8.6)\times100\%}{121{,}500}=(7\times10^{06}\div7\times10^{-3})\%$$

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 ($S_1=8.6km^2$) to the area of the anthropogenic-geo-filtration system ($S_2\approx86km^2$):

$$G_2=G_1\times\frac{S_2}{S_1}=(0.0086\div8.6)\times\frac{88.0}{8.6}\approx(0.086\div86.0)\textit{ tonnes}$$

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

$$r_2 = r_1 \times \frac{S_2}{S_1} \approx (70\times10^{-6} \div 70\times10^{-3})\%$$

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 ($>55^0$). 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.

- An increase in the area of land with geo-mechanical rock balance upset due to a growth in the depth and in area of mining operations within the confines of the Horlivka urban mining agglomeration.
- 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.
- 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.

- Conducting an assessment of the completeness and composition of ecological information from the regional (public) and facility-based monitoring systems.
- 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.
- 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.
- 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.
- 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,[f] 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.

3. The research mission: overview and methodology

This mission considered the effects on water supply of war-induced factors and their interaction with possible contamination from industrial sources. These industrial sources include the outflow of saline water contaminated through uncontrolled mine flooding and through the influx of other anthropogenic (unauthorised) contaminants. These affect the ecological safety of the runoff of the Siverskyi Donets River as the basic source of water supply.

Given the complexity of forecasting impacts of the above factors on water quality, the mission has identified known reserve sources of domestic water, which are used by the local population when the Donbas Water Company suspends water supply. We refer to these informal sources as 'non-controlled', in contrast to the 'controlled' sources within the official state network. We surveyed and sampled both controlled and uncontrolled sources in Donetsk and Luhansk oblasts. In total, we took 61 samples, as detailed in Table 6. The method of water quality assessment used in this study is based on the comprehensive water contamination index, recommended for use by the State Hydrometeorology Committee. This is one of the most widely used methodologies for a comprehensive water quality assessment.

According to the requirements of Sanitary Norms and Rules 2.2.4-171-10 [6], to compute the water contamination index, we applied the following formula:

$$WCI = \frac{1}{n} \sum_{1}^{n} \frac{C_i}{C_{PLCi}}$$

$$SCI = \frac{1}{n} \sum_{1}^{6} \frac{C_i}{C_{PLCi}}$$

$$SCI_B = \frac{1}{n} \sum_{1}^{6} \frac{C_i}{C_{Bi}}$$

In this formula:

- WCI is the water contamination index
- SCI is the soil contamination index
- C_i is the concentration of a contaminating substance obtained from laboratory tests performed on the obtained water and soil samples
- C_{PLCi} is a permissible limited concentration of a relevant contaminating substance (according to Sanitary Norms and Rules 2.2.4-171-10)
- C_{Bi} is a regional background value of the concentration of a relevant chemical element
- n is the quantity of contaminating substances considered during the assessment.

On the basis of the calculated WCI, water quality is assessed and classified as follows:

- very clean ($WCI < 0.3$);
- clean ($0.3 < WCI < 1$)
- moderately contaminated ($1 < WCI < 2.5$)
- contaminated ($2.5 < WCI < 4$)
- of impaired quality ($4 < WCI < 6$)
- of very impaired quality ($6 < WCI < 10$)
- of extremely impaired quality ($WCI > 10$).

Table 6. Overview of water sampling points (controlled and non-controlled territory)

A) In the government-controlled territory of Ukraine

No.	Type of water point	Depth (metres)	Geographical coordinates		Location (population centre)
			Longitude	Latitude	
1.	Shaft well		37°26'02"	48°01'07,2"	Berestky village,Pokrovskyi raion, railway, Southern district of the village
2.	Shaft well		37°11'12,7"	48°02'59,6"	Krasne village, Pokrovskyi raion
3.	Shaft well		37°18'00"	48°04'06,0"	Krasne village, Pokrovskyi raion
4.	Surface horizon		37°18'00"	48°04'06,0"	Krasne village, Pokrovskyi raion, the Solena river
5.	Surface horizon		37°16'29,1"	47°59'33"	Kurakhivske water reservoir
6.	Shaft well		37°17'49,2"	48°01'15,5"	Checkpoint near Kurakhivske water reservoir
7.	Surface horizon		37°60'03,0"	48°06'58,1"	Karlivske water reservoir
8.	Borehole	60	37°29'03,8"	48°34'60,5"	Water pumping station (water in the mine), Maiaky village, discharge
9.	Shaft well	20	37°60'01,5"	48°34'60,0"	Chalk outcrop, Maiaky village
10.	Shaft well	15	37°30'41,9"	49°01'07"	Bohorodychne village
11.	Borehole	30	37°51'00"	49°01'07,0"	Chapel, Bohorodychne village
12.	Borehole	70–80	37°57'04,0"	49°04'00,0"	Sviatohirsk
13.	Borehole	35–40	37°49'15,3"	48°53'33,2"	Piskunovskyi water intake
14.	Shaft well		38°03'53"	48°46'21,3"	Lenina St., Pereizne village, Bakhmutskyi raion,
15.	Shaft well		38°03'51,05"	48°46'44,6"	164 Horkoho St., Pereizne village
16.	Shaft well		38°04'56,04"	48°49'08,8"	37 Shevchenka St., Zvanivka village
17.	Shaft well		37°57'56,05"	48°38'33,9"	Berkhovka village, Bakhmutskyi raion
18.	Borehole	130	37°17'03"	48°37'28,8"	Andriivka village
19.	Spring		37°42'09"	47°10'20,5"	De-militarised zone, Mariupol, Talakivka village
20.	Spring		37°44'56,09"	47°12'22,9"	De-militarised zone, Mariupol, Hnutovo village
21.	Borehole	29	37°60'15,00"	47°21'20,00"	Mariupol, Sartana village
22.	Spring		37°33'39,07"	47°06'21,09"	Malofontanna St., Mariupol town
23.	Surface horizon		37°30'20,04"	47°11'32,08"	Volodarskyi raion, Starokrymske water reservoir
24.	Spring		38°11'46,5"	49°01'54,5"	Kreminnyi water intake
25.	Spring		38°17'37,4"	49°02'12,8"	Staro-Krasnianskyi water intake
26.	Borehole		38°11'04,8"	49°05'28,4"	Zhytnivskyi water intake
27.	Borehole		38°18'31,4"	49°02'01,5"	Rubizhne town, Volodynskyi water intake
28.	Borehole		39°13'25"	48°44'32,1"	11 Enerhetykiv Quarter, Shchastia town
29.	Borehole		39°14'07,3"	48°44'22,6"	30 Druzhby St., Shchastia town
30.	Borehole		39°247	48°734	Shchastia town, the Central water intake
31.	Surface horizon		39°248	48°737	Shchastia town, discharge channel of a thermal power plant
32.	Surface horizon		38°59'08,2"	48°57'30,6"	The Aidar river, Novoaidar urban settlement
33.	Borehole		38°43'50,6	48°91'39,05	47 Pavla Morozova St., Bilohorovskyi water intake, Lysychansk town
34.	Borehole		38°43'95,61	48°91'22,48	Borovskyi water intake, Lysychansk town
35.	Borehole		38°33'27,4"	48°54'14,3"	13 Proletarska St., Voronove village, Lysychansk town, Papasnianskyi raion

B) In the non-government-controlled territory of Ukraine

No.	Type of water point	Depth (metres)	Geographical coordinates		Location (population centre)
			Longitude	Latitude	
1.	Borehole 274		37°96'37,17	48°04'14,6	Makiivka, Narodna Kholodna Balka
2.	Borehole 404		38°07'68,47	48°20'74,47	Barykad St., Korsun village
3.	Surface horizon		37°93'96,24	47°82'24,08	Verkhno-Kalmiuske water reservoir, dam
4.	Borehole		37°69'67,92	47°96'56,14	Dniprovska St., Rutchenkove station, Donetsk city
5.	Borehole 4		37°68'63,36	47°75'94,68	Dokuchaevsk town, the central water intake facility
6.	Borehole 6		37°65'47,50	47°75'63,32	Dokuchaevsk town, the central water intake facility
7.	Borehole		38°04'03,79	48°33'99,61	28 Astrakhanska St., Nikitovka
8.	Spring		37°99'95,69	48°41'73,71	8 Tokareva St., Zaitsevo
9.	Spring		38°08'38,07	48°31'34,97	Horlovka town, military unit, Stirol district
10.	Shaft well		38°26'74,85	48°31'36,74	26 Traktorna St., Vuhlehirsk town
11.	Borehole		38°41'84,79	48°33'71,96	Debaltsevo town, Cheremushky water intake facility
12.	Borehole		38°22'37,98	48°21'38,82	Yenakiieve town, Yenakiivskyi water intake facility # 1
13.	Borehole		37°81'78,16	48°00'74,75	Donetsk city, Durnaia Balka
14.	Shaft well		38°04'52,15	47°75'53,44	Starobesheve town, open-pit mine
15.	Borehole		37°93'73,78	47°69'08,80	Kypucha Krynytsia borehole
16.	Borehole		38°07'73,89	47°67'38,95	Komsomolsk town
17.	Borehole				Samsonovo village
18.	Borehole		38°07'29,93	47°11'80,35	Shyroka St., Novoazovsk town
19.	Borehole		38°48'51,84	47°77'66,47	Amvrosiivka town
20.	Spring		38°22'80,11	47°91'64,16	Ilovaisk town
21.	Borehole		38°43'54,08	48°06'45,07	Shakhtersk town, XVII Partzizdu borehole
22.	Spring		38°61'75,24	48°03'55,36	Torez town, river (Orlova Balka)
23.	Borehole		38°79'53,00	47°98'16,11	Harshyna St., Pervomaiskyi settlement (Saur-Mohyla)
24.	Borehole		37°76'82,66	47°85'14,49	Andriivka settlement
25.	Shaft well		38°56'71,71	48°12'72,65	Rozsypne settlement
26.	Surface horizon		38°28'08,11	48°25'13,53	Volyntsevske water reservoir

4. Key findings on threats to water supply and human vulnerability[g]

4.1 Analysis of the quality of sources for domestic water supply

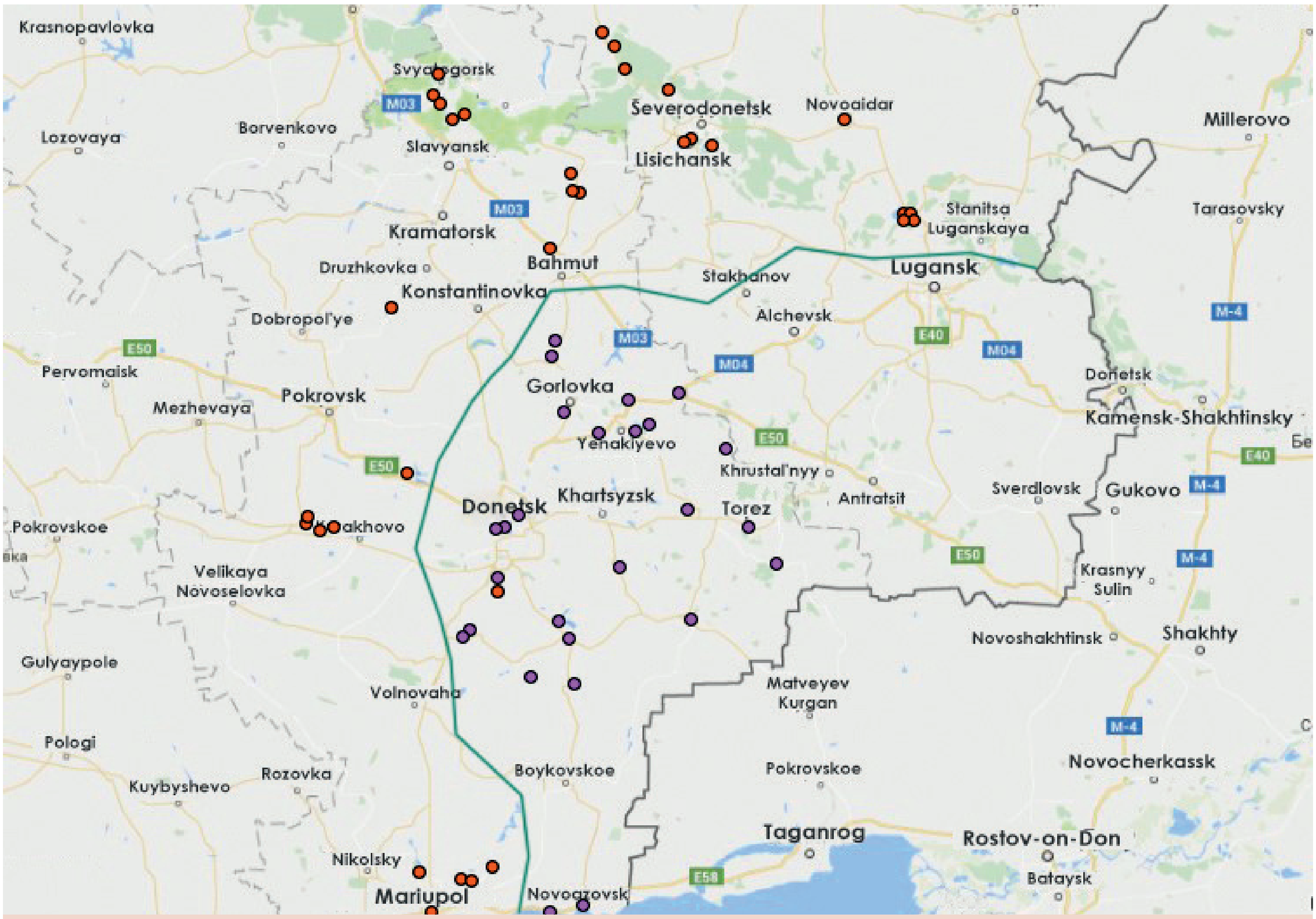
Analysis of water quality in reserve sources of domestic water supply, the geochemical state of soil in the controlled access area (r=30m) and background radiation was based on a standard methodology for ecological-geological surveys of water points, with due regard to a high level of anthropogenic contamination of water-collecting landscapes in Donbas. The locations of the water and soil sampling points are shown in Figure 6.

4.2 Domestic water supply and the conflict in Donetsk and Luhansk oblasts

Providing the population with safe drinking water and preventing the contamination of sources of domestic water supply with effluent and sewage are a priority for human health and life in Donbas in the context of the ATO. The system of domestic water supply in Donetsk and Luhansk oblasts is complex. This partly explains the recent decline in water safety, which is affected by the following specific factors.

- Prevalence of water supply (80–85%) from unprotected surface sources including the Siverskyi Donets, domestic water reservoirs, wells and capped springs with various levels of protection.

Figure 6. Map of water and soil sampling points in Donbas



Notes

Red – sampling sites in Government Controlled Areas

Purple – sampling sites in Non-Government Controlled Areas

Table 7. Quality of water samples in Donbas (government controlled territory)*

No.	Name of the sampling site	Water quality indicators												
		Date of sampling	pH	Water colour, mg/dm³	Turbidity, mg/dm³	Ammonium, mg/dm³	Nitrites, mg/dm³	Nitrate, mg/dm³	Total iron, mg/dm³	Chlorides, mg/dm³	Sulphates, mg/dm³	Calcium, mg/dm³	Magnesium, mg/dm³	Dry residue, mg/dm³
1	Berestky village, a well	25.10.16	7.15	<5	<0.58	<0.10	0.043	9.2	0.06	303	1,467	389	72	2,980
2	Krasne, a well	25.10.16	7.20	10	<0.58	<0.10	0.020	229.8	0.07	187	1,532	335	146	3,470
3	Krasne village, a shaft well	25.10.16	7.50	7	<0.58	<0.10	<0.002	43.6	0.07	207	1,020	285	99	2,198
4	Krasne village, the Solena River	25.10.16	8.20	6	4.50	<0.10	<0.002	8.9	0.14	333	3,119	345	241	5,378
5	Kurakhivske water reservoir	25.10.16	8.80	31	3.90	<0.10	<0.002	<2.2	0.12	596	2,206	226	161	4,350
6	Kurakhivske water reservoir, a checkpoint	25.10.16	7.50	10	0.65	<0.10	0.027	57.3	0.10	76	339	124	80	978
7	Karlovske water reservoir	25.10.16	8.50	21	2.70	<0.10	<0.002	<2.2	0.11	273	1,847	184	157	3,336
8	Maiaky village, a borehole	26.10.16	7.35	7	<0.58	<0.10	<0.002	51.9	0.06	56	124	144	23	720
9	Maiaky village, a well	26.10.16	7.50	<5	<0.58	<0.10	<0.002	8.6	0.05	30	113	102	12	544
10	Bohorodychne village, a borehole	26.10.16	7.35	<5	<0.58	0.10	0.002	49.8	0.05	37	227	142	18	770
11	Bohorodychne village, a well	26.10.16	7.30	<5	<0.58	0.23	<0.002	45.6	0.06	36	199	134	15	711
12	Sviatohorsk town, a borehole	26.10.16	7.25	<5	7.20	3.25	0.020	7.0	2.63	10	13	26	9	180
13	Mykolaivka town	27.10.16	7.70	7	10.00	0.30	0.070	11.2	4.25	119	212	123	20	851
14	Lenina St., Pereizdne village, a well	27.10.16	7.40	<5	2.20	0.10	0.040	65.2	0.21	530	465	265	71	1,892
15	Horkoho St., Pereizdne village, a well	27.10.16	7.50	<5	<0.58	0.10	0.020	69.2	<0.05	434	992	270	86	2,570
16	Zvanovka village	27.10.16	7.40	<5	<0.58	0.10	0.020	380.9	<0.05	175	337	211	81	1,806
17	Berkhivka village	27.10.16	7.80	5	<0.58	<0.10	0.002	98.0	<0.05	101	947	167	81	2,162
18	Andriivka village	27.10.16	7.40	<5	<0.58	<0.10	0.004	9.2	18.1	399	531	221	86	1,706
19	Talakivka settlement, a spring	28.10.16	7.85	32	5.76	0.13	0.022	3.7	0.07	273	996	220	91	2,292
20	Hnutove settlement, a spring	28.10.16	7.90	44	5.22	0.12	0.240	21.8	<0.05	586	1,458	410	102	3,432

* Values in red indicated excessive water contamination with respective substances as defined by the Ukrainian Sanitary Norms and Rules (2010)

Water quality indicators															
Total hardness, mol/dm^3	Total alkalinity, mol/dm^3	Permanganate oxygen consumed, mgO/dm^3	Phosphorus from phosphates, mg/dm^3	Molybdenum, mg/dm^3	Cadmium, mg/dm^3	Zinc, mg/dm^3	Manganese, mg/dm^3	Copper, mg/dm^3	Lead, mg/dm^3	Chronium, mg/dm^3	Nickel, mg/dm^3	Cobalt, mg/dm^3	Beryllium, mg/dm^3	Strontium, mg/dm^3	Lithium, mg/dm^3
25.30	5.5	1.6	<0.04	<0.025	<0.0001	0.219	0.007	0.013	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.020
28.70	11.5	1.9	<0.04	<0.025	<0.0001	0.480	0.006	0.042	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.022
22.30	6.6	1.6	<0.04	<0.025	<0.0001	0.054	0.009	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.022
37.00	7.9	7.7	<0.04	<0.025	<0.0001	0.025	0.015	0.001	<0.001	0.001	<0.005	<0.005	<0.0001	0.194	0.016
24.50	4.0	7.2	<0.04	<0.025	<0.0001	0.028	0.010	0.004	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.016
12.80	6.1	1.0	<0.04	<0.025	<0.0001	0.149	0.016	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.108	0.022
22.10	4.1	5.6	<0.04	<0.025	<0.0001	0.200	0.018	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.100	0.017
9.10	7.1	1.0	<0.04	<0.025	<0.0001	0.198	0.003	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.020
6.10	6.0	<1.0	<0.04	<0.025	<0.0001	0.800	0.003	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.020
8.60	6.1	<1.0	<0.04	<0.025	<0.0001	0.350	0.001	0.005	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.018
7.90	5.6	<1.0	<0.04	<0.025	<0.0001	0.190	0.001	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.019
2.00	2.2	1.0	<0.04	<0.025	<0.0001	0.165	0.020	0.023	<0.001	<0.001	<0.005	<0.005	<0.0001	0.120	0.018
7.80	5.5	1.8	<0.04	<0.025	<0.0001	0.174	0.100	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.175	0.018
19.10	5.6	1.5	<0.04	<0.025	<0.0001	0.060	0.070	0.013	<0.001	<0.001	<0.005	<0.005	<0.0001	0.142	0.018
20.60	5.6	1.2	<0.04	<0.025	<0.0001	0.185	0.004	0.003	<0.001	0.001	<0.005	<0.005	<0.0001	0.130	0.015
17.20	10.0	1.0	<0.04	<0.025	<0.0001	0.300	0.003	0.060	<0.001	0.006	<0.005	<0.005	<0.0001	0.212	0.018
15.00	8.8	1.5	<0.04	<0.025	<0.0001	0.500	0.006	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	<0.100	0.014
18.10	6.2	<1.0	<0.04	<0.025	0.001	0.300	0.270	0.008	<0.001	<0.001	<0.005	<0.005	<0.0001	0.130	0.017
19.20	6.8	4.6	0.10	<0.025	<0.0001	0.141	0.020	<0.001	<0.001	0.001	<0.005	<0.005	<0.0001	0.340	0.020
31.35	5.6	3.8	0.15	<0.025	<0.0001	0.084	0.013	<0.001	<0.001	0.001	<0.005	<0.005	<0.0001	0.400	0.024

No.	Name of the sampling site	Water quality indicators												
		Date of sampling	pH	Water colour, mg/dm³	Turbidity, mg/dm³	Ammonium, mg/dm³	Nitrites, mg/dm³	Nitrate, mg/dm³	Total iron, mg/dm³	Chlorides, mg/dm³	Sulphates, mg/dm³	Calcium, mg/dm³	Magnesium, mg/dm³	Dry residue, mg/dm³
21	Sartana settlement, a borehole	28.10.16	7.25	<5	<0.58	<0.10	0.002	2.7	<0.05	323	1,045	210	79	2,310
22	Malofontanna St., Mariupol, a spring	29.10.16	7.05	<5	<0.58	<0.10	0.002	18.3	<0.05	364	1,457	301	119	3,118
23	Mariupol, Staro-Krymske water reservoir	29.10.16	8.05	24	1.76	0.13	0.085	2.2	<0.05	222	1,579	271	119	2,816
24	Kreminnyi water intake facility	01.11.16	7.30	<5	<0.58	<0.10	<0.002	36.3	<0.05	9	48	74	9	276
25	Staro-Krasnianskyi water intake facility	01.11.16	7.85	<5	<0.58	<0.10	<0.002	8.1	<0.05	45	77	57	4	256
26	Zgytlovskyi water intake facility, borehole # 818	01.11.16	7.80	<5	<0.58	<0.10	<0.002	8.3	<0.05	4	67	48	4	146
27	Rubizhne town, Volodynskyi water intake facility, borehole # 18	01.11.16	8.00	<5	<0.58	<0.10	<0.002	7	<0.05	2	41	4	2	140
28	Shchastia town, a private borehole	02.11.16	7.50	<5	1.12	<0.10	<0.002	10.1	<0.05	73	139	82	19	458
29	Druzhby St., Shchastia town, a borehole	02.11.16	7.50	<5	<0.58	<0.10	0.003	7.1	<0.05	125	198	164	8	623
30	Shchastia town, the Central water intake facility, a borehole	02.11.16	7.50	<5	<0.58	<0.10	0.027	2.6	<0.05	27	70	88	1	315
31	Shchastia town, thermal power station effluent	02.11.16	8.30	33	2.17	0.13	0.015	7	<0.05	182	331	128	42	1,066
32	Novoaidar settlement, the Aidar river	02.11.16	8.30	32	9.3	0.13	0.004	4.9	<0.05	273	281	195	51	1,103
33	Lysychansk town, Belohorovskyi water intake facility	03.11.16	7.5	<5	0.68	<0.10	<0.002	18.6	<0.05	35	104	83	3	348
34	Lysychansk town, Borovskyi water intake facility	03.11.16	7.5	<5	<0.58	<0.10	<0.002	20.1	<0.05	35	98	80	6	334
35	Lysychansk town, Papasnianskyi raion, Voronove settlement	03.11.16	7.6	13	10.22	0.18	<0.002	<2.2	0.88	39	148	89	9	403

Water quality indicators															
Total hardness, mol/dm^3	Total alkalinity, mol/dm^3	Permanganate oxygen consumed, mgO/dm^3	Phosphorus from phosphates, mg/dm^3	Molybdenum, mg/dm^3	Cadmium, mg/dm^3	Zinc, mg/dm^3	Manganese, mg/dm^3	Copper, mg/dm^3	Lead, mg/dm^3	Chromium, mg/dm^3	Nickel, mg/dm^3	Cobalt, mg/dm^3	Beryllium, mg/dm^3	Strontium, mg/dm^3	Lithium, mg/dm^3
21.00	5.5	<1.0	<0.04	<0.025	<0.0001	0.026	0.006	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.340	0.019
25.30	6.2	2.0	<0.04	<0.025	<0.0001	0.025	0.002	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.420	0.020
23.25	3.9	4.6	0.05	<0.025	<0.0001	0.178	0.055	0.003	<0.001	0.003	<0.005	<0.005	<0.0001	0.300	0.018
4.50	3.3	<1.0	0.04	<0.025	<0.0001	0.400	0.003	0.004	<0.001	<0.001	<0.005	<0.005	<0.0001	0.141	0.030
3.20	1.8	<1.0	0.04	<0.025	<0.0001	0.237	0.003	0.002	<0.001	0.001	<0.005	<0.005	<0.0001	0.180	0.029
2.80	2.2	<1.0	<0.04	<0.025	<0.0001	0.232	0.002	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.165	0.028
2.10	1.6	<1.0	<0.04	<0.025	<0.0001	0.157	0.002	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.170	0.028
5.70	3.3	1.4	<0.04	<0.025	<0.0001	0.159	0.011	0.006	<0.001	0.001	<0.005	<0.005	<0.0001	0.19	0.029
9.00	2.2	<1.0	<0.04	<0.025	<0.0001	0.124	0.004	0.002	<0.001	0.001	<0.005	<0.005	<0.0001	0.260	0.028
4.50	3.0	<1.0	<0.04	<0.025	<0.0001	0.155	0.001	0.006	<0.001	<0.001	<0.005	<0.005	<0.0001	0.190	0.031
10.00	5.0	5.4	0.30	<0.025	<0.0001	0.142	0.015	0.002	<0.001	0.001	<0.005	<0.005	<0.0001	0.160	0.028
13.90	6.3	4.2	0.12	<0.025	<0.0001	0.108	0.026	0.008	<0.001	0.001	<0.005	<0.005	<0.0001	0.400	0.028
4.40	2.1	1.0	0.06	<0.025	<0.0001	0.215	0.010	0.004	<0.001	0.001	<0.005	<0.005	<0.0001	0.200	0.029
4.50	2.1	<1.0	<0.04	<0.025	<0.0001	0.157	0.007	0.002	<0.001	0.001	<0.005	<0.005	0.0001	0.154	0.028
5.20	2.5	1.1	<0.04	<0.025	<0.0001	0.144	0.08	0.003	<0.001	0.001	<0.005	<0.005	0.0001	0.164	0.028

Table 8. Quality of water samples in Donbas (non-government uncontrolled territory)*

No.	Name of the sampling site	Water quality indicators												
		Date of sampling	pH	Water colour, mg/dm³	Turbidity, mg/dm³	Ammonium, mg/dm³	Nitrites, mg/dm³	Nitrate, mg/dm³	Total iron, mg/dm³	Chlorides, mg/dm³	Sulphates, mg/dm³	Calcium, mg/dm³	Magnesium, mg/dm³	Dry residue, mg/dm³
1	Narodna Kholodna Balka St., Makiivka town, borehole 274	08.11.16	7.50	<5	<0.58	0.17	0.076	18.0	0.12	247	1,119	256	95	2,570
2	Barykad St., Korsun town, borehole 404	08.11.16	6.75	<5	<0.58	0.24	<0.002	802.3	0.23	217	1,146	315	149	3,048
3	Verkhno-Kalmiuske water reservoir, dam, surface	08.11.16	8.10	19	0.95	0.10	0.037	2.5	0.06	79	249	30	29	673
4	Dniprovska St., Donetsk city, Rutchenkovo station, a borehole	08.11.16	7.30	6	8.30	<0.10	<0.002	65.7	<0.05	86	971	102	69	1,991
5	Central water intake, Dokuchaevsk town, borehole 4	08.11.16	7.00	<5	1.30	<0.10	<0.002	12.2	0.54	394	1,246	285	122	2,654
6	Central water intake, Dokuchaevsk town, borehole 6	08.11.16	7.05	<5	4.80	0.15	<0.002	7.1	1.76	394	1,261	281	125	2,666
7	28 Astrakhanska St., Mykytovka, a borehole	09.11.16	7.15	<5	<0.58	<0.10	0.02	108.3	<0.05	99	507	157	65	1,314
8	8 Tokareva St., Zaitsevo, a spring	09.11.16	7.05	9	<0.58	<0.10	0.004	77.8	<0.05	81	467	138	60	1,283
9	Horlivka town, a military base, a spring in the area of Stirol	09.11.16	6.80	8	<0.58	<0.10	0.004	<2.2	<0.05	91	608	110	106	1,540
10	26 Traktorna St., Vuhlehirsk town, a well	09.11.16	7.45	20	<0.58	<0.10	0.040	183.7	<0.05	72	284	90	35	1,087
11	Cheremushky water intake, Debaltsevo town, a borehole	09.11.16	6.90	5	<0.58	<0.10	0.040	37.8	<0.05	118	315	98	47	1,059
12	Yenakiivskyi water intake #1, Yenakiivo town, a borehole	09.11.16	7.15	<5	<0.58	<0.10	0.020	53.5	0.10	163	602	126	84	1,536

* Values in red indicated excessive water contamination with respective substances as defined by the Ukrainian Sanitary Norms and Rules (2010)

Water quality indicators															
Total hardness, mol/dm³	Total alkalinity, mol/dm³	Permanganate oxygen consumed, mgO/dm³	Phosphorus from phosphates, mg/dm³	Molybdenum, mg/dm³	Cadmium, mg/dm³	Zinc, mg/dm³	Manganese, mg/dm³	Copper, mg/dm³	Lead, mg/dm³	Chromium, mg/dm³	Nickel, mg/dm³	Cobalt, mg/dm³	Beryllium, mg/dm³	Strontium, mg/dm³	Lithium, mg/dm³
20.60	9.6	<1.0	<0.04	<0.025	<0.0001	0.190	0.005	0.006	<0.001	<0.001	<0.005	<0.005	<0.0001	0.187	0.026
28.00	5.3	1.4	<0.04	<0.025	<0.0001	0.400	0.005	0.010	<0.001	<0.001	<0.005	<0.005	<0.0001	0.279	0.027
5.90	3.9	4.7	0.04	<0.025	<0.0001	0.115	0.007	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.500	0.027
10.80	7.6	<1.0	<0.04	<0.025	<0.0001	0.109	0.010	0.004	<0.001	<0.001	<0.005	<0.005	<0.0001	0.175	0.028
24.30	4.7	<1.0	<0.04	<0.025	<0.0001	0.220	0.013	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.217	0.025
24.30	5.1	<1.0	<0.04	<0.025	<0.0001	0.040	0.010	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.365	0.027
13.20	6.5	<1.0	<0.04	<0.025	<0.0001	0.101	0.002	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.370	0.028
11.80	6.2	1.8	0.08	<0.025	<0.0001	<0.025	0.004	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.370	0.027
14.20	7.2	1.2	<0.04	<0.025	<0.0001	0.064	0.020	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.407	0.027
7.35	5.3	2.1	0.08	<0.025	<0.0001	0.056	0.002	0.002	<0.001	<0.001	<0.005	<0.005	<0.0001	0.322	0.026
8.80	6.7	1.2	<0.04	<0.025	<0.0001	0.027	0.011	0.001	<0.001	0.001	<0.005	<0.005	<0.0001	0.425	0.025
13.20	6.4	1.5	<0.04	<0.025	<0.0001	<0.025	0.022	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.510	0.023

No.	Name of the sampling site	Water quality indicators												
		Date of sampling	pH	Water colour, mg/dm³	Turbidity, mg/dm³	Ammonium, mg/dm³	Nitrites, mg/dm³	Nitrate, mg/dm³	Total iron, mg/dm³	Chlorides, mg/dm³	Sulphates, mg/dm³	Calcium, mg/dm³	Magnesium, mg/dm³	Dry residue, mg/dm³
13	Donetsk, Durna Balka	10.11.16	8.50	18	1.25	<0.10	<0.002	17.2	<0.05	272	1,022	83	117	2,372
14	Starobeshevo town, an open pit mine	10.11.16	7.40	<5	1.59	0.42	0.028	22.2	<0.05	359	1,800	373	209	3,384
15	Kypucha Krynytsia borehole	10.11.16	6.90	<5	<0.58	0.10	<0.002	18.8	0.05	333	1,278	305	113	2,656
16	Komsomolsk, a borehole	10.11.16	7.40	10	<0.58	<0.10	<0.002	35.4	<0.05	258	1,035	196	90	2,338
17	Samsonovo village, a borehole	10.11.16	6.90	<5	<0.58	1.25	0.114	17.5	0.05	160	201	9	5	840
18	Shyroka St., Novoazovsk town, a borehole	10.11.16	7.00	15	<0.58	2.1	<0.002	13.2	0.05	343	160	5	4	1,485
19	Amvrosiivka town, a borehole	10.11.16	7.00	7	<0.58	0.10	<0.002	36.0	0.08	129	1,142	285	80	2,314
20	Ilovaisk town, a borehole	10.11.16	7.30	7	<0.58	<0.10	<0.002	143.4	<0.05	164	1,379	237	125	2,860
21	Shakhtersk town, XVII Partzizdu borehole	11.11.16	7.00	<5	<0.58	<0.10	<0.002	35.4	<0.05	86	478	149	47	1,280
22	Torez town, a river (Orlova Balka)	11.11.16	7.20	25	13	<0.10	0.020	<2.2	0.05	106	228	39	24	1,449
23	Harshyna St., Pervomaiskyi settlement, a borehole (Saur-Mohyla)	11.11.16	7.00	<5	0.76	<0.10	0.015	<2.2	<0.05	121	374	126	96	1,365
24	Andriivka settlement	11.11.16	7.20	<5	<0.58	<0.10	0.003	35.1	<0.05	25	253	118	48	868
25	Rozsypne settlement, a well	11.11.16	7.20	<5	<0.58	<0.10	0.003	147.7	0.06	81	222	142	60	976
26	Volyntsevske water reservoir, surface horizon	11.11.16	7.30	17	3.20	<0.10	0.004	<2.2	0.05	56	351	55	39	813

Water quality indicators															
Total hardness, mol/dm³	Total alkalinity, mol/dm³	Permanganate oxygen consumed, mgO/dm³	Phosphorus from phosphates, mg/dm³	Molybdenum, mg/dm³	Cadmium, mg/dm³	Zinc, mg/dm³	Manganese, mg/dm³	Copper, mg/dm³	Lead, mg/dm³	Chromium, mg/dm³	Nickel, mg/dm³	Cobalt, mg/dm³	Beryllium, mg/dm³	Strontium, mg/dm³	Lithium, mg/dm³
13.80	10.2	1.9	<0.04	<0.025	<0.0001	<0.025	0.011	0.004	<0.001	0.001	<0.005	<0.005	<0.0001	0.199	0.032
35.80	3.9	1.1	<0.04	<0.025	<0.0001	0.039	0.040	<0.001	<0.001	0.002	<0.005	<0.005	<0.0001	0.430	0.028
24.50	5.5	<1.0	<0.04	<0.025	<0.0001	0.029	0.002	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.475	0.027
17.20	6.7	2.0	0.22	<0.025	<0.0001	0.043	0.009	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.442	0.028
0.90	4.4	<1.0	<0.04	<0.025	<0.0001	<0.025	0.004	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.390	0.027
0.50	7.0	1.1	0.04	<0.025	<0.0001	0.029	0.003	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.382	0.027
20.80	7.2	1.1	<0.04	<0.025	<0.0001	<0.025	0.030	<0.001	<0.001	0.002	<0.005	<0.005	<0.0001	0.640	0.026
22.10	7.1	<1.0	<0.04	<0.025	<0.0001	0.600	0.005	0.010	<0.001	<0.001	<0.005	<0.005	<0.0001	0.425	0.025
11.30	7.4	<1.0	<0.04	<0.025	<0.0001	<0.025	0.002	0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.820	0.027
3.90	14.8	2.4	0.06	<0.025	<0.0001	0.066	0.033	0.012	<0.001	0.001	<0.005	<0.005	<0.0001	1.240	0.027
14.20	12.2	<1.0	<0.04	<0.025	<0.0001	0.060	0.040	<0.001	<0.001	0.003	<0.005	<0.005	<0.0001	0.740	0.026
9.80	8.1	<1.0	<0.04	<0.025	<0.0001	0.106	0.002	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.680	0.027
12.00	6.6	<1.0	<0.04	<0.025	<0.0001	0.087	0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.0001	0.800	0.027
5.90	4.3	3.4	<0.04	<0.025	<0.0001	0.189	0.025	<0.001	<0.001	0.002	<0.005	<0.005	<0.0001	1.400	0.025

- A limited use of underground freshwater resources, which have a higher level of protection from anthropogenic contamination and the effects of the ATO, as well as a spatial distribution with a possibility of approximation to residential and industrial facilities.
- A decline in the effectiveness of treatment facilities due to interruptions associated with failures of power supply and water-use technologies.
- An increase in the quantity and area of land sites with industrial and household waste, including in water-protection zones of surface sources of domestic water supply.
- An increase in the flow of contaminated saline water from mine workings that are being flooded.

In general, the entire complex of current threats to domestic water supply in Donbas under the armed conflict may be divided into the following groups.

1. Regional deterioration of conditions for the formation of water resources, initially surface water resources, due to the effects of continuing significant anthropogenic factors (notably, discharges of untreated wastewater and contamination of catchment landscapes).
2. Unsatisfactory condition of water supply, sewerage and thermal power networks, a significant share of which are exploited with significant losses (50–65% and more), waterlogging of the territories of towns and villages and corrosion of pipelines, which contributes to additional contamination of water in the networks.
3. An increase in contamination of surface runoff in adjacent territories in the basins of the Siverskyi Donets (the Russian Federation, Kharkiv oblast), the Dniper River and their tributaries.
4. A growing threat of emergencies arising from the water-hygienic state due to critical impacts of the armed conflict, the destruction of basin-level and regional monitoring systems, and challenging conditions for repair works and protective preventive works.

According to the 2016 HD ecological survey of reserve sources of domestic water supply in Donetsk and Luhansk oblast, 88% of samples taken in the government-controlled territory exceeded sanitary-chemical levels established in Sanitary Norms and Rules of Ukraine 2.2.4-171-10. Water reservoirs, wells and natural springs (20 samples, 100%) are characterised by the most critical water-ecological condition. Individual and group borehole water intakes (13 samples) exceed a limited quantity of permissible sanitary-chemical indicators (38%), primarily those of natural origin (such as hardness, dry residue and iron content).

A stable degradation of sanitary-chemical indicators of water samples taken during 2010-2012 in towns and villages correspondingly may bear witness to a growing complication of water-ecological conditions for domestic water supply in Donbas:

- in built-up area of Donetsk oblast' part of samples where contamination registered increased from 39.7% to 49.8%
- in country of Donetsk oblast' part of contaminated samples increased from 17.7% to 17.9%
- in built-up area of Lugansk oblast' part of contaminated samples increased from 56.8% to 59.5%
- in country of Lugansk oblast' part of contaminated samples increased from 86.7% to 88%

Persistent contamination of surface sources of domestic water supply and their water catchment areas is confirmed by a long-term presence of coliphages in the samples, at levels exceeding permissible levels by up to ten times (State Emergency Services in Donetsk oblast, episodic data for 2000-2013, confidential document).

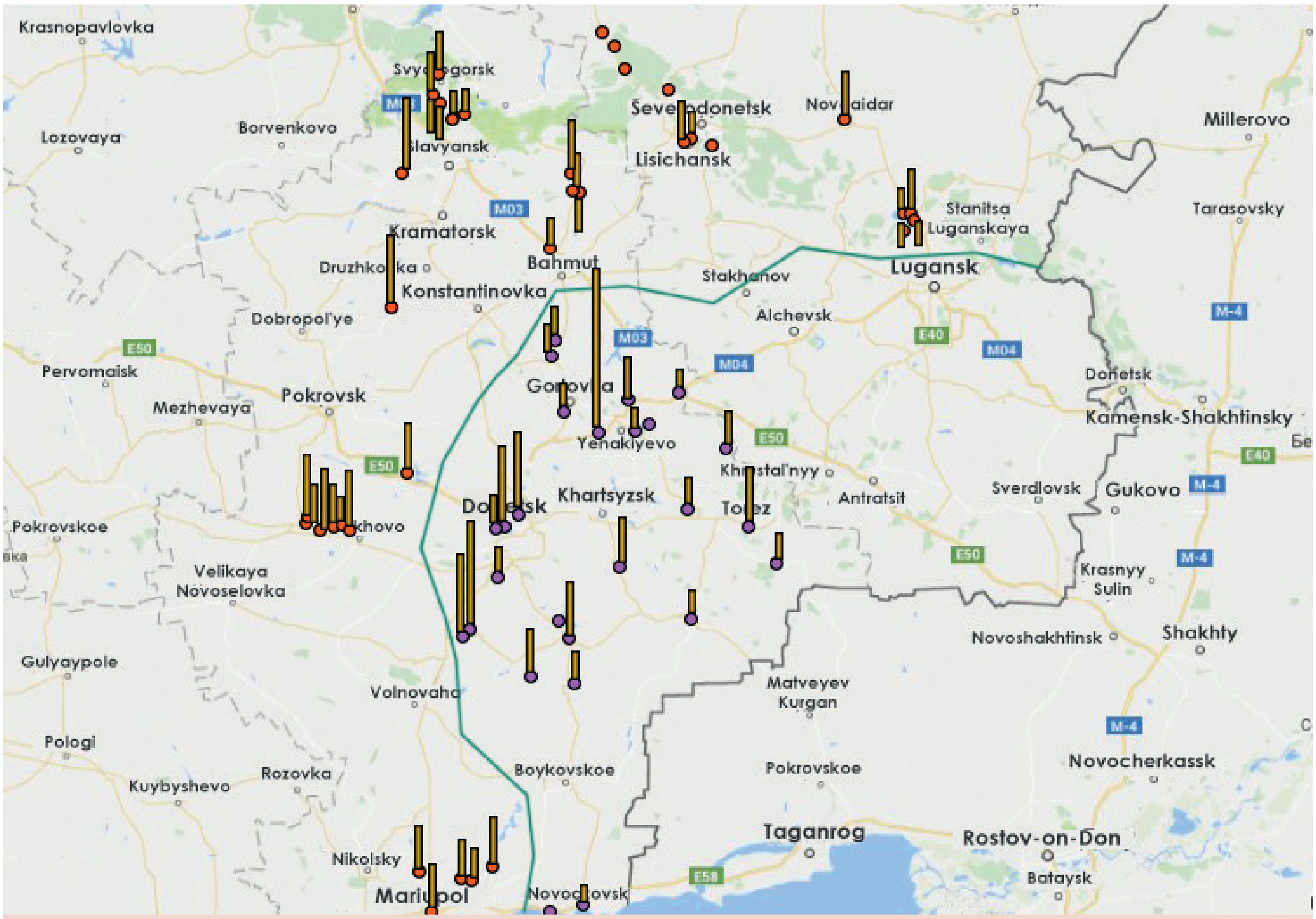
Current regional deterioration of the water-ecological state in Donbas is to a great extent a legacy of the times of abnormal industrialisation of Donbas (the second half of the 20th century). In this period, numerous chemical, oil-processing, metallurgical, energy and coalmining enterprises were built in the water catchment areas of the Siverskyi Donets, the Kalmius, and surface water reservoirs, which constitute sources of domestic water supply. Such enterprises involved ecologically deficient technologies and numerous filtered and non-filtered wastewater discharges. In addition, chemicals were actively used on the land at that time, which worsened ecological conditions for the formation of surface and ground water resources.

Medico-hygienic studies demonstrate that disinfecting, primarily chlorinating, water from surface sources of domestic water supply facilitates the creation of highly toxic compounds (including chlorophenol and trihalomethane). A preliminary analysis of numerous studies [7, assessment by the State Enterprise Research Institute for Medico-Ecological Problems of Donbas] demonstrates that chlororganic compounds in drinking water have cancer-causing properties, as well as a higher impact on the health of teenagers and women. Even under the conditions of very low direct discharge of wastewater into surface sources of domestic water supply, recently there has been a rise in adverse ecological-chemical impacts of numerous discharges of untreated and insufficiently treated wastewater into streams feeding drinking-water reservoirs. In the Siverskyi Donets basin, these include Staro-Krymske, Kurakhivske, Olkhivske, Volyntsevske and the Kazennyi Torets River.

It is worth noting that the current condition of surface hydraulic engineering structures of the main water supply complex, Donbas Water Company, is not adequate to guarantee ecological-chemical safety of water supply when there is a threat of destruction during the armed conflict or when standard operating access is restricted.

The survey of reserve sources of domestic water supply for Donbas under the conditions of the armed conflict conducted by the mission has demonstrated an unsatisfactory state of many hydraulic engineering structures. Initially, this is a concern in the sanitary protection zones immediately around water-use points such as wells, capped springs and individual boreholes. The parameters of the available sanitary protection zones were determined in the 1950s and 1960s. It seems that these do not correspond entirely to the current conditions of surface water formation and its interplay

Figure 7. Distribution of relative indicators of contamination of domestic water supply



Note

Red – sampling sites in Government Controlled Areas

Purple – sampling sites in Non-Government Controlled Areas with underground aquifers due to mine flooding and a rise in the area of anthropogenic and war-induced contamination.

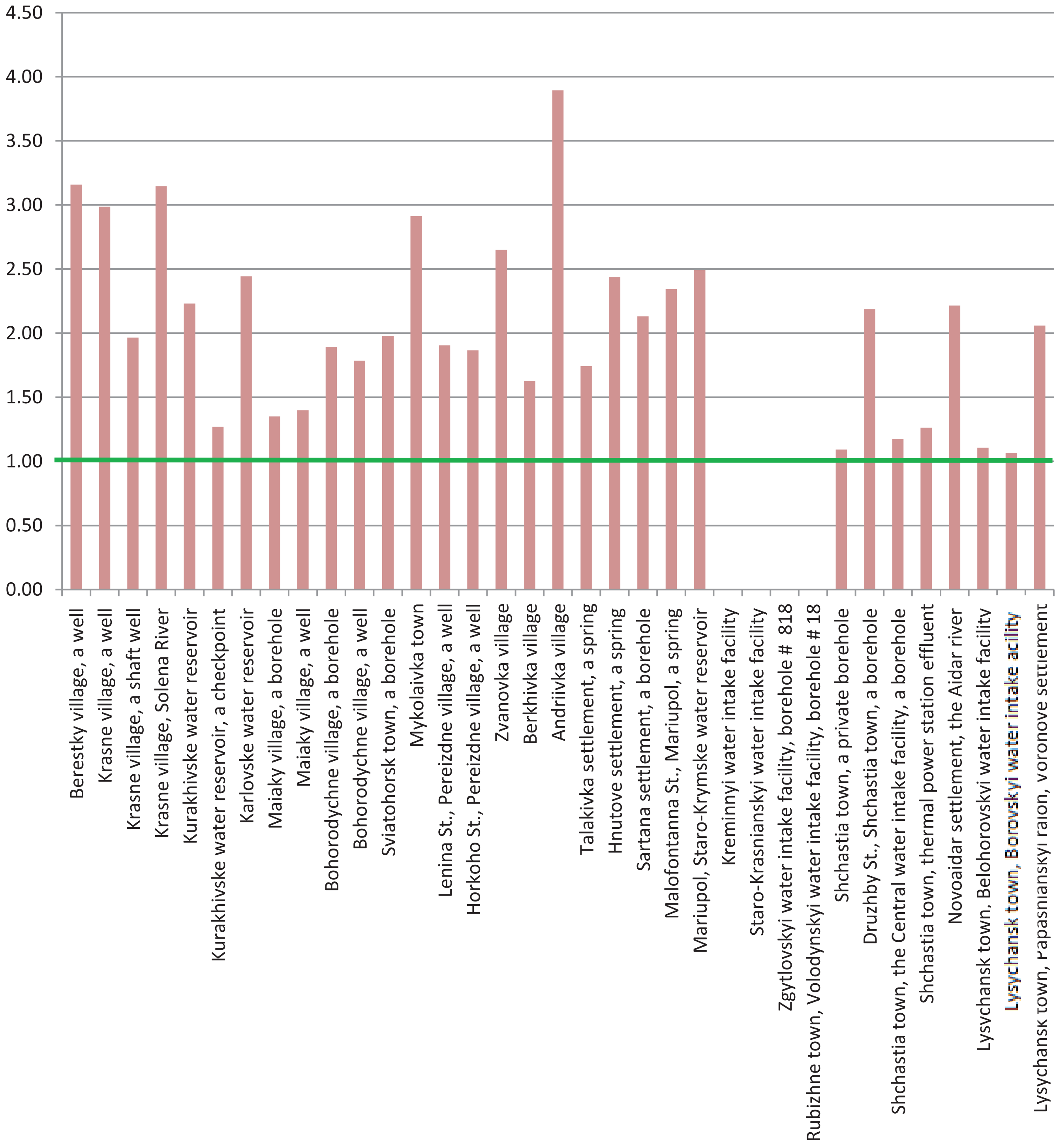
On the basis of the new data obtained by the mission, we conclude that there is a growing number of sources of domestic water supply that do not correspond to the requirements of Sanitary Norms and Rules 2.2.4-170-2010, as well as other normative documents. Contaminants with increasing impact include dry residue, hardness, chlorides and sulphates.

At the same time, numerous research findings [2, 8] prove that highly saline water with an unstable chemical composition adversely affects the human cardiovascular and digestive systems, and derates water-ecological parameters of human health and life (appearance of new diseases, shortening of life expectations, etc.). According to the available data, before the beginning of the armed conflict the fraction of drinking water contaminated in water supply lines reached the level of 84% of all deviations from standards.

In addition, there is an increase in the adverse impact of global climate change factors on the safety of water runoff into the Siverskyi Donets River. The key factors associated with global climate changes that may significantly strengthen negative impacts of unmanaged mine flooding and the armed conflict upon surface sources of domestic water supply may include the following.

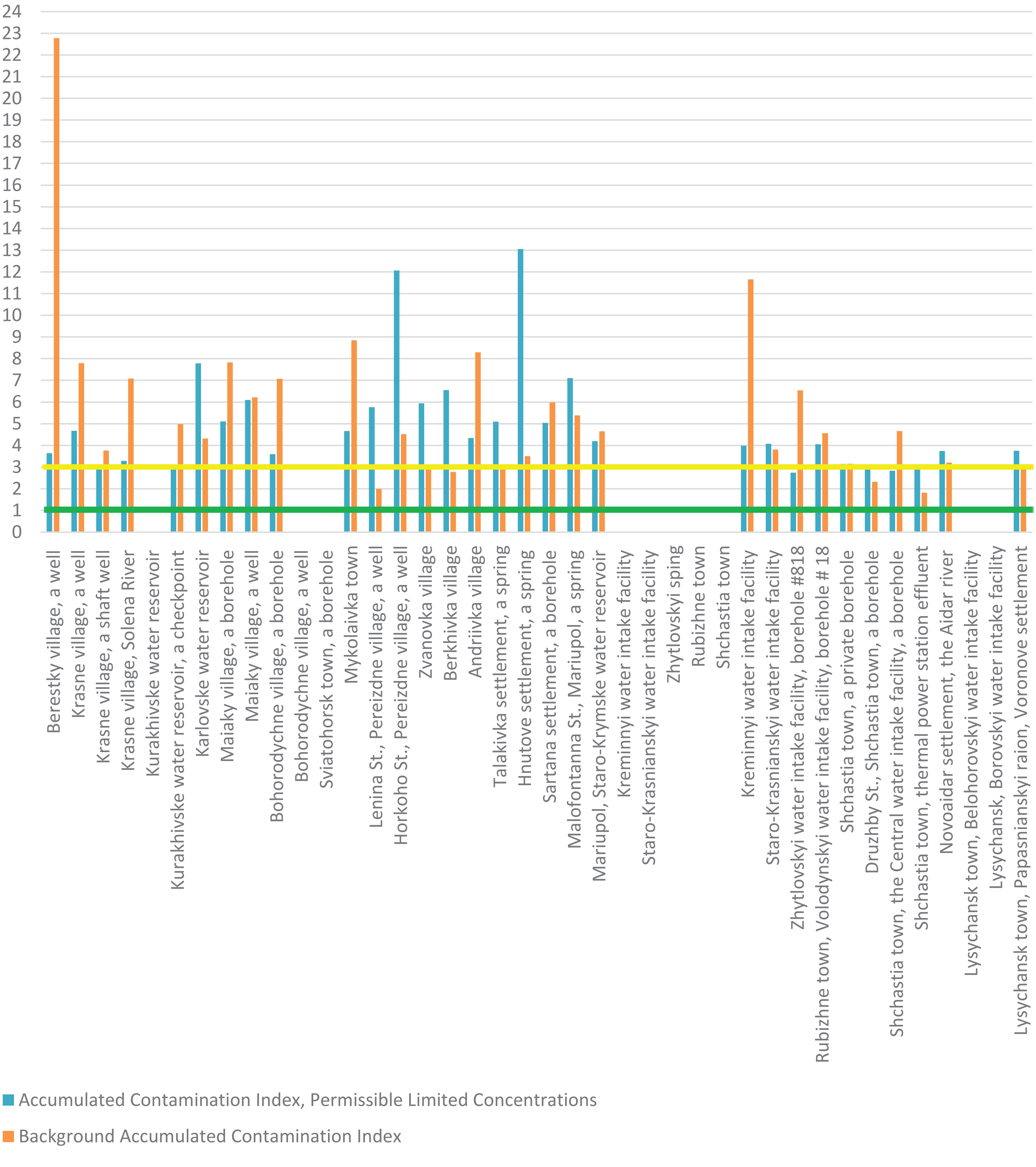
1. A rise in the unevenness of precipitation along with a decline in volume during summer and autumn seasons of increased water consumption.
2. Warming, leading to acceleration of contaminant decomposition and migration into surface water bodies and soil aquifers.
3. A rise in the contaminating influence of wastewater from industrial, residential and agrarian complexes in the Siverskyi Donets basin due to a deteriorating condition of waste treatment facilities and an additional river control.

Figure 8. Distribution of relative indicators of contamination of domestic water supply*



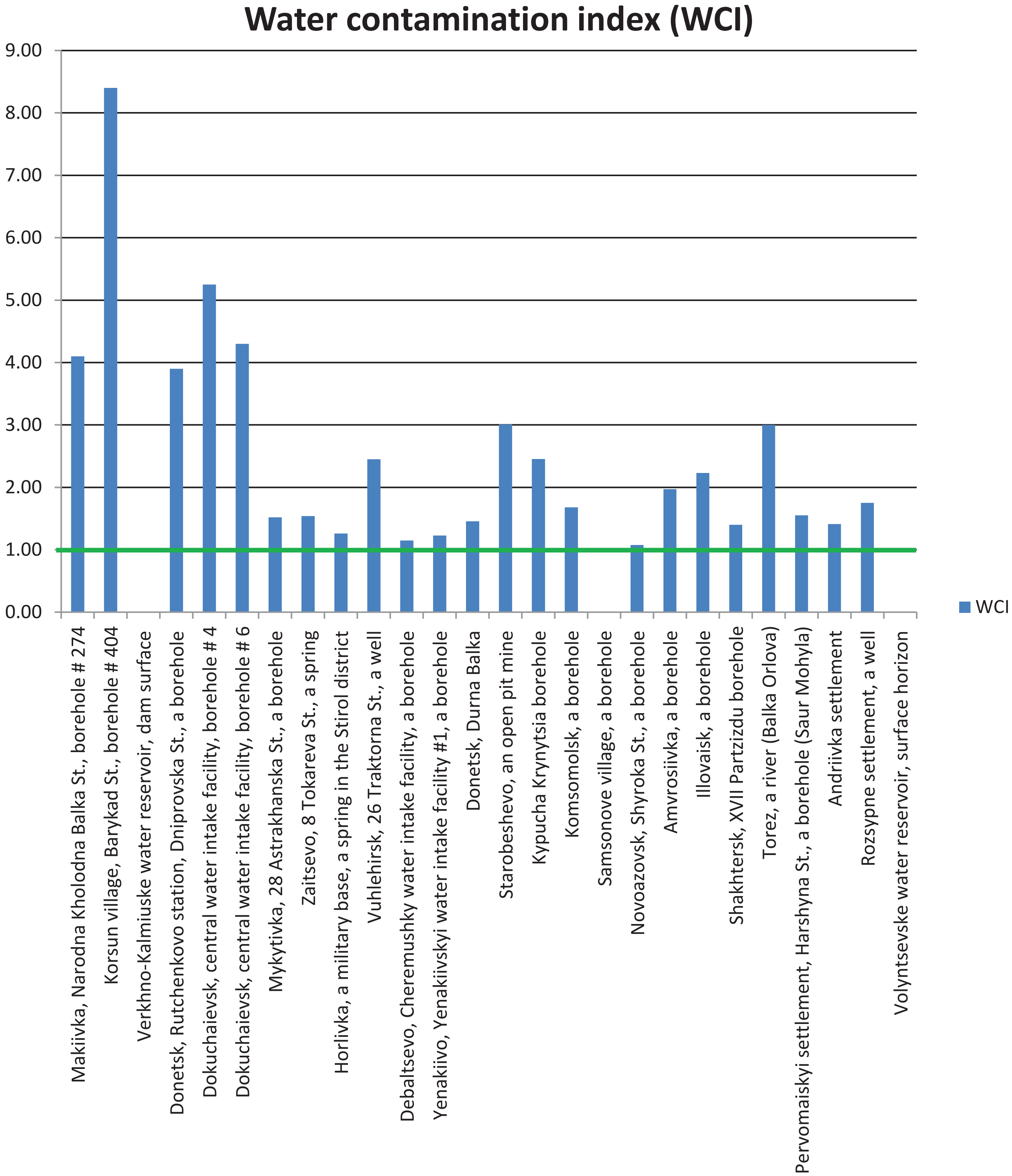
* The green line represents the *acceptable level* of chemicals, according to Ukrainian national standards.

Figure 9. Soil contamination in areas of domestic water supply, controlled territory*



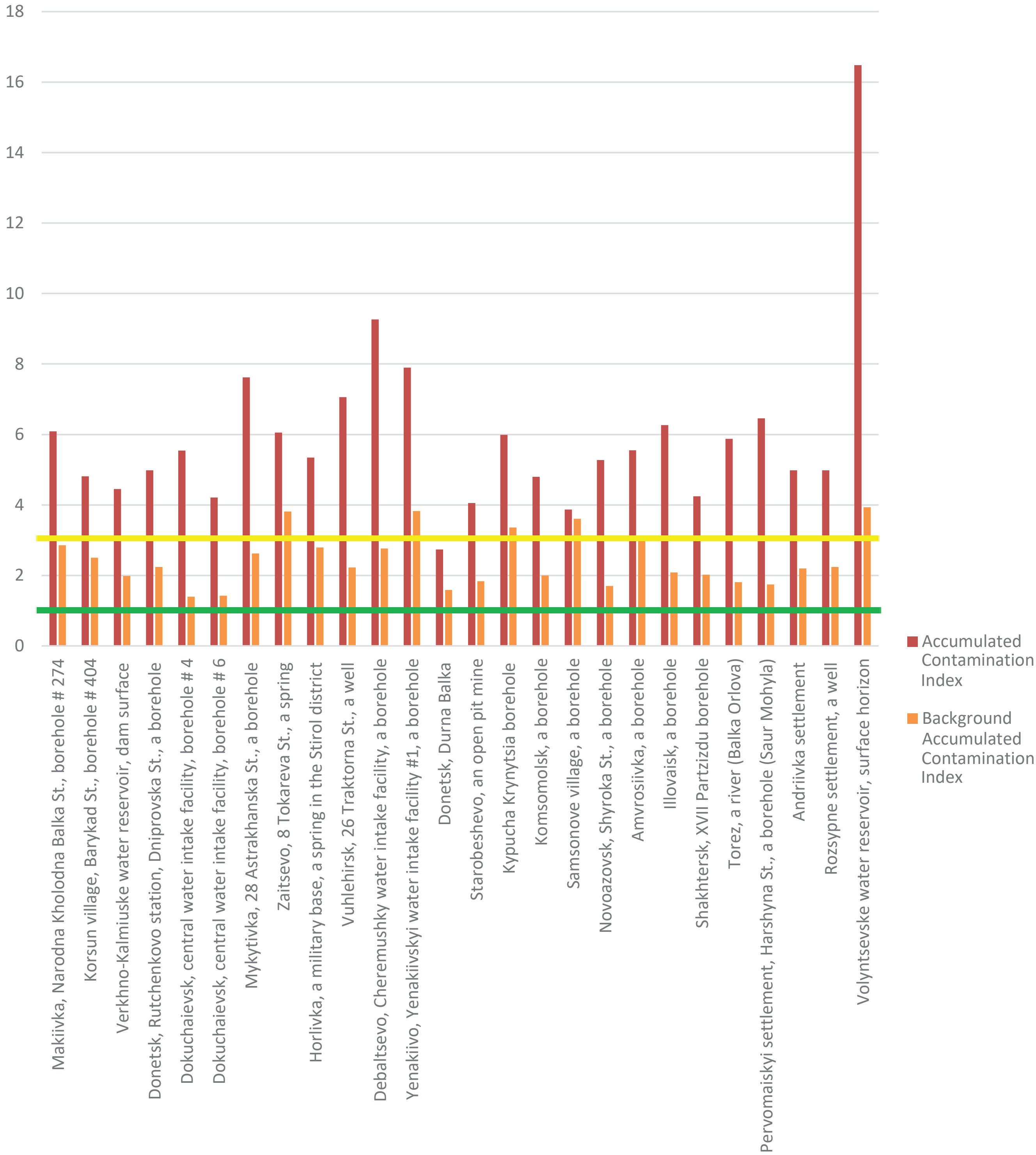
* The green line represents the *acceptable level* of chemicals, according to Ukrainian national standards.
* The yellow line represents an *alarming level* of chemicals, according to Ukrainian national standards.

Figure 10. Average indicators of contamination of domestic water supply, non-controlled territory*



* The green line represents the *acceptable level* of chemicals, according to Ukrainian national standards.

Figure 11. Average indicators of soil contamination in domestic water supply, non-controlled territory*



* The green line represents the *acceptable level* of chemicals, according to Ukrainian national standards.
* The yellow line represents an *alarming level* of chemicals, according to Ukrainian national standards.

5. Conclusions and recommendations

The following conclusions are drawn from the survey of reserve sources of domestic water supply conducted by the research group for this study. The recommendations below are offered as steps to prevent emergencies of water-related ecological origin and to enhance the stability of sources of domestic water supply for the population of Donbas.

5.1 Conclusions

1. Current ecological-resource conditions for the formation of surface and groundwater runoff in Donbas are extremely challenging due to significant spatial and temporal changes of natural and anthropogenic factors. This creates high risks of emergencies of a water-ecological origin. In practically all rivers of the Siverskyi Donets basin, as the main source of domestic water supply, water salinity drops to 0.2–0.5g/dm^3 during seasonal flooding, and in the dry period it rises to 2.5–5.0g/dm^3. This indicates extremely complicated hydrological conditions for the formation of natural surface runoff in Donbas.
2. Accelerated industrial development in Donbas has resulted in large-scale river control and intake of surface water from small and medium-sized rivers in the catchment area. This is in addition to the demand for water from the Siverskyi Donets to Donbas, since the end of the 1950s (through the Siverskyi-Donets–Donbas canal) and from the Dniper River since the beginning of the 1980s (via the Dnipro-Donbas canal). These measures taken to provide Donbas with water have substantially affected natural conditions for the formation of surface runoff.
3. The effects of household and industrial wastewater on river runoff in Donbas are dangerous under the conditions of unstable operation of treatment facilities in the majority of towns and villages. Household and industrial waste released in such rivers as the Vovcha, Kazennyi Torets, (until the Raiske line), Mius (until the Dmytrivna line), Krepenka, Velyka Kamianka, Lozova, Luhan (until the Zymohiria post) before 2013 is estimated to make up to 15% of the river discharge (*translator's note: as the volume of water moving down a stream or river per unit of time*). At the same time, for such rivers as the Byk, Kalmius (at the Rozdolne line), Sukha and Mokra Volnovakhy, Horikhovka and the Siverskyi Donets itself with due consideration of resources formed in the Ukrainian part of Donbas, release in individual low rivers exceeded 50% of the river discharge. In the case of the Byk and Kalmius Rivers, such release quantity has exceeded 100%, indicating possible repeated use of water resources or substantial losses through evaporation from ponds and water reservoirs.

5.2 Recommendations

In our opinion, the following measures to ensure ecological safety, human life and health in Donbas are of primary importance.

1. The activation of ecological monitoring of the ATO zone, including through remote-sensing techniques.
2. The exploration and assessment of new factors associated with ecological threats in Donbas, namely:
    - impacts of uncontrolled mine flooding and flooding of towns and villages and associated hazardous processes of surface and groundwater contamination, surface subsidence and dangerous deformations of residential and industrial buildings and other facilities
    - potential routes of contaminant migration beyond the boundaries of the region
    - growing contamination impacts on the Siverskyi Donets runoff due to the destruction of dams and other hydraulic structures.
3. Additional studies of the threat of radiation, to evaluate hazard levels and given that field monitoring does not permit precise identification of contamination sources.
4. Measures to restore critical infrastructure for water supply, sewerage and the treatment of industrial waste.

Annex. Proposals for monitoring key sources of water supply

No.	Source name	Source location	Monitoring object	Grounds for testing	Environmental elements (water, soil)	Groups of indicators	Names of indicators	Control frequency
Non-controlled territory								
1.	Kypucha Krynytsia underground water intake facility	Starobeshivskyi raion	Anthropogenic water reservoir at the location of a closed-down open pit of Dokuchaivskyi Flux and Dolomite Integrated Plant (wet abandonment)	The open pit has exposed an aquifer for water intake	Open pit water	Microbiological Sanitary-chemical Radiation	Total bacterial count, total coliforms, E.coli, enterococci, coliphages Organoleptic, nitrogen compounds Specific alpha and beta radioactivity	Every three months
2.	Komsomolskyi underground water intake facility	Starobeshivskyi raion	The Kalmius river in the water intake facility's area	Aquifer contamination through water seepage from the Kalmius riverbed caused by landslides resulting from pit undermining operations by the Komsomolske Mining Administration	River water	Microbiological Sanitary-chemical Radiation	Total bacterial count, total coliforms, E.coli, enterococci, coliphages Organoleptic, nitrogen compounds Specific alpha and beta radioactivity	Every three months
3.	Tsentralnyi underground water intake facility	Dokuchaivsk town	–	The open pit has exposed an aquifer for water intake (Dokuchaivskyi Flux and Dolomite Integrated Plant)	The open pit is located on the demarcation line	–	–	–
4.	Verkhno-Kalmiuske subsidiary drinking water reservoir	Yasynuvatskyi raion	Groundwater (a network of surveillance boreholes)	Impact of Musketivsk debris (waste from metals and coke and by-product processes)	Groundwater Soil	Sanitary-toxicological	Salts of heavy metals	Every six months
5.	Volyntsevske subsidiary drinking water reservoir	Yenakiieve town	The Olkhova river and tributaries of the water reservoir	Mine water impact	Water	Microbiological Sanitary-chemical	Total bacterial count, total coliforms, E.coli, enterococci, coliphages Nitrogen compounds	Every three months
6.	Olkhovske drinking water reservoir	Khartsyzk	The Olkhovatka river and tributaries of the water reservoir	Mine water impact	Water	Microbiological Sanitary-chemical	Total bacterial count, total coliforms, E.coli, enterococci, coliphages Nitrogen compounds	Every three months

Endnotes

a) Sampling results from sites in both government and non-government controlled territories are available upon request to the Centre for Humanitarian Dialogue.

b) Batchy folds are complexes of various geological fold structures with varying forms and angles of bedding.

c) There are two types of data in geological databases on mineral resources including waterfields or oilfields: prognosed –mapped and calculated as a result of desk study; and explored – practically confirmed as a result of geological search.

d) Analysis provided by, among other sources, the Sanitary-Epidomologic Agency in Donetsk Oblast; the Design and Research Institute of Technology of the Russian Federation, with radio-geochemical surveys provided by the State Geology Committee of Ukraine, and radio-ecological inspections provided by the National Commission for Radiation Protection of Ukraine.

e) Including : Regional monitoring of the geological environment by the state regional geological enterprise HRHP 'Donbasheolohiia' and the state company DK 'Ukrvuhlerestrukturyzatsiia', an ecological-geological inspection of the Yunkom mine by the author (October 2001), expert recommendations from the Nuclear Research Institute and the Geological Sciences Institute of the National Academy of Sciences of Ukraine, as well as relevant competent organisations of the Russian Federation (VSEGINGEO, VNIPIpromtechnologii, Gidrospetsgeologia, and others).

f) Source: В питьевую воду на Донетчине может попасть ртутная порода – ГУР [Mercury can enter the drinking water in the Donetsk Region – GUR, Main Directorate of Intelligence] http://news.liga.net/news/politics/10563900-v_pitevuyu_vodu_na_donetchine_mozhet_popast_rtutnaya_poroda_gur.htm

g) This section provides an analysis of the most relevant findings of the sampling mission. Full sampling data, including ecological profiles of sampling points from sources of domestic water supply in both government-controlled and non-government controlled can be made available to interested parties through a request to the Centre for Humanitarian Dialogue (see contact information).

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