Strategic Concept Note

for natural resources revitalization in Solotvyno, and to prevent further pollution of the Upper-Tisza River

Executive Summary

The Project REVITAL 1 started in 2019 and encountered severe delays due to Covid-19 and Russia's war in Ukraine. Consequently, there were amendments made in the contract and a couple of prolongations of the project were made. The work (specifically the field work) has been an enormous sacrifice and self-motivation of all partners of the project as logistical challenges and security concerns prevented more efficient and effective work.

During the project a variety of data were collected (geological, hydrogeological water quality and quantity) providing exact information on the targeted area and revealing deterioration of the situation in Solotvyno.

This Strategic Concept Note and a documentation on the complex monitoring system both are providing a good and important base for future actions and are supporting the decision makers at all levels. The project activities build on several previously conducted missions by Hungarian authorities, EU Civil Protection Team and ImProDiReT project.

The data collected should also serve as a base of the future developments and actions (new elements of the improved monitoring system, rehabilitation activities, new investment possibilities, disaster management, etc.), but must be planned according to the mid and long term with no harm to the environment and considering the safety issues for the inhabitants of the Solotvyno. There is an always present appetite to re-open the salt mining, but without a joint and coordinated effort no positive outcome is foreseeable.

The applied methods used in the project (geophysics, applied geological and hydrogeological methods, anchoring contamination sources, pre-monitoring, and numeric modelling) can be utilised in overall water management.

For the implementation of the project **3 specific objectives were identified**: 1. to examine

and evaluate the current environmental state of the Solotvyno salt mine and its wider surroundings with the aid of innovative technology, 2. to set up investigative monitoring and to design an appropriate future complex monitoring system for tracking the surface and near subsurface water qualitative and quantitative changes and the soil movements. 3. to raise awareness and promote the results of the project on different levels. The results have been achieved to some extent (with the hindering factors described already) and it will be up to local and regional authorities to push the suggested actions further. It is obvious that only with the joint effort by local, governmental authorities and involvement of scientific institutions the greater success can be achieved.

Map of the studied salt dome area with lakes (fresh and salt), creeks, drainage system (GeoGold Ltd.)

As results of the Project activities numerous maps, data, reports etc, have been produced and the Strategic Concept Note captures the most important elements of the work performed by all project partners.

During the centuries, due to the salt rock excavation made first on the surface, and later, due to the development of mining and borehole techniques to the deeper ways, the protecting layers (palah) partly destroyed and disappeared. Because of these activities, the surface of the salt dome became open, contacting directly with the air humidity and precipitation, moreover, is closer contact with the flowing surface and shallow groundwater, too, and the salt karstification processing has started here. Sinkholes, dolines, craters, and finally the disruption of the mines have been coming into play, and all these phenomena are the consequences of the salt dissolving.

The problems of the mining activity in Solotvyno, which has been operating for hundreds of years, mainly started in the 60s and 70s. As the volume of salt extraction increased from 0.5 million tons per year to 1 million tons per year using explosives in deep mines, the amount and speed of harmful phenomena also increased.

Forced blasting extraction also increased the number of environmental disasters, the causes of which can be classified into three main groups.

1) Disruption of the natural water-tight layer near the surface (a layer of salty clay a few meters thick below the Quaternary cobble-gravel-sand alluvial sediment layer, locally known as 'palah') because of mining activity and research drillings

2) Complete lack of maintenance of the drainage gallery system (the dewatering system at an average depth of 30 m, which surrounds the cultivated mine area and aims to drain the groundwater of the Quaternary cobble-gravel- sand layer near the surface, located above the 'palah' layer that provides the natural protection of the salt dome) created about a hundred years ago. The absence of gallery and dewatering management started in the 70s, continuing with the incorrect handling of the resulting problems and the lack of further prevention.

3) Use of improperly performed and forced blasting procedures to increase salt production.

Consequences:

a) Water intrusions into mines, dissolutions processes in the salt dome

b) Formation of cracks and mine lakes that penetrate to the surface

c) Detectable annual ground level subsidence of 1-2.5 cm/year

From 2007 to 2010, flooding of two operational mines and formation of huge earth surface gaps and other hazardous geological phenomena took place at the State Enterprise "Solotvynskyi Solerudnyk" activity territory. An expert conclusion of the Ministry of Emergencies of Ukraine has defined this ecological disaster as a state level emergency.

In 2o1o the Ministry of Emergencies of Ukraine announced a State of Emergency in Solotvyno salt mine area. In 2008, the first indications showed significant changes in the water quality of the Tisza River which originated from the collapsed salt-mine of Solotvyno. Although the intensity of salt contamination had recently decreased, the problem had not yet been solved. Rock salt in the Solotvyno deposit has been mined since the time of the Roman Empire in cone-shaped pits that have been preserved on the western edge of the deposit [Ivanchenko et al., 1967]. Underground development of the deposit (mines) began in the second half of the 18th century.

To address the Solotvyno potential environmental emergency for the first time in the history of the Union Civil Protection Mechanism (UCPM) the UCPM was activated by a Member State and non-Member State of the EU in 2016 (Civil Protection authorities of Hungary and Ukraine). The UCPM deployed a scoping mission between 2 to 9 July the same year to support the national authorities and respond to the joint request of assistance. At the same time Hungarian authorities deployed a small team of experts to strengthen the future activities and support the UCPM Team in drafting the Terms of Reference. The scoping mission produced a technical report shared with Member States and Participating States (PS) of the UCPM and Ukrainian authorities (UA) and a draft *"Terms of Reference "* (ToR) for an advisory mission.

Based on the findings of the scoping mission, it was decided to deploy an advisory mission to conduct a *"comprehensive risk assessment at the Solotvyno salt mines area"*. The deployment took place from 14 September to 7 October 2016. As a result of the mission an assessment report has been delivered and that has served and still does as a guiding principle of any activity in the Solotvyno area regarding mining.

The analysis deriving from the local and locational endowments of Solotvyno provides conclusions and recommendations by giving a comprehensive picture on the factors that shape the territorial, economic, and social cohesion of the settlement. It is important to give a deeper understanding of the context of the complex, cross-sectoral issues that shape the present of Solotvyno that are in strong connection with the salt mining and the environmental risks assessed throughout other parts of the document.

It can be said that in the current state, a maximum of 4600 kg/d of NaCl is released from mines and 6600 kg/d from saltwater lakes, i.e. a total of 11 200 kg of rock salt is loaded into

the Tisza River. Assuming a rock salt density of 2100 kg/m^3, this would result in a daily leaching of 5-5.5 m^3 of rock salt per day, which would mean a maximum of nearly 2000 m^3 of cavitation below the surface per year.

The overall methodology of the REVITAL 1 consists of desk research, use of statistics and conducting a series of interviews, site visits and measurements and data collection and analysis. During the desk research, information on Solotvyno was searched via finding and summarising, reviewing bibliography in the topic of Solotvyno's socio-economic life. Statistical data from the official sources of the Statistical Office of Ukraine as well as statistics from other databases built during the years in the frames of CBC[1] and transnational projects and regional analyses were also used to provide territorial evidence. Still, it must be noted that sometimes there are strong limitations owing to lack of latest data on settlement and regional levels. Due to these limitations the analysis many times could use data only from earlier years than of the administrative change of 18th July 2020.[2]

It can be stated that the situation of the urban development of Solotvyno heavily depends on the utilisation level of local endowments and locational aspects. From a geographical point of view the settlement is situated on the westernmost part of Ukraine, in Transcarpathia. Solotvyno has been in a disadvantaged peripheric situation as strong EU[3] borders persist, and major transport connections avoid the urban-type settlement. However, Solotvyno can capitalise from being a peaceful corner of Ukraine, its closeness to European markets, and the future decrease of the negative border effects (by the construction of a new bridge crossing to Romania in particular). Potentials lie in being in a stronger functional integration with Sighetu Marmației, Romania. Solotvyno is also the centre of its surrounding settlements. Solotvyno has functions that make the urban-type settlement outstanding from the settlement network: health care facilities, spa tourism, many organisations and institutions connected to the ethnic minorities. Land movements connected to the results of mining activity push authorities and the local government to rethink land use planning and the relocation of functions and citizens, which could only be done with great care,

[1] Cross-Border Cooperation, also knowns as Interreg A

[2] Solotvyno remained in the same district (Tiachiv Raion), however the number of districts was reduced thirteen to six making comparisons difficult. In the text different denominations are used for Solotvyno. Solotvyno can be regarded as: 1) as an urban-type settlement (mistechko);2). and from June 2020 as a territorial community (hromada) that consists of few other settlements as a basic administrative level of Ukraine. worth keeping in mind that administratively Solotvyno is an urban-type settlement and not a city municipality by law.

[3] European Union

especially on the ethnocultural implications. Environmental protection is of great importance since the pollution of the groundwaters and the Tisza itself impacts a wider transnational river basin which calls for joint initiatives in water management and environmental protection at least. Waste management is unresolved in Solotvyno that implies further calls for action.

The development of Solotvyno and any environmental intervention cannot be carried out without considering the multi-ethnic character of the urban-type settlement, which could be better addressed in the future as a basis for socio-economic improvements. Population retention force should be increased by effective and efficient policies and concrete actions that would keep the population at their homelands. Regarding economic structure after the collapse of salt mining, diversification could play an important role. The lack of large enterprises after the shrinking mining industry could be counterbalanced by the support for SMEs[4] in tourism. Mono-structural economy has been shifting towards an economy characterised by emerging tourism. In the economy a lot depends about the tourism and health sector. The emergence and quality shift to complex health and recreational tourism that is based on hospitals and the salt waters is of great significance. Water and ground pollution, waste, landslides and other movements and the well-being of the local population are inseparable areas.

There is no significant difference in land subsidence between 1992-2000 and 2002-2010. In both periods, it is clearly visible that **the very high-risk area is the former salt mine, the salt ponds, and the several hundred-meter strips bordering them** if it affects built-up areas. **This means subsidence of up to 25 mm/year** (obviously, this shows higher values in the vicinity of the ruptured craters). **The most endangered utility provider is the electrical distribution network plant located around Mine 9 (near Shaft 10) in the NE part of the very high-risk area.**

Interpretation of satellite images was carried out to establish the basic patterns of earth surface deformations for further assessment of risks associated with the development of hazardous natural and technogenic geological processes within the Solotvyno salt dome structure and adjacent territories.

Assessment of vertical displacements of objects and the ground surface was carried out using interferometric processing of satellite radar monitoring data by means of satellite constellations Sentinel-1A and 1B (DInSAR analysis data for 2016-2021, SBAS approach, Copernicus EMSN-

[4] Small and medium-sized enterprises

030, EMSN-064; PS+SBAS approach, Center of the Special Information Receiving and Processing and the Navigating Field Control, Ukraine). According to satellite radar monitoring by means of new satellite constellations including Sentinel-1A and 1B and innovative data processing techniques (Persistent Scatterers – PS & Small Baseline Subset –SBAS). 2016-2021 studies performed by the Center of the Special Information Receiving and Processing and the Navigating Field Control, Ukraine.

The research area was 33 sq. km. The final information products (raster and vector) were created, which made it possible to analyse changes in spatial and temporal dimensions. Remote sensing radar data preparation and pre-processing operations were performed in ENVI software, SarScape modules, and thematic processing operations based on interferometry results (ArcGis software) was done.

Ground deformation mapping and monitoring by satellite (2020-2021)

According to the latest satellite radar monitoring data (for the period 06/30/2020-10/12/2021) the assessment of the vertical deformations of the ground surface, buildings, and facilities within the Solotvyno was done. As a result, 5 areas of intensive subsidence were identified (with an average subsidence rate from -6 to -126 mm/year) (Fig. 9 B). It was established that the subsidence zones near the mine No. 7, 8, 9 are significant in area and each has a significant subsidence mould, in which the largest subsidence is determined in its centre, and, when moving away from the centre, the intensity of subsidence of the ground surface gradually decreases. **The territory of mine No. 7 and the western and eastern parts of the mine No. 8 area was identified as unsafe.**

The highest values of surface deformation from –94.93 to –139.98 mm at vertical displacement rates from –34.08 to –67.54 mm/year were established for objects/sites (critical infrastructure facilities) for the period 2016-2020, located within the emergency zone above mines, which is characterised by the most intensive development of karst-suffusion processes.

According to the results of retrospective processing in the study area, zones of concentrated deformations and the dynamics of subsidence in the points of radar measurements were determined (Figure 13). Based on the assessment of the vertical displacements of ground surface, obtained using interferometric processing of satellite radar monitoring data for the period 2016-2021, the values of the accumulated deformations of the earth's surface reach -385.12 mm, it was determined that mines No. 7, 8 and 9 pose a threat to the technogenic safety of the Solotvyno settlement.

The results obtained from all data analysis should be used for continuous risk assessment of the Solotvyno rock salt deposit and adjacent territories. To ensure life safety in Solotvyno, the results need to be used for territory development and monitoring system establishment.

Using corner reflectors and InSAR technology an early warning system could be installed over the area. This InSAR-based monitoring system could improve the civil safety conditions quite a lot, and provides an objective, transparent surface deformation information for anyone throughout a web gis application. This application can be installed on local people's smart phones, and they will be able to receive direct information about their residential district.

After finalisation the processing of the geological data and assessment of the geophysical measurements and information it has become clear, that the alluvial terraces of the Tisza River covering each other reached the slopes of the Magura Mountains, moreover they also covered the relatively higher positioned salt dome but not as thick way like other places.

According to the hydraulic gradient, the water from precipitation and groundwater flow system continuously flows into the Tisza in the alluvial layers of highly permeable cobble, gravel, sandy gravel, and sand mainly from East to West, passing through the salt dome.

Originally, the salt dome was covered some few metres of salted clay layers (palah), protecting it against any humidity and/or water. But, **due to the mining activities, which finally caused serious surface destruction, this protecting layer became open providing so-called ‘hydraulic windows’ to harmful and fatal processes**.

View of today’s abandoned mines (white numbering) with the mining chambers and mine openings as potentially and really threatening underground spaces against water *(Geogold Ltd)*

InSAR measurements revealed the spatial and temporal distribution of historical surface deformations Solotvyno in Ukraine. Through the analysis of interferometric data it helped to understand the nature of the Solotvyno salt dome surface deformations from the 1990s to the end of 2000s. ERS and Envisat SAR imagery archives covering the above-mentioned time frame have been processed and interferometric deformation history of the area was investigated concluding **the results** listed below:

- The central part of Solotvyno and adjacent southern slopes of the Magura were detected as fast-moving distinct surfaces during both decades, while other surfaces remained permanently stable.
- Risk levels were computed from interferometric and geological data, showing that high risk levels occur at the dome and surrounding area, while the level of risk decreases with the distance measured from the centre of the salt dome.

The continuous dissolution of the Solotvyno salt dome is influenced by the replenishment of fresh water, the amount and intensity of precipitation (especially the accumulation of winter precipitation), the flow of natural waters coming from the direction of the Magura mountain

range, as well as anthropogenic effects, mainly water withdrawals and wastewater introductions.

The salt dome in a prominent position divides geomorphologically the region into two, from the salt dome to the Magura Mountains to the North, and from the salt dome to the Tisza to the South. The slope from the Magura Mountains to the mine area is 5-7.5%, so the rainwater flowing from here attacks the mining area. The resolution of protecting against water was a gallery dewatering system, which was created more than a hundred years ago at an average depth of 30 m. The dewatering system, which was built several kilometres long, surrounding the cultivated mining area, has not been in operation for decades.

Collapsed mines, through this long leakage path, burden the Tisza in smaller quantities, but constantly, the salt load of which is, at the same time, significantly increased by the introduction of the used salty water of the salt lakes operated for the purpose of tourism into the Tisza, concentrated through the Glod stream and other artificially created drainage ditches.

The data show that the environment protection system in the Tiachiv Raion is underfinanced. Although **Solotvyno** has significant Badenian salt outcrops and salt karstic features – whose morphology transforms rapidly –, these heritages are not protected and not under any restrictions. Moreover, these **salt resources are not just a heritage or a tourist sight, but a vast environmental and hydrogeological hazard** as well.

During the project, a well-group consisting of 15 piezometer wells was established (wells marked MON), in which regular/continuous water level and water chemistry test measurements were carried out for a year. Private residential wells of similar depth (6-15 m) were also included in the measurements (a total of 8).

The interpretation based on the measurements also covered the detection of seasonal differences. Figure 20 clearly shows the broad N-S groundwater flow starting from the slope of the Magura Mountains, which suddenly changes direction and turns E-W when it reaches the former mining area. This is true for most of the flowing water, but a smaller part of the flowing water avoids the mine area and flows towards the Tisza, keeping its flow direction almost N-S.

The EC measurements, since 2016, show **that fresh water is being accessed in the Shaft 10**. The value EC=500-650 µS/cm, in 2016, was reduced to EC= 200-400 µS/cm based on the robot measurements in 2021, which changes to EC= 400-450 µS/cm in the zone between 10-130 m (in 2016, a value of 650 µS/cm was measured in 150 m). At a depth of 130-140 m, a transitional mixing zone can already be seen (the value of EC= 450 µS/cm increases to a value of 3200 µS/cm), which came higher compared to the minimum depth of 150 m registered in 2016.

The robot measurements in 2021 show a constant value of EC= 3200 µS/cm from a depth of 140 m to the bottom of the shaft, which is a conductivity of approx. EC= 1000 µS/cm is higher than the EC= 2180 µS/cm measured in 2016 in 198 m.

Slow salt dissolution takes place in the depths to reach a state close to saturation. The saturation process is not yet complete.

The above is also confirmed by the temperature profile measured in the shaft. The value of low-conductivity fresh water at t = 8 C° rises to t = 24 C° after the transition zone of 130-150 m and remains constant until the bottom depth.

The mine shafts located hundreds of metres deep are practically impassable due to the collapses detected by the robot. At the same time, shaft 10 is statically stable and provides additional measurement options for investigating water chemistry changes at depth.

The prosperity of Solotvyno including tourism, agriculture and mining is heavily dependent on decrease of environmental and man-made risks and hazards that hamper the success of Solotvyno in shifting to a more sustainable and new development path. Without comprehensive territorially integrated interventions Solotvyno will not be able to utilise its territorial capital and local endowments, and problems will be reproduced on a longer term.

The sinkholes, the salt resource, the brine and the soil are **exposed to the threat of pollution.** Especially tourism (with the medical centres, the beaches, and the accommodations) and the agriculture, can fall into crises which directly affect the local community.

The spontaneous and uncoordinated management of the recreational area and the proximity of the abandoned mines cause hazards. The contamination of the sinkholes – by the illegal littering – has a direct effect on the water quality of the beaches. The incidental pollution of the water in the Lake Kunigunda would impair the reputation of Solotvyno and decrease the number of the future tourists. Unfortunately, due to the abandoned mines and the irresponsible behaviour of the locals, these **salt resources have been contaminated, which impairs the future potential of tourism.** To avoid this, it is crucial to create a well-working waste management system and to halt the illegal littering. Another hazard can be the unclosed territory of the mining area since the visitors frequently roam here between the sinkholes just because of interest or short cut. Furthermore, the **constant danger of landslide and subsidence deters the new investors and companies, as they**

do not want to invest in a risk zone. In addition, there are some smaller scale land movements around the recreational area of Solotvyno too. Local businesses try to mitigate and react to these processes, however according to local sources, no major movements have occurred recently. What can be dangerous is the underground flow of water between the two parts of the settlement of Solotvyno, and the effect of such invisible waters is unknown yet. Few accommodation facilities are affected by the movements.

Salt mining has a long tradition in Solotvyno given that the development of modern-day Solotvyno was based on mining in the first place. This also means that the situation of salt mining shapes the present and future of the local economy, and it is not secondary to what will happen to the sector.

With the UX-1Nepo diving robot the UNEXMIN Georobotics Ltd. the project partners produced 3D maps, captured high-resolution video footage in the Solotvyno mining area and evaluated the results of the dives. In addition, the robot carried out water sampling and water parameter measurements (electrical conductivity, pH, oxygen fugacity, temperature, pressure). The main expected outcome of the work was to better understand the potential subsurface sinkholes beneath the Solotvyno municipality and to complete the information needed for modelling the local groundwater flow system.

A modernised and improved hydrodynamic model of the Solotvyno salt mine area and its surroundings was created based on the refined filtration parameters of the suprasaline deposits of the Solotvyno salt dome structure and an updated database, which made it possible to predict the direction and the speed of groundwater flow over time. The model was improved based on the received new materials regarding the peculiarities of the geological structure and hydrogeological conditions of the research area, as well as the initial data on groundwater pre-monitoring . Its functional compliance with natural and anthropogenic conditions has been proven. The database for further research has been significantly expanded. The direction of movement of groundwater and its speed in time have been determined.

The area of influence cannot be reduced by wells, except by artificially reducing the flow of water through the bottom of the lakes formed by the collapse of the existing salt pits and continuously forming, by narrowing or blocking the exits of the pits and shafts even below the groundwater bodies, so that the salt water in the flooded mine pits is brought into full equilibrium by saturation, and in this way further desalination is induced only by fresh water

infiltrating along the tectonic lines. This would not impede the use of salt ponds for tourism at all but would merely reduce the salinity load on the Pleistocene riverbank layer and the Glod and Mlinsky streams that discharges it. In this way, the salt concentration in the crater lakes (above collapsed mine chambers) would be reduced slightly, but the groundwater would be reduced substantially. Well water production should be eliminated or banned in the current area of influence of the salt dome.

Salt dissolution in deep layers must be curtailed, otherwise it will cause a steadily accelerating phenomenon, with increasing amounts of salt being dissolved along increasingly large, dissolved surfaces, causing ever larger underground cavities and accelerating subsidence. The process can only be stopped by a radical reduction in deep groundwater flow, which is possible because of the geological and hydrogeological conditions. Reasonable solutions can slow the process down, and significant artificial interventions can reduce it completely, but this should be started as soon as possible, while it is still possible to reduce the process and the environmental damage does not destroy the living conditions of the population in the area.

Considering the complicated geo ecological situation, development and functioning of the permanent complex monitoring system of the natural and man-made geosystem of Solotvyno is the priority objective, it would provide an opportunity for timely detection and assessment of dangerous changes in the state of the geological environment and factors of threats to the safety of life at the local and cross-border level. The SCN provides information on the Planned Complex Monitoring System, that includes monitoring of ground surface deformations using DInSAR (interferometric processing of satellite radar monitoring data with PS & SBAS techniques); hydrological and hydrogeological monitoring (water quantity (levels, flow rates), quality / chemical composition); geophysical survey (microgravity, geoelectric and seismic methods); geodetic survey (verification of remote studies of the ground surface deformations); on-site hazardous geological processes development (karst & suffosion (subsidence, sinkholes, collapses), seasonal floods and flash floods, flooding, slope mass movement (erosion, landslides); modelling (up-to-date improvement of hydrodynamic model); risk assessment, preliminary substantiations of protective measurements.

Main conclusions

- It could be concluded that some findings of the previous projects (ImProDireT) and even EUCPT mission (in 2016) **reiterate the previous conclusions that there is a deficiency in information exchange and sharing between all the stakeholders involved in (the consequences of) the mining in Solotvyno.** The state of emergency is still present and so far, no answers, senses, or solutions on how to lift the state of emergency can be found.
- **The settlement zone of Solotvyno is directly adjacent to or enters the geodynamically active part of the salt dome diapir structure, the core of which has exits to the surface.**
- **The earth's surface because of long-term active mining operations with the use of drilling and blasting technologies at the last stage of deposit development is disturbed by mines and other workings, sinkholes and karst-suffusion sinkholes.**
- **There are more than 140 local karst development sites with a total area of more than 11.22 hectares and a volume of karst sinkholes and mine collapses of more than 5 million cubic metres.**
- **The growth of the tourism sector cannot be achieved without preventing the spread of pollution**. The local salt resource is the most important value of the area, and currently it gives the brand of Solotvyno. However, if this geological resource is polluted further, Solotvyno will not be able to utilise this special endowment anymore.
- In some areas relocation and building of new housing and infrastructure could be the only viable option.
- Badly planned relocation policy could cause uncontrolled negative impacts on the minority groups that would affect the whole society of Solotvyno.
- Lack of large enterprises after the collapse of the salt mining company is persistent.
- Solotvyno needs new economic areas in the form of an industrial park to stimulate economic growth.
- The labour market is very mono-structural with focus on tourism as the new main source of income after the collapse of the mining industry.
- Mining as an industry has collapsed, but **there is a chance to restart mining in Solotvyno further away from the older mines** that would disturb the urban areas less.

- It is unfavourable that just some parts of the generated waste are treated, but the **system of waste management**[5] does not work well either, because the proportion of recycling is low. In 2020 most of the waste (97.9%; 160 974.6 tons) was placed in a landfill and just 1.9% (3 199 tons) was incinerated and 0.2% (267.8 tons) was recycled in Transcarpathia.
- **On the territory of flooded and non-working (abandoned) mines, there is an expansion of the subsidence area and a gradual flattening of the slopes around karst craters and sinkholes. At the same time, the existence of karst-suffosion sinkholes (collapses) with vertical walls is an indicator of the continuation of active karst-suffosion processes.**
- **In difficult economic conditions (military aggression of Russia, especially its acute phase from 2022 and to a certain extent COVID-19), the population of Solotvyno finds opportunities and resources to implement projects for the development of tourist infrastructure. There is an involvement in use, for building territories where vertical displacements are recorded. For balneological purposes, brine is pumped out of the sinkholes of mine No. 7.**
- **Patterns of the distribution of ground surface vertical displacements, which are fixed not only in the contour of mining operations but also beyond them, are revealed; the accumulated ground surface deformations in the areas of critical infrastructure facilities were assessed.**
- **The highest values of surface deformation from –94.93 to –139.98 mm at vertical displacement rates from –34.08 to –67.54 mm/year were estimated for critical infrastructure objects for the period 2016-2020, located within the emergency zone above mines, which is characterised by the most intensive development of karst-suffusion processes.**
- **Based on the assessment of the vertical displacements of ground surface, obtained using interferometric processing of satellite radar monitoring data for the period 2016-2021, the values of the accumulated deformations of the earth's surface reach -385.12 mm, it was determined that mines No. 7, 8 and 9 pose a threat to the technogenic**

[5] Waste management 2017, 2020: http://www.uz.ukrstat.gov.ua/statinfo/navkol/2018/povod_vidhod_rajony-2017.pdf; http://www.uz.ukrstat.gov.ua/statinfo/navkol/2021/povod_vidhod_rajony-2020.pdf

safety.

- **The results highlight a totally different situation in the Romanian part, as it was detected in Solotvyno. The whole territory of Sighetu Marmatiei presents a stable condition, and there are not any districts of the town, which shows a geographically recognizable pattern of surface movement. Scattered locations of few unstable points are detectable. It means that the revealed local instability most probably in connection with structural problems of a building, or slope conditions.**
- **A modernized hydrodynamic model of the Solotvyno rock salt deposit and adjacent territories was developed, which includes information on five layers (geological units – formations) with maps of the velocity vectors, isolines of groundwater level, flow lines provided for two aquifers (Quaternary and Tortonian) with and without considering tectonic disturbances of various ranks.**
- **Hydrodynamic modeling with considering tectonic disturbances (faults) in the model showed the deformation of the model groundwater flow lines, that indicates an increase in water exchange in the fracture zones areas. This can accelerate and intensify the spread of saline water in aquifers.**
- **Based on results of solving several inverse problems, it has been established that that the hydrodynamic situation reproduced on the model reflects the natural conditions with sufficient probability thus the obtained model can be used to solve practical problems.**
- **The created hydrodynamic model made it possible to determine the network of monitoring hydrological and hydrogeological observation points optimally required for informative and reliable monitoring.**
- **Operation of the monitoring system are required for the sustainable use of natural resources (brines and rock salt) and protection against transboundary spread of surface and underground water pollution.**
- **Based on obtained studies results (field observations, remote sensing satellite radar monitoring data analysis, geological and hydrodynamic modelling) the complex monitoring system plan, which fits into the wider regional framework for tracking the surface and near subsurface water qualitative and quantitative changes and the ground surface deformations in Solotvyno area have been developed.**

Main recommendations

- ➢ **Considering the complicated geo ecological situation, development and functioning of the permanent complex monitoring system for the Solotvyno salt dome structure and adjacent territories is the priority objective.**
- ➢ **Ecological-technogenic and socio-economic parameters of Solotvyno settlement revitalization must be evaluated after the anticipatory creation of an informational and effective monitoring system with the possibility of a highly probable spatio-temporal assessment of the long-term (tens of years) transition to an equilibrium geodynamic state of the subsoil in this territory.**
- It is a topic of **further investigation to find out if it is environmentally and economically feasible to support the redevelopment of the salt mining sector.** Strict and improved monitoring should be deployed in case of positive answers.
- Mining can also be seen as a joint cultural heritage of the settlement and the wider region including the hromada of Solotvyno, which can support international tourism.
- Some of the former mining facilities and premises could be targets of innovative sports and recreational developments such as extreme sports, urban games, escape rooms, theatre etc. as well as interactive open-air and underground exhibitions. A thorough and proper Risk assessment is a must to do before any decisions are made and before any activity starts.
- Try to better build upon the potential lie in the cross-border influencing zone of Sighetu Marmației especially in the field of labour and student mobility and trade by initiating cross-border more institutionalised cooperation forms and governance structures (e.g. urban platform).
- Focus on urban functions, institutions, and services of regional importance (tourism facilities, hospitals etc.) and attraction to maintain and strengthen urban development.
- The governance and cross-border tackling of the joint challenges of the Tisza Basin can be tackled; stronger cooperation in the field of water and risk management is needed.
- Relocation and any new developments of larger scale should consider the wider socio-economic relations, the urban fabric and community ties within the settlement, and

territorially integrated approach should be supported that stretches beyond the sole demolition and construction of individual buildings.

- Encourage circular economy approaches, first by improving waste processing that can also provide additional jobs and income.
- Eliminate illegal ad hoc landfills and filled sinkholes along the floodplain of the Tisza in and around Solotvyno. Try to reuse or recycle the removed materials and waste.
- Establish a new modern landfill facility of EU standards further away from the river and the salt mines and protect the surface and ground waters from pollution and transmission.
- Support awareness raising activities (e.g., by waste collecting and recycling competitions)
- Better base any sort of international relations including trade, tourism, and culture on the multilingual and multicultural environment available in Solotvyno.
- It is a topic of further investigation to find out if it is environmentally and economically feasible to support the redevelopment of the salt mining sector. Strict monitoring should be deployed in case of positive answers.
- Mining can also be seen as a joint cultural heritage of the settlement and the wider region including the hromada of Solotvyno, which can support international tourism.
- The sources of pollution and the spread of it should be localised to avoid contamination to make tourism impossible or at least less attractive.
- **Create the conditions/system for the use of natural resources, for health tourism (medical, rehabilitation, recreational) within limits that do not pose additional risks to life and do not have negative consequences for the environment (primarily the spread of pollution).**
- **Consider legalising the use of brines for balneological purposes.**
- **Improving the procedure, accounting / control, and technology for using brine from karst sinkholes as a type of subsoil (mineral resources) use with a solution to the problem of their environmentally safe drainage and disposal (possibly by re-**

discharging into mine shafts or creating a polder system outside the city downstream of the Tisza River).

- **The hydrodynamic model became the basis for determining the number and spatial location of the network of monitoring hydrological observation points and hydrogeological wells in accordance with the developed plan of the monitoring system and observation regime (see Subchapter 3.9.3., Figure 70).**
- **Apply the developed hydrodynamic model as the basis of a continuously updated hydrodynamic model as an element of the complex monitoring system of the Solotvyno rock salt deposit and surroundings for the purpose of sustainable management& use of natural resources.**
- **It is recommended to establish a Complex Monitoring System, that includes monitoring of ground surface deformations using DInSAR; hydrological and hydrogeological monitoring (water quantity & quality); geophysical survey (microgravity, geoelectric and seismic methods); geodetic survey; on-site inspection of hazardous geological processes development; modelling (up-to-date improvement of hydrodynamic model); risk assessment, preliminary substantiations of protective measurements.**
- **The implementation of a monitoring system with an integrated permanent hydrodynamic model should become a tool for managing the use of natural resources in the Solotvyno settlement – brines and rock salt - as the main factor for its sustainable economic and social development.**

Finally, <u>the first stage</u> of the project has been done with aims of monitoring and investigation of the problem and detecting its causes and spread of the contaminants in the area.

We suggest <u>a second stage</u> of the project that could assess different techniques for management of salt-water in the study area and Tisza River. Then select and design the best technique that can be implemented to protect the area from contamination based on social, economic, and environmental aspects.

List of abbreviations

CBC: Cross-Border Cooperation

CESCI: Central European Service for Cross-Border Initiatives

DInSAR: Differential Interferometric Analysis data

DG ECHO - Directorate General for Civil Protection and Humanitarian Aid Operations

EQS - environmental quality standard in the field of water policy (Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 EU: European Union

EUSDR: Danube Region Strategy of the European Union

EUSDR PA4: Priority Area 4 'To restore and maintain the quality of water' in the Danube Region

EUSDR PA5: Priority Area 5 'Environmental risk' issues in the Danube Region

ICPDR: International Commision for the Protection of the Danube River (seat in Vienna)

IGS NASU: Institute of Geological Sciences of the National Academy of Sciences of Ukraine

ImProDiReT - Improving Disaster Risk Reduction in Transcarpathia

PS: Persistent Scatterers

SAR: Synthetic aperture radar

SBAS: Small Baseline Subset

SMEs: Small and medium-sized enterprises

SWQS: surface water quality standard

TEN-T: Trans-European Transport Network

UAH/hrn: Ukrainian hryvnia

UCPM - European Union Civil Protection Mechanism

UNESCO - United Nations Educational, Scientific and Cultural Organization

Table of Contents

1. Background

1.1. Short history of the Salt Mine (area)

Rock salt in the Solotvyno deposit has been mined since the time of the Roman Empire in cone-shaped pits that have been preserved on the western edge of the deposit [Ivanchenko et al., 1967]. Underground development of the deposit (mines) began in the second half of the 18th century. The first shallow mines in the region began to be built in 1745 (Olexandrivka village, Georgy mine) [Kityk et al., 1983]. The name of the town – Salzgruben (German "salz" – salt), Slatina (Romanian), Faluszlatina-Aknaszlatina (Hungarian), Selo Slatina + Slatinské Doly (Slovak) – contains the root "salt" in various languages. The systematic development of salt excavation in the Solotvyno deposit began in 1778. Most of the mines are in the central part of the deposit. A total of 9 mines were operated within the Solotvyno salt dome structure. Below is a brief description of salt mining.

Mine No. 1 "Khrystyna" was completed in 1778 and is the first underground mine in the deposit [Ivanchenko et al., 1967]. Salt was mined in 1778-1781. Mining operations were stopped due to a large amount of clay material in the rock salt, and the mine was filled in.

Mine No. 2 "Albert" was built in 1781 near the "Khrystyna" mine. It also revealed mostly contaminated salt and was therefore closed. Salt was mined in 1781-1789. Later, the mine was flooded with groundwater and liquidated in 1870.

Mines No. 3-4 "Kunihunda" and "Mykola" were built in 1790 and 1799, respectively. They were connected to each other and salt was mined in one chamber approximately 180 m high. Salt was mined until 1905. The absolute mark of the bottom of the chamber according to A.F. Yelizarova was equal to +160 m [Elizarov, 1955]. In 1903, water began to flow into the mine, in 1908 it was flooded, and later filled in.

Mine No. 5 "Yosyf" was built in 1804 to the east of the mine "Krystina". It was operated until 1850, after which it was closed due to the low quality of rock salt. Salt reserves and the mine became a reserve. In 1895, the mine was flooded.

Mine No. 6 "Old Liudvih" was completed in 1804. Salt was mined until 1810. Due to the low quality of the salt, it was closed.

Mine No. 7 No. "Frantishek" (later named after Khrushchev) was opened in 1809. In 1862, a railway line was connected to the mine, and in 1870, salt lifting was mechanized. The mine was operated until 1955. The first and second horizons were mined and an ascent to the third horizon was equipped. The first horizon was at the absolute mark of +53 m, and the second horizon, which was at the absolute mark of +75.8 m was exploited since 1923. The development of the rock salt deposit was carried out by bell-shaped underground chambers. Later, mining was carried out using quadrangular chambers, the shape of which has been preserved to this day. The height of the chambers reached 110-120 m, which, along with the small size of the support cells, was the reason for the deformation of the shaft of the mine, the appearance of cracks, and later the collapse of the support cells. As a result, mine No. 7 was preserved in 1953, and closed and flooded in 1955.

Mine No. 8 "New Liudvih" (later named after Stalin) was operated from 1886 to 2006. Mine No. 9 was started to be built in 1962. It was effectively operated until 2008. The deposit was developed using a chamber salt extraction system. From the mid-1990s, hydrogeological and engineering-geological problems began at the deposit, which led to a hazardous ecological situation of a man-made nature (Expert Conclusion of the Ministry of Emergency Situations of Ukraine dated 2010.12.09 No. 02-17292/165; Expert Conclusion of the State Service of Ukraine on Emergency Situations No. 3-2013; Decision of the Transcarpathian Regional Commission on Technogenic and Environmental Safety and Emergency Situations dated 2013.04.29). As a result, the work of the state enterprise "Solotvyno Salt Mine" was stopped, the operation of the underground departments of the speleosanatorium of the Ukrainian Allergology Hospital of the Ministry of Health of Ukraine and the regional hospital was stopped, and the unique low-background laboratory for the elementary particles study of the Institute of Nuclear Research of the National Academy of Sciences of Ukraine was lost.

At the Solotvyno deposit, in addition to the operational mines, a large number of drainage mines, shafts, and tunnels with a branched network of underground water drainage facilities with a total length of 18,000 linear metres were passed. Karst sinkholes have formed in the area adjacent to the old mines and in places of more intensive groundwater movement.

Table 1. *Basic operational data for the mines of the Solotvyno rock salt deposit [Shekhunova et al., 2015, https://doi.org/10.30836/igs.2522-9753.2015.146791]*

Name of the mine	Mine exploitation years	Mine liquidation year	Number of operational horizons	Absolute mark of the mine basis, m	Number of chambers	Chamber sizes, m			Width of inter-chamber cells, m	Ceiling height, m
						Length	Width	Height		
"Khrystyna", №1	1778-1781	No geological materials and operational data were preserved								
"Albert", №2	1781-1789	1870	1	+200	1	70	8-12	-		
"Kunihunda", №3	1790-1905	1908	1	+160	1	380-390	16-32	125-130		
"Mykola", №4	1799-1905	1908								
"Yosyf", №5	1804-1850	1895	2	-	-	100-105	30	-		8-20
"Old Liudvih" №6	1804-1810	1930	1	+207	1	35	35	18		
"Frantishek", "Khrushchev" №7	1809-1953 1923-1953	1955	2+1*	+129 +75,8	8 8	45-120 45	35 13	110 40	10-30 20-40	12-32 12
"New Liudvih", "Stalin", №8	1886-2006	2007	4+1*	+162,4 +100 -23 -81	8 20 20 20	50 45-50 40-130 40-100	25 25 20 20	39-40 60 65 65	35-45 30-35 30-35 30-35	40-60 20 20 20
№ 9	1977-2008	2010	2	-81 -146	18	55-315	15-20	68	30-35	

* – designed, but not constructed operational horizons

Conclusions

- **The settlement zone of Solotvyno is directly adjacent to or enters the geodynamically active part of the salt dome diapir structure, the core of which has exits to the surface;**
- **The earth's surface as a result of long-term active mining operations with the use of drilling and blasting technologies at the last stage of deposit development is disturbed by mines and other workings, sinkholes and karst-suffusion sinkholes;**
- **There are more than 140 local karst development sites with a total area of more than 11.22 hectares and a volume of karst sinkholes and mine collapses of more than 5 million cubic metres.**

Recommendations

Ecological-technogenic and socio-economic parameters of Solotvyno settlement revitalization must be evaluated after the anticipatory creation of an informational and effective monitoring system with the possibility of a highly probable spatio-temporal assessment of the long-term (tens of years) transition to an equilibrium geodynamic state of the subsoil in this territory.

1.2. First transnational indications of the problems

From 2007 to 2010, flooding of two operational mines and formation of huge earth surface gaps and other hazardous geological phenomena took place at the State Enterprise “Solotvynskyi Solerudnyk” activity territory. An expert conclusion of the Ministry of Emergencies of Ukraine has defined this ecological disaster as a state level emergency (Minutes No 14 as of December 3, 2010).

The hydrogeological and geotechnical conditions of the mineral salt deposit in Solotvyno, in the Transcarpathian region of Ukraine, are reported to be precarious. Due to the dissolution process and mining works, a number of underground cavities and sinkholes have formed.

According to official data, the degraded territory covers approximately 300 residential houses, a school, a kindergarten, two municipal institutions, power lines, the gas pipeline network, local roads, and a cemetery. A policy of resettlement of 70 residential houses has been initiated, but the inhabitants have not been resettled due to religious or familial reasons; this illustrates the diverse cultural and social currents in the area.

In December 2010, the situation related to these dangerous exogenic geological processes within the territory of Solotvyno salt mines was classified as an emergency by a decision of the Trans-Carpathian Regional State Administration. Later, this decision was approved by the expert report of the Ministry of Emergency Situations of Ukraine (No. 02- 17292 /165 dated from 09.12.2010). This resulted in the announcement of an environmental disaster at state level by the Ministry.

According to the report of the Integrated Tisza River Basin Management Plan, 2011, compiled and published by the International Commision for the Protection of the Danube River (ICPDR), Vienna, Austria: "*The Tisza River Basin is blessed with rich biodiversity, including many species no longer found in Western Europe. The region has outstanding natural ecological assets such as unique freshwater wetland ecosystems of 167 larger oxbow-lakes and more than 300 riparian wetlands.*"

In 2008 a new SWQS (surface water quality standard) standard was proposed for Chloride - 200 mg/l-, as threshold value for the designation of good surface water quality.

Measurements by the Upper Tisza Regional Water Directorate (Nyíregyháza, Hungary) showed maximum chloride concentrations (see the Figures relevant below) above this threshold in 2008 (more than 500mg/l at Tjachiv, 35 river km downstream from Solotvyno).

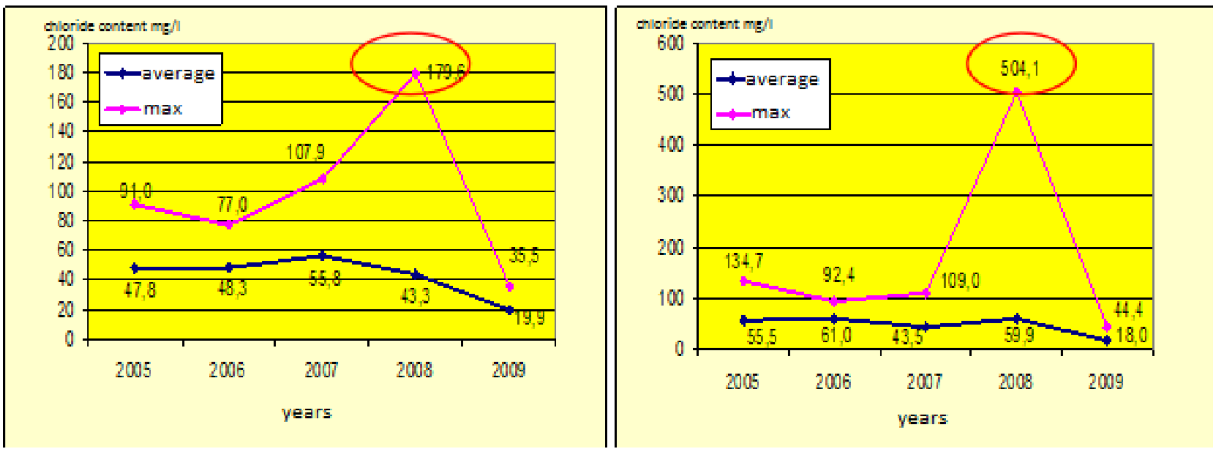

***Figure 1** Values of the maximum and average chloride content measured on the Tisza river (**EQS = 50 mg/l**) - left: at the Ukrainian-Hungarian border (at Tiszabecs/ Вилок, 104 river-kilometers from Solotvyno), right: at Тячів/Técső (35 river-kilometers from Solotvyno) (based on the official letter to the Hungarian Governmental Commissioner authorized for Crossborder Water Issues between Hungary and*

Ukraine on the on-site mission in Solotvyno, inthe subject of salt contamination of the Tisza River, on 15 May 2009)

After closing the period of active mining in Solotvyno the average annual concentrations of chloride have been reduced. A distinction has thus to be made between instantaneous peak concentrations (also taking seasonality into account) and overall long-term chloride concentrations in the river water.

At high water levels of the Tisza River, i.e., during flood events (or due to seasonal changes), pressure gradients in the alluvium of the Solotvyno mine area are affected. This is especially true for the floodplain of the Tisza River, possibly leading to a mobilisation of saline water present in the alluvium (hyporheic flow). Especially after an extended dry period (several years), the mobilisation of (hyper-) saline water might lead to a peak in salt load in the Tisza River prior to a flooding event.

Both scenarios could possibly damage the flora and fauna downstream, however the impact depends on the concentration and time. A long-term contamination would further impact downstream drinking water supply wells, the salinization of agricultural grounds and could have an irreversible impact on flora and fauna.

Some of the processes leading to higher chloride levels in the Tisza River can be seen as a normal inflow of salt due to the dissolution of the salt dome. However, the disturbance by the mining activities has increased the karstification and dissolution of the surface of the dome. The natural weathering is accelerated. It is expected that the base concentration will rise slightly but it is also possible that an equilibrium has been reached, that therefore will be always changing according to the variability of the level of the Tisza River.

The mobilisation of hyper-saline water after a period of relatively dry weather followed by long intense rainfall is a credible and even more likely change according to the weather patterns. It is therefore likely that this event will occur.

The likelihood of major floods of the Tisza River is unpredictable because of climate change (flash floods). This can possibly be an event that will lead to the process of mobilisation of hypersaline water. In that case, the chloride concentration in the river will rise after the flood. The situation around the Solotvyno salt dome is already contributing to an effect on the Tisza River.

The risk of an event resulting in a higher concentration of chloride is likely. The chloride concentration elevation can in such a case contribute to threshold values downstream being exceeded.

1.3. EU response and the first deployments

It was on 12 January 2016, when Hungarian and Ukrainian civil protection authorities addressed a letter to Commissioner for Humanitarian Aid and Crisis Management Christos Stylianides regarding a cross-border environmental pollution concern at the Solotvyno salt mine complex in Ukraine.

For the first time in the history of the Union Civil Protection Mechanism (UCPM) the UCPM was activated by a Member State and non-Member State of the EU. The UCPM deployed a scoping mission between 2 to 9 July to support the national authorities and respond to the joint request of assistance. At the same time Hungarian authorities deployed a small team of experts to strengthen the future activities and support the UCPM Team in drafting the Terms of Reference. The scoping mission produced a technical report shared with Member States and Participating States (PS) of the UCPM and Ukrainian authorities (UA) and a draft *"Terms of Reference"* (ToR) for an advisory mission.

Based on the findings of the scoping mission, it was decided to deploy an advisory mission to conduct a *"comprehensive risk assessment at the Solotvyno salt mines area"*. The deployment took place from 14 September to 7 October 2016.

1.4. UCPM Advisory mission - main findings of the EU Mission's Risk assessment

The following findings were concluded during the mission of the EU Civil Protection Team (UCPM, Advisory mission to Ukraine "Solotvyno salt mine area" Risk Assessment report):

1. Man-made activities in combination with natural processes have resulted in an overall decay of the mine and surrounding area. This is still ongoing without it being actively managed.
2. The overall area is extremely complex in terms of hydrogeological systems and the geological structure, including terrain elevation, karstification and (sub)surface water flows. Therefore, more investigations and assessments are required to get a more credible understanding.
3. The consequences of outdated mining technologies and practices along with uncontrolled

and unmanaged mining processes taking place over several years have resulted in the general situation and state of emergency. However, the possibility of an effective and environmentally sustainable use of salt resources may be viable.

4. Poorly managed development and land use is contributing to the complexity of the issues and overall situation.
5. Through the risk assessment process, key areas of uncertainty and vulnerabilities were identified and the EUCPT was able to provide a number of recommendations to reduce and address the uncertainties and put in place the next steps and potential further actions/programmes.
6. The requirement for a suitable and viable monitoring system was acknowledged and the recommendations are contained under the coordination of the *pillar* "protecting the environment" of the EU Strategy for the Danube Region (EUSDR).
7. Although the EUCPT has not identified a significant level of salt contribution from the assessed area into the Tisza River, since the ending of mining operations in 2010, further investigation and regular monitoring is required.
8. The tipping of domestic and industrial waste is evident within the mine and surrounding areas (a notable increase has been observed since the scoping mission) and is considered a potential risk for health and environment.
9. The EUCPT was unable to make any conclusive observations on the follow up of the immediate recommendations from the scoping mission. However, Ukrainian Stakeholders (at all levels) expressed a positive encouragement and anticipation for the final advisory mission "Risk Assessment" report to act as a platform to move and address the immediate recommendations and potential future actions to address the situation at the Solotvyno mine and surrounding areas.
10. The EUCPT has developed and captured both a digital archive of legacy data and activated both the Emergency and Risk/Recovery modes of Copernicus Satellite mapping capability, including radar data.

The overall conclusion is that the vulnerability of the population in the hazardous area is high. There are significant uncertainties arising from the mining area, in terms of collapses (craters), sinkholes and potential landslides, which could either, have a direct impact on

human life or an impact on buildings, houses and other constructions (infrastructure), as well as consequential effects on society and the economy. An additional finding is that the widespread propagation of domestic and industrial waste is a potential hazard to health and the environment.

The same report contained a number of recommendations, and they were also among the major factors to elaborate and submit a project Revital I. not all of the recommendations are immediately ready to be implemented by the project, but the key ones were very important to take the work and recommendations by the EUCPT forward:

1. Implement a long-term monitoring system including, among others:

- Monitoring to establish a "benchmark" for the monitoring parameters.
- Ground movement and ground levels, including landslides delivered to a common platform;
- Groundwater quality parameters and groundwater levels;
- Consideration of monitoring vulnerable critical infrastructure and housing

2. Undertake proactive, coordinated, short and medium term mitigation planning in conjunction with the monitoring and vulnerability programmes.

3. Work in proactive collaboration with the EUSDR (short to long term) by:

- Establish a regular exchange of data and information;
- Exploration of funding opportunities for the recommended monitoring system

4. Conduct a detailed geological, hydrogeological, lithological and geomechanical model, including, among others: (short term and ongoing)

- Further hazard footprint mapping;
- The further developing of hydrogeological understanding, including seasonality and karst processes
- Further investigation of the linkage between Black Moor and the mining area and establishment of a monitoring network, including water level and quality, such as catchment vs precipitation

5. ***Revise the land use plan as a land use management plan (medium to long term), to include, among others:***
   - A robust application of building codes and the implementation of the construction laws
   - Survey on mitigation by civil engineering programmes
   - Contingency planning for restoring critical infrastructure and business continuity planning

6. ***Community safety (short term action, but ongoing), among others***
   - Improve public awareness campaign on the hazards and risks in the mining area and surroundings
   - Involve local population in further risk assessments, related to the decision-making process

7. ***Develop, implement and maintain a robust Waste Management Plan (medium to long term), including:***
   - Domestic and commercial waste
   - Sewage system
   - Hydrocarbon underground storage (former soviet military base)

8. **Consider an environmentally sustainable *Economic Development Plan (medium to long term), including*;**
   - The exploration of the Solotvyno mine and surrounding area
   - The leisure (lake) area
   - The effective use of salt resources (brine and rocksalt) for health purposes (hospital: speleotherapy)
   - Consider industrial heritage to conserve old mining industrial archaeology

1.5. Results of the relevant projects

Improving Disaster Risk Reduction in Transcarpathia (ImProDiReT)

ImProDiReT was a 2-year project funded (75%) by the DirectorateGeneral for European Civil Protection and Humanitarian Aid Operations (DG ECHO). The project objective was to develop new approaches and methods for the joint development of Disaster Risk Reduction (DRR) strategies involving multiple stakeholders. The project duration was between March 1, 2018 - February 29, 2020. The project mission was to develop a coordinated community-driven Disaster Risk Reduction (DRR) action plan aimed at protecting and building resilience of the Transcarpthian people, their environment, property, and cultural heritage.

Co-funded by the Union Civil Protection Mechanism (UCPM) Prevention and Preparedness Programme, the recently completed ImProDiReT project developed community-based methods to improve risk governance structures and raise awareness among the local population about the disaster risks in Solotvyno village and the wider Transcarpathian region. Through multi-hazard risk assessments, risk evaluation and an inclusive decision-making approach, the project acted as a key enabler for bringing together relevant stakeholders from the local, national, regional and international cross-border level.

A High Level Solotvyno conference organised by ImProDiReT on the 29th of January 2020, was organised that ended with a joint declaration. This joint declaration stated that the solution of the situation is complex and should be solved by installing an agency that can operate within a specific mandate and which will involve all stakeholders at all levels. Social-economic development is seen as the most potential driving force for lifting the emergency situation in Solotvyno.

During the ImProDiReT project lifecycle **it was concluded that there is a deficiency in information exchange and sharing between all the stakeholders involved in (the consequences of) the mining in Solotvyno. This has led, to the opinion of the ImProDiReT project, to a kind of deadlock in improving the situation.** The state of emergency is still present and so far, no answers, senses or solutions on how to lift the state of emergency can be found.

Based on this opinion and endorsed by the governor of Transcarpathia the project members decided to facilitate a high-level conference aiming to find a way to bring the situation in Solotvyno to a "new" normal condition.

It was concluded to:

- **Continue implementing the recommendations of the EUCPT Advisory mission's recommendations from 2016;**
- Continue developing and advancing in leveraging opportunities and possibilities regionally through EU programmes and other sources of funding (f.e. EUSDR)

- Establish and ensure coordination and control mechanism at local, regional and national levels;
- Encourage finding solutions on the emergency situation;
- Communicate to the public the current situation and safety and security risks in the Solotvyno area;
- Ensure liquidation of the negative sequences of the old mining activity leading to a diminished risk for the people and the environment;
- Create and sustain an operational monitoring system for the safety and environmental monitoring of the Solotvyno mine area;
- **Consider allowing limited mining as long as it does not have negative environmental and safety consequences;**
- Allow usage of the salt and salt water for health tourism (medical, rehabilitation and recreational) as long it does not have negative environmental effects;

1.6. Support from EU Strategy for the Danube Region Priority Area 4 & 5

The Danube Region Strategy of the European Union (hereinafter: EUSDR) was launched on December 8, 2010, with the publication of the founding documents (Communication Report, Action Plan) and was confirmed during the Hungarian EU Presidency in the first half of 2011.

The EUSDR has established some basic principles, namely, it has set itself the goal of trying to implement the "principle of equalisation" in the EU's largest watershed in terms of territorial extent, and the most colourful from a political, social, economic and cultural point of view, basically in the economic and social sphere, using EU funds; furthermore, it designated "pairs of countries" to coordinate in relation to the exploration of problems and their solution.

The EUSDR is not only the strategy of the Danube River, but also of the countries located in the Danube Basin, from infrastructures through environmental management and the enhancement of competitiveness to the strengthening of the region's security policy.

According to the relevant documents mentioned above EUSDR has 14 Priority Areas that all manage ecological, economic, social, security, and knowledge-based issues. Highlighting among the 14 Priority Areas, Priority Area 4 (coordinated by Hungary and Slovakia) deals with water quality issues in the whole territory of the Danube Region (14 countries, around 100 million inhabitants) to restore and maintain the quality of water. The other highlighted one is Priority Area 5 dealing with environmental risks (coordinated by Hungary and Romania). Goals of both priority Areas are absolutely relevant for handling and managing the problems of Solotvyno.

Water-related Priority Areas 4 and 5 must specifically deal with watercourses, such as the Danube, Tisza, Sava, and e.g., also with the Prut River (Ukraine, Romania, Moldova). In the case of these rivers, the preparation of jointly created and coordinated strategic (river basin management) plans aimed at assessing and improving the condition of the rivers and the waters in their watersheds, also through the mentioned projects, is emphasised. And since the flood protection management of rivers is prioritised in relation to the protection of life and property, this can only be realised effectively through joint flood protection projects.

The EUSDR basically supports the implementation of the goals of EU policies (in our case, through a series of projects managed by it), so in order to improve the state of the waters of the region (water protection of rivers, lakes, coastal zones, in relation to the Black Sea, groundwater, and wetlands belonging to the region), full-scale wastewater treatment, from cleaning to the introduction of water-saving technologies and the extraction of pollutants to flood protection, drought, and disaster management strategies.

Based on the above, it is no coincidence that already in 2015, a high-level state administration delegation visited the Trans-Carpathian Region led by the Ministerial Commissioner of the Hungarian Ministry of Foreign Affairs and Trade (who was also the national head of the EUSDR), and with the participation of the Hungarian coordinator of PA 4 to learn about the situation in Solotvyno.

Scoping and Advisory Missions took place after the 2015 visit in 2016. The three missions formed the basis for handling the situation in Solotvyno with the support of the international projects - ImProDireT and REVITAL 1.

2.Solotvyno analysis

2.1 Geographical and environmental features

2.1.1. General overview on the location and the main landscape features

The settlement of Solotvyno is in the Transcarpathian region which is the westernmost part of Ukraine and the north-eastern part of the Carpathian–Pannonian Region. Owing to its geographical features, this region has always been an outer periphery, being far from the main centres and economic zones. Especially in Ukraine, Transcarpathia is separated from the capital region of Kyiv by the ranges of the Carpathians, which results in weak linkages with the other parts of the country. In geographical aspect Transcarpathia is relatively small (12 800 km^2) and the majority (80%) of its territory is mountainous with 2 000 metres peaks. Therefore, the region's relief is articulated with ranges (such as the Eastern Beskyds, the Verkhovina, the Gorgany, the Chornohora, the Svydovets, the Polonina Krasna, the Polonina Borzhava or the Polonina Runa), rivers (such as the Rika, the Teresva, the Borzhava, the Latorytsya or the Uzh) and narrow valleys of the rivers and streams. There are only two lowlands or plains in the area; these are the Chop-Mukachevo Plain (part of the Great Hungarian Plain) and the **Marmarosh Basin**, which belongs to the Upper Valley and possesses large amounts of mineral resources. The mountainous area and home to Solotvyno itself, the rapid-flowing rivers and the secluded valleys hamper the accessibility of the territory not just from the core of Ukraine but from the Carpathian Basin too. Although some parts of the region with the lowest altitude – which is the western edge of Transcarpathia – is geographically opened to the Carpathian Basin, the free (or relatively rapid) movement is hindered by strict border regimes. Additionally, the special location of Transcarpathia is much more complex since it is surrounded by the hard external border of the Schengen Area (Hungary and Slovakia) and the EU considering the neighbouring Hungary and Romania. The strictly controlled EU border makes the border crossing time-consuming and complicated; therefore, the accessibility of the Hungarian, Slovakian and Romanian logistics centres and cities is unfavourable. However, the eastern-western axes of the transport network cross the region, due to the passes across the Carpathian ranges. Two road and two rail routes of the TEN-T[6] network touches Transcarpathia – from the direction of Hungary the Mediterranean corridor, from the direction of Slovakia the Rhine-Danube corridor, but both of them pass through the northern part of the region and do not affect the Marmarosh Basin. The gate role of the Chop city is very important, as it combines the international railway lines which come from the direction of Hungary (Záhony) and Slovakia (Čierna nad Tisou). The international road traffic concentrates in Mukachevo city because the main transit routes (M06 and M24) meet in the vicinity of the urban-type settlement and connect Mukachevo with the neighbouring main cities such as with Košice (via Uzhhorod) and with Nyíregyháza (via Berehove). Thereby Transcarpathia, where Solotvyno is located, is a gate between Ukraine and the EU, but the level of the transport infrastructure lags compared to the neighbouring countries' facilities and currently there is no chance to close the gap in this field in the near future.

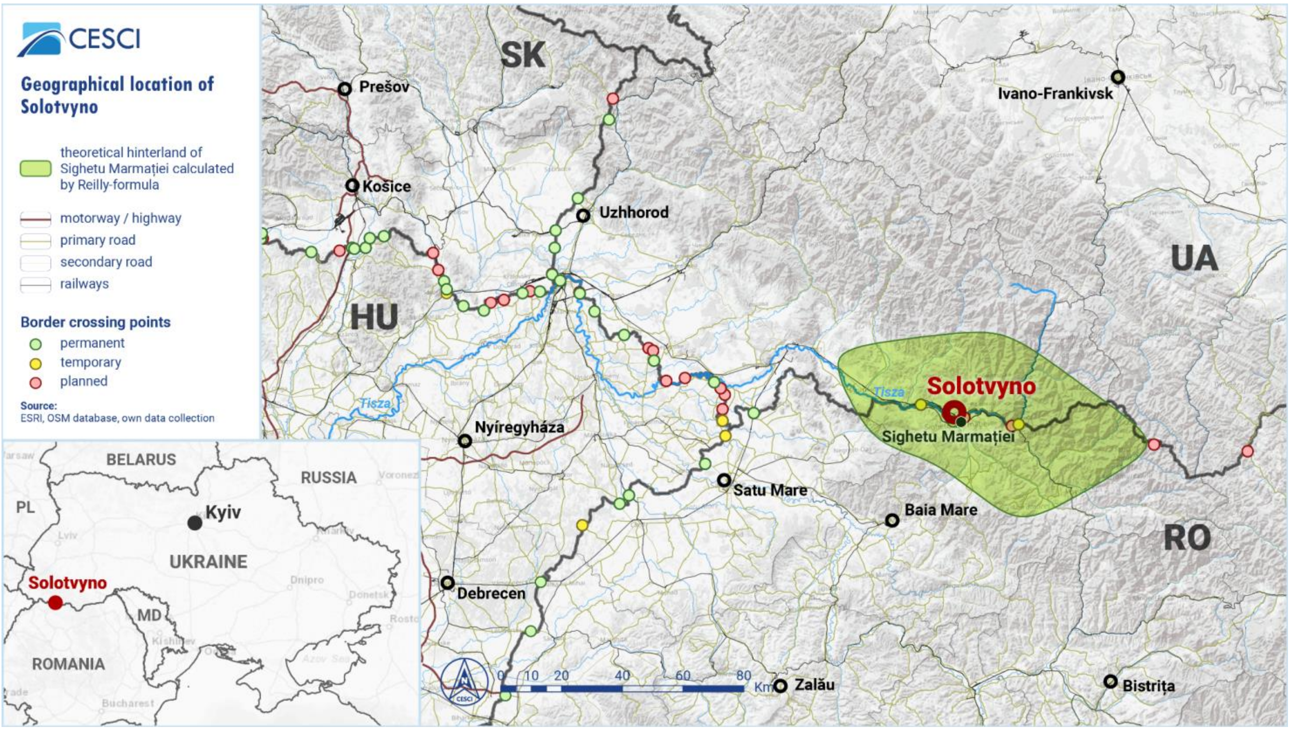

Figure 2. Map

[6] Trans-European Transport Network

Conclusions

- Solotvyno is part of an outer periphery within Ukraine.
- Solotvyno is located next to EU Member States and the Schengen Area.
- Solotvyno's territorial capital is largely described by its closeness to Romania as well as being situated in the Tisza valley.

Recommendations

- Try to be involved in initiatives that support better interconnectedness, connectivity, and multimodality to TEN-T corridors in the light of EU integration.
- Better address the potential lie in the European gateway role of the Tisza valley (also in the light of the hardening shipping options due to Russian threat).
- Consider the closeness to EU markets of Romania, Slovakia and Hungary despite the large distance to Kyiv.
- Try to capitalise from the safe environment as Transcarpathia has been little impacted by Russia's war on Ukraine.

2.1.2. Settlement and transport network, urban functions

Solotvyno, the urban-type settlement (mistechko) and the central administrative settlement of its hromada consisting of few other settlements, is on the periphery of the region in terms of **transport**. However, this situation implies many unexploited opportunities owing to its special geographical location. The settlement is part of the secluded Marmarosh Basin, bordered by the (or Tisza) River, which forms the border between Romania and Ukraine. The **cross-border bridge** above the River provides a linkage with the Romanian town of Sighetu Marmației which was the former centrum of the transboundary basin. Since 2007, when the bridge was built, the new crossing decreased the outer periphery character of the urban-type settlement, and enhanced cross-border labour mobility of Ukrainian citizens and trade with the neighbouring Romanian city. The valley of the means a great corridor in the southern part of Transcarpathia, but this endowment is not utilised owing to the minimal number of border crossing points and the great distance from the international transit routes. In the past there have been more bridges over river but many have collapsed or have been destroyed. The **lack of bridges and the almost entire absence of the border crossing points** are a critical disadvantage of the region, which restricts the economic, social and transport connection in the Marmarosh Basin even today. A new four lane bridge next to Solotvyno in Bila Tserkva is expected to be built by 2024 according to the original plans which would create the second direct connection with Romania (the other is the Nevetlenfolu – Halmeu crossing) along the southern borders of Transcarpathia, Ukraine. The increased travelling needs including freight traffic and bus traffic could be fulfilled by this new bridge between Sighetu Marmației and Bila Tserkva creating significant progress compared to today's one lane wooden bridge designed for pedestrian and car traffic exclusively. Along the river there is a settlement string encompassing settlements such as Khust, Steblivka, Bushtyno, Tiachiv, Teresva, which connects Solotvyno with the central parts of the region. The main road and railway line follow the watercourse as well, but the track of the railway is not complete since Solotvyno is the end of the network and the direct connection to Rakhiv is unsolved. Although the required track exists, for a long period of time it was out of service, as the track crosses the state border and runs to the Romanian side between Teresva and Dilove. It has been a positive change in accessibility for Solotvyno too, that the train service between Sighetu Marmației and Teresva has been re-established.

The narrow valleys and the limited number of border crossing points influences the **settlement network around Solotvyno**. Solotvyno's potential functional connections are open towards three directions, where the eastern-western axis is the dominant since it is the only corridor between the Rakhiv Raion and the centrum of the region. The southern direction is also relevant, because of Sighetu Marmației (the "counterpart" of Solotvyno) which has the biggest population in the basin. This southern direction has the only road connection with Romania in the eastern part of Transcarpathia. Since the local centres such as Tiachiv and Rakhiv are located far (30-40 km) from Solotvyno and the **influencing zone of Sighetu Marmației** is distorted and truncated by the border, Solotvyno was able to become the local centre of its vicinity. Administratively Solotvyno became the **micro regional centre** (main settlement of the Solotvyno hromada) of six settlements with 35-36 thousand inhabitants recently because of the renewed administrative subdivisions of Ukraine. Despite this location, Solotvyno does not belong to any of the raion. Furthermore, the Ukrainian administrative units – border of the Tiachiv and the Rakhiv Raions – cut Solotvyno's hinterland in two. Consequently, Solotvyno is located on the edge of the Tiachiv Raion, administratively separated from its eastern neighbouring settlements.

Concentrating on **local assets and functional specificities of the urban-type settlement**: because the Marmarosh Basin (and especially Solotvyno) is rich in minerals, Solotvyno's socio-economic status has always been different from the neighbouring settlements. From the point of economic structure (almost mono-structural mining industry), high density of functions connected to the multi-ethnic background, the health and later the health tourism facilities. The work at the **salt mines** demanded a great amount of labour force and experts with the necessary knowhow, which triggered a massive population growth and a diverse nationality pattern in the vicinity of Solotvyno.

It has also required a **complex institutional system**, which has considered the different cultural and language features of the inhabitants. Solotvyno as an urban-type settlement continuously ensures access and functioning of churches for different religious orientations as well as educational institutions for different minorities. Therefore, Solotvyno is one of the main centres of the minorities. After the closure of the salt mines and the subterranean allergology hospital, a great recession had started, but some of the workplaces have remained and currently provide livelihood for the local people (Onencan et al, 2018). These workplaces are largely linked to the tourism industry, especially **health tourism facilities**, as the saline water and the remaining overground allergology hospitals still attract visitors and patients. In Solotvyno the basic medical and educational functions – such as medical centre, emergency service, pharmacy, kindergarten, elementary school and high school – are provided for the inhabitants. It is worth mentioning that Solotvyno has three kindergartens based on the different ethnic groups (two of them are maintained by the Solotvyno hromada and one by charity). The school system is widespread, since every ethnicity has their own primary school; there are a secondary school, a boarding school (for disadvantaged pupils) and a vocational training centre, which attract the pupils not just from Solotvyno, but also from the vicinity (hromada) of the urban-type settlement as well. The transport endowments of the urban-type settlement underline the importance and functionality of Solotvyno. The settlement with its bridge is the link between the two sides of the river, and this is the only border crossing point with Romania in the south-eastern part of Transcarpathia. The railway connection of Solotvyno is ensured, but the urban-type settlement is a railhead and there is no rail connection with the eastern neighbouring settlements. Regardless of this isolation from the rail network, the railroad is used for transporting passengers and cargo goods. Moreover, Solotvyno is a linkage (or entering) point for those neighbouring settlements that do not have access to the national railway network.

Solotvyno provides important public functions for local inhabitants, visitors, and surrounding settlements. This fact became clear when in 2010 the company in control of the mines inspected the affected area and concluded that 133 houses were not fit for use and should be evacuated around the mines and sinkholes (European Union Civil Protection Team, 2016). The idea of **relocation of the inhabitants** emerged, however the dwellers did not want to change their location for a settlement (Tereblya) with fewer functions. The Ukrainian government built up 133 homes after 2010 in Tereblya for the people, who live in a high-risk zone in Solotvyno, but the majority of the affected population did not move, because they did not want to give up their multi-lingual institutions and churches provided in Solotvyno, or they did not see their own future in a smaller settlement with fewer services and less developed public infrastructure (Onencan et al., 2018). There were further reasons too, like the local patriotism, the existing work opportunities in Solotvyno or the uncertainty, the problematic ownership, and the quality problem of the new houses in Tereblya. Despite these reasons relocation might be considered inevitable on a longer term since not just the resident zone, but many public functions **are under risk (threat) by the landslides and subsidence**. The list of endangered buildings contains a school, a kindergarten, two institutions owned by the community (hromada) of Solotvyno, but the cemetery, the local roads, the gas and drinking water pipelines, plus wastewater collection pipelines and the electric distribution centre near the Mine 9, too are also in the risk zone according to the risk assessment carried out (Onencan, A. M. et al 2018).

Conclusion

- Apart from mining heritage, the cultural diversity, the hospitals and health-recreational tourism sets Solotvyno on a higher tier of its surrounding settlements.
- Solotvyno can be regarded as a small urban settlement (“city” in a functional sense) by the functional diversity and importance of some of their institutions and services provided.
- The spatial, urban relations of Solotvyno are hampered by the lack of border crossings and the east-west direction of the Tisza valley.

- The relocation of population from endangered areas to various environmental hazards pose various difficulties.

Recommendations

- Take into account the functional urban area (catchment area) around Solotvyno, and redefine its role in service provision for the surrounding rural settlements in the light of the administrative change of 2020.
- Try to better build upon the potential lie in the cross-border influencing zone of Sighetu Marmației especially in the field of labour and student mobility and trade by initiating cross-border more institutionalised cooperation forms and governance structures (e.g., urban platform)
- Focus on urban functions, institutions, and services of regional importance (tourism facilities, hospitals etc.) and attraction to maintain and strengthen urban development.

2.1.3. The housing

It is important to mention the **conditions of the housing** where the local community members live, as the deficiency and unsafety of these houses urge the evacuation of the affected inhabitants. The broadening sinkholes, the landslides, and the subsidence act as a vast threat to the key infrastructure and the residential houses. From time to time, **relocation and building of new residential areas is a common activity** in Solotvyno. The historical centre of Solotvyno around mine number 8, where various institutions and a huge proportion of the local population lived, was the most affected by land movements and resettling. Local citizens step by step moved to other parts of Solotvyno due to threats to their daily living. As early as the 1970s severe problems emerged with the residential areas close to the mines and holes. That was the reason for the appearance of multi-storey residential blocks in the housing stock further away from threatened (endangered) areas.

Most of the housing is obsolete and does not fit to the requirements of the current circumstances. These buildings are mostly one or two-storey-high and the concrete platforms are approximately one metre thick without any reinforcement. The material of the walls was made of earth and cement blocks, but in some cases the structure of the houses contains adobe, bricks, rock, or wood. The isolation of the houses is not solved everywhere, and sometimes the plaster is missed, too. Based on that, the comfort level of the houses is low, but the connection to the running water is ensured. Of course, the residential houses are under the effect of mining, since the subsidence and landslide are common phenomena in the residential zone, too. Due to these unexpected events, most of the time cracks appear on the walls or on the floors of the houses, which are clear evidence that the buildings are in the danger zone. Additionally, because of the absence of retaining walls the total collapse of the buildings is a threat. According to the previous surveys 300 residential houses are in the danger zone and 133 of them were said to be non-suitable for living (Onencan, A. M. et al 2018). To reduce the number of casualties and homeless people, the state created a relocation program which has not been implemented as described previously – the resistance of the local inhabitants to relocate.

Detailed analysis on the potential endangered areas and the expected economic loss can be read in former related projects (see chapter 2.5 on results of The European Union Civil Protection Team's report as of 2016 "Solotvyno salt mine area" and the related risk assessment report". Also, this document contains important evaluations on the topic in the frames of chapter 3 with its risk assessment. Based on information from June 2022 (Interview with Mr Kocserha), currently, only a few buildings are in imminent danger. Cracks are visible on a few residential buildings in two streets mostly (interview with Mr Kocserha, 2022). Still, it is of great importance to reconsider land use and urban planning according to hazardous areas as the situation is still quite uncertain especially regarding the underground and groundwater movements and land movement in deeper layers.

The socioeconomic damages and the negative economic impacts would be much higher in case the subsidence and landslide affect a public institution or a public utility as relatively low numbers of households are in imminent threat. In Solotvyno both are possible. The incidental damage of the gas pipeline, the drinking water or the electric power system would generate enormous losses for the settlement, not to mention the transport system, because the main road and the railway ensure the transport of the local products and resources in the potentially affected zone. Without these connections the local factories and businesses would be out of operation. Moreover, a school, a kindergarten and two municipal institutions are in the danger zone too, where the affected social groups are outstandingly vulnerable.

To summarise, the housing stock due to its location poses risk in some parts of the urban-type settlement to the infrastructure and the population. To address the issue, there should be an agreed plan (with financial envelope) for ensuring and restoring (that cannot be replaced in the short term) some of the critical infrastructures and institutions. It might be important to continue the relocation of the affected residents from the potential danger zone with respect to their cultural and national background. The life-threatening buildings need to be demolished and sufficient retaining walls need to be constructed to prevent the potential casualties and further accidents.

Conclusion

- Housing stock is in bad condition, and buildings are exposed to hazards at certain areas of Solotvyno.
- In some areas relocation and building of new housing and infrastructure could be the only viable option.

Recommendations

- Rethink the land use planning and urban development policy by strict zoning and strict construction permits that push new developments to focus on areas with low hazards.
- Support mobile structures and buildings of high-quality materials that can be more resilient to landslides, cracks, and other movements.
- Adapt a monitoring system and survey from time to time the condition of buildings.
- Relocation and any new developments of larger scale should consider the wider socio-economic relations, the urban fabric and community ties within the settlement, and territorially integrated approach should be supported that stretches beyond the sole demolition and construction of individual buildings.

2.1.4. Environmental protection

Due to the lack of heavy industrialization and the few anthropogenic interventions in the region, the **environmental values of Transcarpathia** have been preserved with its mountainous landscapes and primaeval forests. It is worth mentioning that the most valuable areas are under UNESCO[7] protection (Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe) and furthermore three national parks (Enchanted Land National Park, Synevir National Park, Uzhanskyi National Park) were established in the region to protect and maintain the

[7] United Nations Educational, Scientific and Cultural Organization

environmental and geological values for the next generations. Additionally, beside the nature parks there are many other protected areas, with different levels of protection like biosphere reserves, regional landscape parks, partial reserves, natural monuments, or protected sites. It is important to highlight the Carpathian Biosphere Reserve with its more than 500 km^2 territory, which is not just the largest protected area in the region, but it has possessed the European Diploma of Protected Areas since 1998.

Despite this protected environmental heritage, the rest of the forests and natural habitats are endangered by massive and insufficiently managed logging and polluting. In Transcarpathia the volume of **expenditure on environmental protection**[8] (in thousand UAH[9]) raised 105 955.7 hrn (+59.5%) between 2017 and 2020 from 178 002.9 hrn up to 283 958.6 hrn. In 2020 the highest amount of money was spent by Uzhhorod city (102 649.4 hrn; 36.1% of the total expenditure), Rakhiv Raion (75 121.3 hrn; 26.5%) and Mizhhiria Raion (39 063.4 hrn; 13.8%), but on the other hand the lowest amounts were recorded in Khust Raion (1.2 hrn), Mukachevo Raion (10.3 hrn) and Tiachiv Raion (16.9 hrn). During the examined period between 2017 and 2020 the greatest increases (in number) were detected in Uzhhorod city (+41 785.2 hrn), Rakhiv Raion (+48 072.6 hrn) and Vynohradiv Raion (+11 756.3 hrn), and the most significant decreases were in Perechyn Raion (-5 726.4 hrn), Khust city (-5 548.8 hrn) and Mukacheve city (-2 399.1 hrn). In the Tiachiv Raion – where Solotvyno belongs – moderate reduction happened during the three years with 21.8 hrn, which means 56.3% decrease since 2017 (38.7 hrn).[10]

The data show that the environment protection system in the Tiachiv Raion is underfinanced. Although **Solotvyno** has significant Badenian salt outcrops and salt karstic features – whose morphology transforms rapidly –, these heritages are not protected and not under any restrictions. Moreover, these **salt resources are not just a heritage or a tourist sight, but a vast environmental and hydrogeological hazard** as well, as it is located in the catchment area of the . In case of unexpected events (such as flood, subsidence or landslide) the abandoned mines' saline waters can easily flow into the fresh water of the , and raise its **chloride concentration (Stoeck et**

[8] Expenditures on environmental protection 2017, 2020:
http://www.uz.ukrstat.gov.ua/statinfo/navkol/2018/vitrati_rajony-2017.pdf;
http://www.uz.ukrstat.gov.ua/statinfo/navkol/2021/vitrati_rajony-2020.pdf
[9] Ukrainian hryvnia, or hrn, the official currency of Ukraine
[10] State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region

al. 2020). **The first relevant indication of high salt concentration in the Tisza River was realized and reported by the Hungarian Water Authorities in 2008.** The is a complex and international river with significant ecological importance, that is why it is so crucial to prevent it from the brine of Solotvyno's salt mine. Despite the fact that Solotvyno does not have any protected area in its boundaries, there are many others along the , which are affected by the environmental risk of Solotvyno, such as Natura 2000 site Superioară (Upper) in Romania, Vynohradivska Tysa in Ukraine or Upper in Hungary. Not to speak of the importance of the drinking water: the public water is ensured by bank filtration not just in Solotvyno, but in many parts of Romania and Hungary as well.

Conclusions

- Transcarpathia is rich in nature protection areas that can be a basis for nature-related tourism
- The Tisza valley and the basin is of international importance and relevance as the upper and lower sections of the river form a joint cross-border functional area in which pollution, man-made and natural disasters can spread and form a great common challenge.

Recommendations

- The governance and cross-border tackling of the joint challenges of the Tisza Basin can be tackled; stronger cooperation in the field of water and risk management is needed.
- Better transnational cooperation is needed to cope with the protection of the quality of waters.

2.1.5. Waste and wastewater management

According to the available official data, the **generated waste**[11] between 2017 (173 390 tons) and 2020 (144 983.3 tons) decreased by 16.4% in the Transcarpathian region. In 2020 the largest amount of waste was generated in Uzhhorod city (51 234.6 tons; 35.3% of the region's total value), Mukacheve city (36 098.8 tons; 24.9%) and Vynohradiv Raion (19 035.3 tons; 13.1%), while the

[11] Waste generation 2017, 2020: http://www.uz.ukrstat.gov.ua/statinfo/navkol/2018/utvor_vidhod_rajony-2017.pdf; http://www.uz.ukrstat.gov.ua/statinfo/navkol/2021/utvor_vidhod_rajony-2020.pdf

Velykyi Bereznyi Raion (45.6 tons), Khust Raion (220.1 tons) and Berehove Raion (233 tons) produced the fewest amount of waste. The Tiachiv Raion is on the 7th place with its 3 806.1 tons waste, just ahead of Uzhhorod Raion (2 854.3 tons), but lag behind Rakhiv Raion (5 371.2 tons) and Svaliava Raion (5 840.8 tons). In the majority of the raions, the generated waste was fewer in 2020 than in 2017 and in the case of the exceptions the degree of increases was much lower than the degree of decreases in the other parts of the region. The highest reductions were in Vynohradiv Raion (-14 234.9 tons), Tiachiv Raion (-3 526.3 tons), Uzhhorod city (-2 813.6 tons) and Irshava Raion (-2 218.3 tons), while in Svaliava Raion (+583.7 tons), Khust city (+473.2 tons) and Berehove city (+163.2 tons) the amount of generated waste rose. In proportion the largest reductions were measured in Velykyi Bereznyi Raion (-94%), Mizhhiria Raion (-82.6%) and Irshava Raion (-81%), but on the other hand in Khust city (+152.7%) the increase was more than 100%. In the case of Tiachiv Raion, the rate of decrease was 48.1% (2017: 7 332.4 tons), so it fits to the tendency of the region.[12]

It is unfavourable that just some parts of the generated waste are treated, but the **system of waste management**[13] does not work well either, because the proportion of recycling is low. In 2020 most of the waste (97.9%; 160 974.6 tons) was placed in a landfill and just 1.9% (3 199 tons) was incinerated and 0.2% (267.8 tons) was recycled in Transcarpathia. Depositing of the waste in landfills is the accepted and common way of waste management; the proportion of this method exceeds 85% in every raions and cities with regional significance. This value in Tiachiv Raion was 97.9% (5 894.8 tons) which was most of the local waste. The usage of other methods was insignificant: the incinerated waste was only 125.5 tons (2.1%) without any recycling. Correlating to the year of 2017, the proportion of landfill-usage rose (from 93.9%; 7 407 tons) and the role of incineration was marginalised (from 6.1%; 481 tons); it was the same tendency on regional level too (landfill-usage 96.2%; incineration 3.7%). (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The treatment of the solid waste does not function well either. Evidently the residents dispose of their domestic waste into the sinkholes because the waste transportation system does not meet the needs of the hromada (Móga et al., 2019). The landfill is in the heart of the urban-type settlement

[12] State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region
[13] Waste management 2017, 2020:
http://www.uz.ukrstat.gov.ua/statinfo/navkol/2018/povod_vidhod_rajony-2017.pdf.
http://www.uz.ukrstat.gov.ua/statinfo/navkol/2021/povod_vidhod_rajony-2020.pdf.

because of historical reasons. It is located next to the hole of mine 7, which has a negative effect on the local waters and soils. Large amounts of trash were moved to the landfill even from the neighbouring settlements. Given its large size, it is impossible to just close the area. What was managed to do is the reduction of the incoming waste; now only Solotvyno's garbage is dumped there. Since there is no other place to bring waste, this is the only landfill around. The settlement leaders would like to create a new one and eliminate the overloaded old landfill, but insufficient funds are available. In the past a processing plant was planned but it did not enter the realisation phase (interview with Mr Kocserha, 2022). As for **Solotvyno**, the contamination of the natural endowments is another emerging problematic area. The sinkholes, the salt resource, the brine and the soil are exposed to the threat of pollution. Especially tourism (with the medical centres, the beaches, and the accommodations) and the agriculture, can fall into crises which directly affect the local community. Despite the majority of houses in Solotvyno being connected to a sewer, the **sewage treatment** facility built in the 1970s does not work properly and **the wastewater flows almost directly into the Tisza river**. In the last decades updating the sewer system enjoyed lower priority than improving drinking water supply (European Union Civil Protection Team, 2016). In addition, from other parts of the urban-type settlement the wastewater flows directly into the sinkholes without any filtration, which further enhances the occurrences of landslide and subsidence. Moreover, due to subsidence many sewage water pipelines were possibly broken and remained hidden contaminating groundwater.

After the closure of the salt mines, **the tourism industry – currently the main sector that provides workplaces for the locals** – was able to survive the local economic recession. It is mainly the pollution of saline water and the destructive sight of illegal waste dumping which deteriorates the tourism potential of Solotvyno. It is important thus to limit water and soil pollution by limiting the leaking, the transmission of polluted materials and groundwater, increasing the level of treatment, and by dealing with the central landfill.

Conclusions

- The reform and development of strict waste management is crucial because the untreated sewer water, the landfill-usage and the unregulated disposal of waste are a great risk to health and the environment, since it does not just impair the quality of the salt resource, the drinking water and the fresh water of the Tisza, but it deprives the region of its potential developmental opportunities (tourism etc.).

Recommendations

- There are opportunities in creating, maintaining, and developing waste management systems by building knowledge exchange opportunities as well as technology transfer, know-how exchange with the Hungarian organisations responsible for waterworks and sewage treatment.
- Encourage circular economy approaches, first by improving waste processing that can also provide additional jobs and income.
- Eliminate illegal ad hoc landfills and filled sinkholes along the floodplain of the Tisza in and around Solotvyno. Try to reuse or recycle the removed materials and waste.
- Establish a new modern landfill facility of EU standards further away from the river and the salt mines and protect the surface and ground waters from pollution and transmission.
- Support awareness raising activities (e.g., by waste collecting and recycling competitions).

2.2. Population structure

2.2.1. demographic situation

The **population**[14] of Transcarpathia, where Solotvyno is situated, is higher than one million inhabitants (2020: 1 250 129 persons), thereby Transcarpathia is in the middle of the ranking of Ukrainian regions by population's size. However, the territorial distribution of inhabitants is uneven due to the geographical differences of the region, since the plains and the broader valleys are much more suitable for settlement. It is worth highlighting that the bigger cities and towns of regional significance (Uzhhorod, Mukacheve or Khust) are in the meeting-point of the lowlands and the mountainous areas like a gate which links the mountainous passes and valleys to the plain. As mentioned earlier, the **Tiachiv Raion** (174 580 inhabitants) possesses the highest number of inhabitants in the region, it is ahead of the main cities and their raions as well. Aggregately 14% of the Transcarpathian population lived in the analysed raion in 2020, that is why it is the gravitational

[14] Population 2020: http://www.uz.ukrstat.gov.ua/statinfo/dem/2021/nasel_0101_2021.pdf

centre of the region's southern part (it is more than the aggregated value of Khust city and Khust Raion). It implies that Tiachiv Raion is a decisive actor in the region with its labour and consumption force, which can be a huge asset in the future to build up a competitive economy. Nevertheless, **the dynamics of demography are negative and correspond to the regional trend**, as the population has decreased by 720 inhabitants since 2015. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

Unfavourable demographic tendency[15] is observed in **Tiachiv Raion** too. In 2020 natural decrease (-1.5‰) was lower than the regional average. During the past five years the degree of change – according to natural reproduction – was more significant in Tiachiv Raion (-4.4‰-point) than in the region (-3.6‰-point), whereby the examined raion adapts to the north-eastern raions' reproduction trend. In 2015 these territories were positive (Tiachiv Raion: 2.9‰) except with their natural increase, but up to 2020 their natural reproduction values fell into decline and lost their advantage over the other parts of Transcarpathia. On the other hand, the exact value of natural reproduction in Tiachiv Raion was still more favourable than the regional level in 2020, which suggests that the effect of previous beneficial rate has not vanished completely. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The **population density** reflects the geographic and settlement pattern of the region which implies considerable territorial differences between the urban and the mountainous areas. All in all, the flat raions' average density was more than 100/km^2, while around foothills the raions' average value was around 90/km^2 and in the mountainous raions was under 50/km^2. Compared to the year of 2015 the population density has decreased in almost every analysed territorial unit (in Transcarpathia with -0.7 point), but Uzhhorod city and Uzhhorod Raion were exceptions where the former one increased by 6.4 point and the latter by 1.1 point. These positive data show and confirm the attractiveness and power of the regional centre. The territorial pattern of population density is diverse in the **Tiachiv Raion**, as the geomorphology determines the network of the settlements. Most of the local population is concentrated on three river valleys (especially on the southern part of the raion), thus the percentage of uninhabited areas is considerable. The highest population density accumulated along the valley since the largest settlements (such as Tiachiv, Solotvyno, Teresva or Bushtyno) are in this easter-western natural corridor and are interconnected by the river.

[15] Live births and deaths 2020: http://www.uz.ukrstat.gov.ua/statinfo/dem/2020/prn_01-12_2020.pdf

The other two valleys are the tributaries of the (the Tereblia and the Teresva), which are North-South passages towards Mizhhiria Raion, and combine the rest of the raion's population. It is worth mentioning that Tiachiv Raion does not have any – in regional aspects – significant city thereby the population density and the built-up density lag the urban areas of Uzhhorod (3 068/km^2) or Mukachevo (3 043/km^2). It implies that the functions of urban areas are missed as well and just Tiachiv and Solotvyno can compensate for this drawback. Due to this "forceful role" of Solotvyno, the settlement's socio-economic status markedly determines the demographic trend of the raion. In 2020, the population density of the raion (96/km^2) was slightly below the regional average (98/km^2) – due to the raion's northern mountainous area – which was the same situation in 2015. Although the tendency of change was negative (-0.3 point), the degree of change was moderate.

In the absence of the available data, the exact fertility rate cannot be calculated, therefore just the **live birth rate**[16] can be analysed which shows the number of live births per one thousand inhabitants. This indicator in 2020 was 10.8‰ in Transcarpathia which was little higher than in Slovakia (10.4‰) or Romania (10.3‰), and better than in the EU (9.1‰) or Hungary (9.6‰). In 2015 the live birth rate was significantly higher in Transcarpathia (13.3‰) than in five years later. In the case of **Tiachiv Raion**, the value of live birth rate does not differ significantly from the regional tendency. In 2020 the value of the indicator was 10.6‰, which was slightly below the regional average (10.8%), and it was at a similar level with the neighbouring Khust Raion. In 2015 Tiachiv Raion was also in the middle of the ranking by 13.5‰, but it barely exceeded the regional average and the Khust Raion. It indicates that during the past five years the Tiachiv Raion (-2.9‰-point) was more affected by the decrease of live birth rate than the region or Khust Raion. However, the eastern neighbour of Tiachiv Raion (Rakhiv Raion) had totally different values since it had one of the highest favourable live birth rates in the whole region. This youthful labour force – in the direct vicinity of Solotvyno – means a great opportunity to boost the local economy and it can be the basis of future employment development. If Solotvyno and Tiachiv Raion are not able to cease the continuous decrease of live birth rate, these territories need to attract and retain the local human capital of Rakhiv Raion.

The demographic endowments of a territory are markedly influenced by the level of **migration**[17]. In 2020 Transcarpathia was hit by a negative migration balance (-0.33‰), but on a

[16] Live births 2020: http://www.uz.ukrstat.gov.ua/statinfo/dem/2020/prn_01-12_2020.pdf
[17] Number of arrivals and departures 2020: http://www.uz.ukrstat.gov.ua/statinfo/dem/2020/prn_01-12_2020.pdf

smaller territorial level the situation was more complex. Migration surplus was detected in the most important urban areas – such as in Mukacheve city (4.85‰), Uzhhorod city (3.28‰), Berehove city (0.67‰) – and in the neighbourhood of the capital of the region (Uzhhorod Raion with 3.28‰), but the other two urban areas as well – Chop city (0‰) and Khust city (-0.03‰) – performed above the regional level. It indicates that the major towns in the region have preserved their attractiveness, since these places can provide the most jobs with a higher living standard. The issue of migration was particularly relevant in the case of the mountainous northern raions where the difficult accessibility, the few jobs, the low wages and the poor living conditions cause the main problems (e.g., in Volovets Raion with -4.21). Considering the past five years, the level of migration was consolidated, since in 2015 the migration loss of Transcarpathia was 1.31‰ which means 0.98‰-point improvement. Although in 2020 the **Tiachiv Raion** did not belong to the group of the most disadvantaged (mountainous) raions, the migration deficit was significant here too (-1.2‰). **The population lost by migration was higher than the regional average** which proves the unfavourable living conditions of the raion. It is an interesting territorial pattern that the intensity of (negative) migration decreases towards the western part of the valley. The reason for this phenomenon is the better accessibility and connectivity of the western raions, since the accessibility of the remote Marmarosh Basin is really complicated and time-consuming. Correlating to the year of 2015, the volume of migration has moderated since the migration deficit was -2.2‰ at that time. Despite this high migration loss, the structure of ranking did not change markedly, because the significant migration deficit was a regional trend in 2015. The Tiachiv Raion was below the regional average but more ahead of the most disadvantageous territories. To sum up, Tiachiv Raion fitted to the regional tendency, since the extent of change (+1.02‰-point) was only slightly above the regional level. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

With special regard to **Solotvyno**, two groups of the population are mainly affected by flows of emigration. One group are the **ethnic Hungarians** who were mostly connected to mining that has lost its population retention/attraction force that would keep former employees in Solotvyno. It is important to emphasise the high migration loss because of the high mobility skills of the Hungarian minority. The asset of dual citizenship – provided by the Hungarian government – has facilitated the emigration to Hungary or to the other parts of the EU, that are attractive not just for the Hungarians but for the other ethnicities too. The majority of these out migrations are long-term or final, which cause a significant change in the ethnic feature of Transcarpathia. Owing to this opportunity, the people who wanted to emigrate have already left Transcarpathia and Solotvyno before 2020, therefore the volume of migration loss was higher in 2015 than in 2020. The other group of people who are harder to attain consists of **people in their working age** and a stratum of entrepreneurs. Many have found jobs in Hungary, in the Czech Republic or further away from their hometown. The closure of the salt mines and the disappearance of other previous job opportunities compel the local labour force to move and change residence place. In Solotvyno there are residential buildings where out of the 400 flats approx. 30% of the flats are vacant.

Unfortunately, in the last years Ukraine became a conflict zone which has intensified the migration processes in the country. Transcarpathia is located far from the battlefields, but the effects of Russia's war on Ukraine reach this part of the country too. Those who left the country from Solotvyno cannot or do not intend to return in the short term. Due to the worsening of the conflict the current volume of the migration is indefinable, however the main tendencies are evident. The population replacement is a huge concern for Transcarpathia, as many of the inhabitants – who have the appropriate documents – left the region. Thousands of Ukrainian citizens left the country towards Hungary across Transcarpathia daily even during October and November 2022. On the other hand, a great number of the refugees and migrants came from Eastern-Ukraine to find safer shelter in Transcarpathia. There are 156 000 officially registered refugees as of November 2022 in the oblast. However, according to data from mobile service providers, their number could reach almost 350 000 according to Viktor Mikita, governor of Transcarpathia.[18]

This trend will change dramatically the ethnic balance, impair the cultural diversity of the region and cause a huge challenge to accommodate and cater the newcomers. It includes not just the placement of the refugees, but the employment and educational sectors as well. The public institutions will be overburdened, since the kindergartens and schools need to be able to receive the arriving younger generations, and the hospital needs to be ready to treat not just the wounded and injured people, but the newcomers with common health problems. Considering that the arrangement of all these problems requires many resources, which Transcarpathia does not possess at all.

Moreover, the younger generations and the economically active population are more prone to migrate. These people are motivated to leave behind their families to obtain competitive salaries in

[18] https://www.youtube.com/watch?v=Y3KGRzj71YU (Last download: 24.11.2022).

the European Union. Nowadays it affects the senior groups too, because many of them cannot take care of themselves, therefore they follow their previously migrated children. It is evident that the migration dissolves the local community which causes not just cultural loss, but serious demographic and social problems too. Due to the unfavourable process of migrations the fertility rate, the economic activity and the labour force has been decreasing in Transcarpathia which constantly impair the region's opportunity to tackle and overcome the disadvantaged economic situation.

The massive out migration and the decline of the fertility rate can dramatically modify the age structure of the society. Previous studies show that Transcarpathia's population pyramid is relatively balanced, since the proportion of the younger generations is higher than in the neighbouring countries which ensures an important benefit for the region. Within Transcarpathia Rakhiv Raion and Vynohradiv Raion have the most favourable age structure, while in the urban areas and in the mountainous raions the ratio of youth is not as dominant as in the previously mentioned two southern raions. The percentage of the economically active population is the highest in the neighbourhood of the urban areas – such as in Uzhhorod Raion, Mukachevo Raion or Berehove Raion – where most of the workplaces are situated. The secluded raions with difficult accessibility – Volovets Raion, Velykyi Bereznyi Raion, Mizhhiria Raion – have the greatest number of elderly people, but the percentage of the senior people is also just a minority in the whole society. Even if increasing ageing is not a current problem in the region, it is necessary to deal with the improvement of the elderly care system since the actual condition will not be sufficient for the future demand.

The improvement of elderly care system concerns **Tiachiv Raion** as well, however the current presence of the senior population is not dominant in the raion. It is like the Rakhiv Raion, where the population is young, and the problem of ageing has not arisen yet. However, these raions are affected by the negative impact of migration which concerns mostly the younger generations. If other sectors (for example the tourism) will be hit by a crisis – like the salt mining did in Solotvyno –, the outmigration will intensify, and economic depression will be followed by a demographic crisis.

It is important to draw attention to the distinct ageing tendency of the local minorities. The most evident change has happened in the case of the Hungarians and the Roma people. Since the law facilitation to get Hungarian citizenship the percentage of the senior population has increased in the settlements with a significant Hungarian minority.[19] Furthermore, the situation is further aggravated by the low natural growth of the Hungarian minority, which is not just lower than the regional average, but it turned to natural loss. By contrast, the Roma fertility rate is higher than of the other nationalities, which can be an important asset for the region, nevertheless their unfavourable living standards hamper their integration into the society and labour market.

Conclusions

- Solotvyno and the surrounding microregion face intensifying population loss due to outmigration.
- Aging will become a real problem in the future.
- The Hungarian minority has decreased and is expected to further shrink, while the Romanian minority has a more stable population.
- Economic depression pushed many young people and entrepreneurs to leave.

Recommendations

- Population retention can be stronger by focusing on crisis-proof jobs and better addressment of the needs of younger generations.
- Elderly care and health care should be improved with the ageing population.

2.2.2. Ethnic structure

Not just the favourable geographical location, but the **diverse ethnic structure** of Transcarpathia and Tiachiv Raion is underutilised because these minorities can have a key role in networking since their sociocultural attitudes can contribute to build up a close bond with the western countries. Unfortunately, the current condition of the minorities is unknown because the last census of population was in 2001 which makes it impossible to draw a clear conclusion. In the year of the census there were 7 nationalities whose ratio was over 0.1%. The majority of the nationalities was Ukrainian and Ruthenian (the latter one is not considered to be a separate nationality) who give 80.5% of Transcarpathia's population. The biggest minority of the region was the Hungarian, whose ratio was over 10% (12.1%) with 151 500 persons. Most of them lived in the

[19] On May 26th, 2010, the Hungarian Parliament adopted the amendment of the 1993 LV Act on Hungarian citizenship, introducing the simplified naturalisation procedure.

border area, namely in Berehove Raion (76.1%) and Vynohradiv Raion (26.2%), but their rate was higher than 10% in Mukachevo Raion (12.7%) and Uzhhorod Raion (33.4%) too. Although in the major cities their presence was under 10%, in Berehove city the Hungarian was the biggest ethnic group with 48.1%. Besides the Hungarians the Romanians (2.6%) and Russians (2.5%) should be emphasised since their ratios were above 2%. The Romanian population of Transcarpathia was concentrated on the southern raions (Tiachiv Raion 12.4%, Rakhiv Raion 11.6%), but their ratio in the regional significant towns is negligible. The case of the Roma people was more complex, because their proportion was 1.1% (14 000 persons), but de facto their number could be more than 40 000 persons. According to the census, the majority of the Roma lived in Berehove city (6.4%), Berehove Raion (4.1%) and Uzhhorod Raion (4.1%), whose native language was dominantly Hungarian.[20]

The **ethnic complexity** of Transcarpathia is noticeable in **Tiachiv Raion** since the Marmarosh Basin and the upper valley of has been a meeting and melting spot of different nationalities. The case of Solotvyno is more complex, because the local (mining) potential and opportunities attracted many people regardless of their ethnicity which resulted in a diverse ethnic pattern. Uniquely, Solotvyno has not lost its endowment yet, because the inhabitants of the urban-type settlement consist of three ethnic groups, which have their own education institutions and cultural organisations where they can use their own native language and practise their own religion. This **diversity can play a key role in the future development of the settlement and its community (hromada)**, since the local tourism is able to address not just the Ukrainian tourists, but the Romanians and Hungarians from the neighbouring countries as well.

In 2001, approximately 171 900 people lived in Tiachiv Raion, most of them (83.2%, 143 000 inhabitants) were Ukrainians. The rest of the population was mainly Romanian (12.4%, 21 300 inhabitants), as the raion is adjacent with Romania.[21] The Transcarpathian Romanians live in the neighbourhood of the Romanian border, especially in Solotvyno where most of the inhabitants are **Romanian**. Local Romanians can also have vivid relation with Romania through the border bridge on the, especially with the historical centrum of the wider area, Sighetu Marmației, which concentrates more than 30 000 inhabitants and provides services with regional importance on the Romania's side, but partly also for Romanians living in Ukraine. Since this ethnic group gives the

[20] Population census: http://db.ukrcensus.gov.ua/MULT/Database/Census/databasetree_en.asp
[21] Population census: http://db.ukrcensus.gov.ua/MULT/Database/Census/databasetree_en.asp

largest proportion of the local society, their capacity of their institutional system (schools and churches) is utilised. Owing to the vivid connection with the other side of the border, the demographic condition of the local Romanian population is favourable, and it is not endangered seriously by demographic loss. As Solotvyno is the center of the surrounding settlements on the Ukraine's side inhabited by Romanians as well, the urban-type settlement has experienced population gain from the direction of the neighbouring villages. Solotvyno has experienced Romanian migration surplus given that it is an attractive urban migration target for many Romanian villagers. Especially in the 1980s and 1990s numerous newcomers settled down in the family houses which were sold to them from local citizens of Hungarian background.

The third largest ethnic group in the Tiachiv Raion in 2001 (the latest official data available) was the **Hungarian** with 2.9% (5 000 inhabitants), which concentrated in the main settlements: Tiachiv and Solotvyno. According to the last census, the proportion of the Hungarian minority is the second largest ethnic group in Solotvyno. The district called "Little Slatina" (Kisszlatina in Hungarian) is the original Hungarian settlement area, which was inhabited almost entirely by Hungarians. The Hungarian population was heavily connected to the mining industry; as it grew larger historically, Hungarian people moved to the place. Their demographic condition is not as favourable as for the Romanians, partly since they do not have an active and close bond with the other Hungarian minority groups in Transcarpathia or with Hungary. They form a secluded language enclave which depends on only their own demographic resource. This separation enhances their exposure to outmigration and demographic ageing, and there is a little chance for the renewal of the community.

Since the diverse local public institutional system – which includes the kindergartens, the schools, the public educational organisations, and health care services – follows and reflects the ethnic structure of the settlement, the inhabitants insist on their hometown and to their local community. These strong bonds triggered a massive resistance against the relocation program in the past, which offered a resolution to the problem of the evacuation of the endangered dwellers. However, the idea of relocation would alter the ethnic pattern and the institutional system, since the appointed settlement – which is dominantly populated by Ukrainians – cannot provide such diverse institutional network as Solotvyno, which means: the relocation will destroy the historically evolved heterogeneous local communities with their characteristic and valuable heritages. The local people are aware of it, that is why there is a low intention to move. If the process of relocation is inevitable, the population should be relocated to the nearest settlement that suits their ethnicity. This procedure makes it possible that the affected population be harmed as little as possible.

Conclusions

- There is still a very complex multi-ethnic background of the local population. Solotvyno and its surroundings is the heartland of the Romanians living in Transcarpathia. There are a relatively large number of public functions ensured and institutions operating in the hromada thanks to the three diverse and large national groups.
- The ethnic heterogeneity supports mutual understanding, peaceful intercultural and cross-border cooperation, furthermore the language knowledge supports easier business, labour and tourism connections, interactions with the Romanian side of the border, but with Hungarian communities and inland fellow Ukrainian population too.
- Badly planned relocation policy could cause uncontrolled negative impacts on the minority groups that would affect the whole society of Solotvyno.

Recommendations

- Consider potential relocation approaches and urban service developments, local educational, religious etc. policies that ethnic heterogeneity is an added value that makes Solotvyno an outstanding centre of its vicinity.
- Better base any sort of international relations including trade, tourism, and culture on the multilingual and multicultural environment available in Solotvyno.
- Make Hungary and Romania, the national and local stakeholders in urban and regional planning, minority policy interested in investing in the joint heritage of the three countries (e.g., by supporting cross-border thematic cultural routes, reconstruction of historical monuments).

2.3. Economic structure

2.3.1. Enterprises

Since the population retention of an area depends significantly on its economic condition, the analysis of the local enterprises is essential. In Transcarpathia the **number of enterprises**[22] accounted for 6 655 units in 2020 which was higher by 544 units than in 2015 (6 111 units). According to the data, the growing number of companies was owing to the five regional significant towns given that during the past years these urban areas have thrived by 592 units, while at the same time 48 companies were ceased in the raions. In 2015 most of the enterprises was in the raions (52.2%, 3 187 units), but in 2020 the majority shifted to the towns as 52.8% of the businesses (3 516 units) operated in the five main towns.

On the level of raions, Uzhhorod city and Mukacheve city are the economic engines of the region. In 2020 31.4% of the companies were operating in Uzhgorod city (2 089 units) and 13% were functioning in Mukachevo city (868 units). Compared to the year 2015, these cities could improve the quantity of the companies to a great degree (Uzhhorod by 315 units, Mukacheve by 181 units), which means that the territorial concentration of the companies has intensified. Relevant improvement happened in Berehove city (251 units) and in Khust city (252 units) too, because the former one increased by 47 units and the latter one by 48 units which conforms to the economic development of the urban areas. In the case of the raions, Uzhhorod Raion had the largest number of businesses by 603 units, which accounted for 9% of the total amount of the enterprises. This favourable quantity was due to Uzhhorod city and its economic importance. Surprisingly, Mukacheve city could not support the catching up of its raion, since up to 2020 Mukachevo Raion lost 47 companies and it was preceded by Tiachiv Raion. With respect to the ranking, Uzhhorod Raion was followed by the raions with the largest population such as Vynohradiv Raion (454 units) and Tiachiv Raion (359 units) whose ratios were above 5%. These raions lagged behind the economic centres of the region, but they stood out from the rest of the raions. Logically, the mountainous raions had the lowest economic potential since they are on the geographical periphery. Good examples for this Volovets Raion (64 units), Velykyi Bereznyi Raion (66 units) and Perechyn

[22] Performance indicators 2015, 2020:
http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2016/osn_pok_rajon_2015.pdf
http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/osn_pok_rajon_2020.pdf

Raion (85 units) where the number of enterprises did not reach 100 units and in the case of the two former raions, their economic significance was under 1%. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

Overall, the economic potential of **Tiachiv Raion** – after the great economic downturn of **Solotvyno** – is still remarkable since its large population provides a massive labour force for the region. Between 2015 and 2020 the number of companies increased by 17, which helped to close the gap between the raion and the economic core of Transcarpathia located around Uzhhorod and Mukachevo. Regarding the volume of the population, it shows that the number of inhabitants per company has decreased by 26 persons, so in 2020 486 residents belonged to a company. Since Solotvyno is one of the biggest settlements in Tiachiv Raion, thereby its economic competitiveness within the raion is unquestionable. Still, the **lack of real large companies in Solotvyno** and surroundings describes the current structure of operating enterprises. That is also a reason why a **new industrial park has been established** with a territory of 33 hectares. It could be an important asset for the whole microregion in terms of business development since there are not many such parks in the whole oblast/region. Plans have been established to develop the furniture and wood industry within its premises. These plants would decrease population loss and work abroad (e.g. in Sighetu Marmației (Romania), Hungary and Czech Republic). The industrial park could give space to processing facilities related to salt mining as well. Furthermore, it is an interesting fact that Romanians of Solotvyno are more known for having entrepreneurship skills and motivation to have an SME. This is owing to historical reasons too as they used to be involved in business are trade activities. For instance, from the money earned by seasonal work during the communist regime even back then, they tried to start a business, they entered the collective farm. Part of their payment was wheat, corn, sunflowers, etc. which they processed and sold to northern regions, but local Romanians and Ukrainians also processed Karelian wood to sell.

Considering the main sectors and activities, the regional and economic significance of an enterprise depends remarkably on the **size of the company**[23]. In 2020, Transcarpathia had only 3 large companies which make up 0.04% of the region's enterprises. Two of them belonged to the industrial sector, while one of them operated in the sector of transport and warehousing. The percentage of enterprises with medium size was 4.4% including 292 units. Most of these enterprises

[23] Performance indicators 2020: http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/kil_pidpr_econom_2020.pdf

(40.4%) was connected to the industrial sector (118 units), but other sectors represented themselves too, such as healthcare (12% with 70 units), agriculture and forestry (7.5% with 22 units) or transport and warehousing (7.2% with 21 units). More than 90% of the regions' businesses was small companies, since their number exceeded 6 000 units (95.6% with 6 360 units). In the case of small companies, the wholesale and retail trade sector included the highest number of enterprises (1 466 units, 23.1%), but the industry sector had 1 017 units (16%), the agriculture and forestry sector included 994 units (15.6%), the real estate sector incorporated 645 units (10,1%) and the construction concentrated 535 units (8.4%). The other sectors are negligible. It is important to highlight that the vast majority (88.8%) of the small enterprises was micro companies with 5 647 units. Compared to the year of 2015, the number of companies increased in almost every size category, except the big companies, where no changes were registered. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

From **sectoral perspective**[24] the largest sector was the wholesale and retail trade with 1 501 enterprises, which gave 22.6% of the region's companies. The industrial sector (1 137 units, 17.1%) and the agriculture and forestry (1 016 units, 15.3%) were quite on the same level, but during the past years the industry had preceded the agriculture, since the former one gained 223 new companies and the second one shrank by 100 units. The real estate sector (649 units, 9.8%) and the construction sector (543 units, 8.2%) contained over 500 companies, while the transport and the warehousing (390 units, 5.9%) and the scientific activities (355 units, 5.3%) did not fall under 300 units. There were more than 100 companies in the field of administrative services (291 units, 4.4%), information and telecommunications (232 units, 3.5%), accommodation and catering (207 units, 3.1%) and healthcare (171 units, 2.6%). The other services such as the arts, sports, entertainment, the education or the financial activities were under 50 units (less than 0.7%). Since 2015, the greatest improvement has happened in the field of industry (+223 new enterprises), construction (+87 units), healthcare (+87 units) and wholesale and retail trade (80 units), meanwhile the agriculture and forestry (-100 units), the accommodation and catering (-29 units) and the scientific activities (-19 units) have decreased the most. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

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[24] Number of enterprises by type of economic activity, 2020: http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/kil_pidpr_econom_2020.pdf

All things considered, the industry is the most decisive sector with its large size companies and increasing number of enterprises. However, the number of "big" companies is still low, which results in disproportion between the enterprises. **Solotvyno** – which possessed one of the biggest salt mines in Transcarpathia – still has a significant (but dramatically degraded) role in the industrial sector which has been complemented with the opportunities of the tourism sector. Moreover, the location of Solotvyno – surrounded by forests – makes it possible to enhance the advancement of the forestry and construction sectors.

Like the company size, the **number of employees of the enterprises**[25] is also a significant indicator of economic performance. In Transcarpathia 88 779 employees were registered in 2020, whose majority belonged to the raions (50.5% with 44 823 empoyees), but the proportion of the five important towns was also remarkable (49.5% with 43 956 empoyees). The main employers of the region were the two big towns (Uzhhorod city with 21 034 employees and Mukacheve city with 16 165 employees) which together possessed the 41.9% of the regions' employees (37 199 persons). According to raions, Uzhhorod Raion (10 057 employees, 11.3%) and the two most populous raions – Vynohradiv Raion (6 313 employees, 7.1%) and Tiachiv Raion (4 779 employees, 5.4%) – were on the top of the list just ahead of Svaliava (4 661 employees, 5.3%) and Mukachevo Raions (3 853 employees, 4.3%). In the light of the data, the region's employment axis covers the meeting strip of the lowlands and the foothills. Consequently, the most unfavourable numbers (less than 2 000 employees) were detected in the case of the north-eastern raions – such as in Volovets Raion (823 persons, 0.9%), Mizhhiria Raion (1 137 persons, 1.3%) and Velykyi Bereznyi Raion (1 200 persons, 1.4%) – whose infrastructure and accessibility are backward and the number of economic active population is relatively low. Compare to the year of 2015, the degree of change in proportion was the highest in the Khust Raion (+117.9%, +1 704 empoyees), Volovets Raion (+66.9%, +330 employees) and Tiachiv Raion (+63%, +1 847 employees), which justify the economic development of the Marmarosh Basin. By contrast, greatest recession happened in the lowlands such as in Berehove Raion (-24.4%, -407 employees), Mukachevo Raion (-14.5%, -652 employees), Berehove city (-11.6%, -485 employees) and Vynohradiv Raion (-11.3%, -805 employees). (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

[25] Number of employees in business entities, 2020: http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/kil_zpr_subj_rajon_2020.pdf

As for **Solotvyno**, it is the **SME sector** which managed to employ more people compared to the previous years due to the collapse of large industries, namely the salt mining sector. It is important to note that even during the Soviet times the number of employees were limited apart from the salt mine, which forced local men especially to be employed outside of the raion and often far from Transcarpathia (interview with Mr Kocserha, 2022).

The value of the total **labour costs**[26] shows the aggregated amount of labour costs which was paid by the enterprises. This number in Transcarpathia – in the year of 2020 – was 9 783 922 thousand UAH. Its proportion corresponded to the previous ranking since it has a correlation with the number of employees. Uzhhorod city (2 190 281 t. UAH) and Mukachevo city (1 847 391 t. UAH) were ahead of the raions such as Uzhhorod Raion (1 5995 959 t. UAH), Vynohradiv Raion (820 038 t. UAH) and Tiachiv Raion (569 937 t. UAH). Additionally, the ranking was closed by Chop city (78 513 t. UAH), Volovets Raion (81 010 t. UAH) and Mizhhiria Raion (92 980 t. UAH) where the number of the total labour costs did not exceed 100 000 t. UAH. On the other hands, the **volume of sold products**[27] shows a different pattern from the labour costs and the number of the employees. In 2020, the whole amount of sold products was 64 377 347 thousand UAH of which more than the half was concentrated to Uzhhorod city (17 227 811 t. UAH, 26.8%), Mukacheve city (13 523 221 t. UAH, 21%) and Uzhhorod Raion (11 214 225 t. UAH, 17.4%), while the other territorial units' proportion was under 5% except for Tiachiv Raion (4 022 643 t. UAH, 6.2%) and Mukachevo Raion (3 533 7002 t. UAH, 5.5%) which were slightly above it. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The financial balance determines **the profitability of the enterprises**[28]. In Transcarpathia 74.2% of the companies were profitable in 2020, which was a backsliding compared to the year of 2015 (79.2%). The percentage of the profitable enterprises was especially high – more than 80% – in the lowlands (Vynohradiv Raion 86.1%, Berehove Raion 85.3%) and in the Tiachiv Raion (83.3%). The majority of the territorial units (12 of them) belonged to the category of 70-80%, while Uzhhorod city (67.6%), Perechyn Raion (65.8%) and Chop city (57.4%) were under 70%. Unfortunately, since 2015 the percentage of the profitable companies declined in every territorial

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[26] Performance indicators 2020: http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/osn_pok_rajon_2020.pdf
[27] Performance indicators 2020: http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/osn_pok_rajon_2020.pdf
[28] Financial results of enterprises 2015, 2020:
http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2016/fin_res_rajon_2015.pdf;
http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/fin_res_rajon_2020.pdf

unit. The regional average was -5%-point which was exceeded by only six units. The lowest decrease took place in Berehove city (-0.2%-point), Uzhhorod city (-1.3%-point) and in their raions (Uzhhorod Raion -2.3%-point, Berehove Raion -3.5%-point), but the value of Tiachiv Raion (-4.1%-point) and Mukacheve city (-4.2%-point) was above the regional level too. The most vulnerable companies – where the decrease was more than 10%-point – were in the mountainous area since Volovets Raion decreased by 17.8%-point, Svaliava Raion by 13.8%-point, Velykyi Bereznyi Raion by 13.1%-point and Perechyn Raion by 10.5%-point. According to the financial balance or financial results of the territorial units, 5 units shifted into the positive category, 6 units shifted into the negative category, while the rest of the units did not change their category: 4 units stayed in the positive and 3 units got stuck into negative category. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

In the case of **Tiachiv Raion**, the number of employees – thanks to the remarkable number of local population groups – has increased since 2015, and the raion took place in the leading group. Based on the volume of the sold products, Tiachiv Raion, although lagged significantly from the region's economic core, it was still outstanding compared to the rest of the raions. According to the profitability, the raion had the third most favourable value even if it was a decreased outcome compared to 2015. Finally, the financial balance of the Tiachiv Raion improved, since its financial result became positive in the year of 2020. As Solotvyno is one of the most important and biggest settlements of the Tiachiv Raion, it has a considerable role within the raion, and it heavily determines the raion's economy.

Conclusions

- Lack of large enterprises after the collapse of the salt mining company is persistent.
- Solotvyno needs new economic areas in the form of an industrial park to stimulate economic growth.

Recommendations

- Develop the new industrial park to attract larger companies, processing industries of higher added value.

- Within the framework of EU standards support the furniture industry, salt processing and other viable companies that could decrease working abroad and increase the density of enterprises.
- Consider the entrepreneurial skills and connections of ethnic Romanians who have better growth prospects and who are more likely to create and run business.

2.3.2. Employment

The **number of employees by type of economic activity**[29] of enterprises is accessible only in regional level too. More than 40% of the employed persons in Transcarpathia worked in the industry sector (42.4%, 37 626 workers) in 2020 which outstood from the other sectors. This implies a one sector-oriented (mono-structural) economy, what raises the vulnerability of the employment. The second and third most important sectors were healthcare (23.9%, 21 184 workers) and wholesale and retail trade (10.8%, 9 574 workers) given that their proportions exceeded 10%. Transport and warehousing (5.8%, 5 137 workers) and agriculture and forestry (5.5%, 4 883 workers) represented significant roles in the employment of the region too by more than 5% proportion. The rest of the sectors did not employ more than 1 000 workers in the region. Consequently, the condition of the scientific sector and the education is unfavourable and undeveloped, since the low workforce cannot generate huge improvement and progress in the field of research and innovation which would be able to boost the economy. During the past years since 2015, the number of employees increased by 16.6% (+12 637 workers). While the healthcare and social assistance improved by 647.2% (+18 349 workers), the industry sector declined by 10.6% (-4 453 workers). The outstanding development of the healthcare sector suggests that the healthcare was able to absorb those unemployed persons who had worked previously in the industrial sector. Beside the healthcare sector, the construction (+27.4%, +613 workers), the transport and warehousing (+5.7%, +276 workers) and the information and telecommunication sector (+5.6%, +44 workers) could succeed, while the financial and insurance activities (-36.4%, -106 workers), the real estate sector (-22.4%, -494 workers), the temporary accommodation and catering (-20.8%,

[29] Number of employees in enterprises by type of economic activity 2015, 2020: http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2016/kil_npr_pidpr_econom_2015.pdf; http://www.uz.ukrstat.gov.ua/statinfo/pidpr/2021/kil_npr_pidpr_econom_2020.pdf

-312 workers) and the scientific and technical activities (-20.4%, -230 workers) decreased the most. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The **number of full-time employees**[30] complements the previously described data belong to the enterprises. In 2020, 148 580 full-time employees worked in Transcarpathia whose majority was registered in the city of Uzhhorod (25%, 36 612 persons) and Mukacheve (15%, 22 492 persons). There were only three other territorial units where the number of the full-time workers reached roughly the number of 10 000. These areas were the Uzhhorod Raion (7%, 10 762 persons), the Vynohradiv Raion (7%, 10 077 persons) and the Tiachiv Raion (7%, 9 709 persons), while the most lagged behind areas were Chop city (1%, 1 718 persons), Berehove Raion (2%, 2 972 persons) and the north-eastern mountainous raions (Volovets Raion: 1%, 2 060 persons; Velykyi Bereznyi Raion: 2%, 2 504 persons; Perechyn Raion: 2%, 3 237 persons). Since 2015, the volume of change in the numbers of full-time employees meant mainly reduction, as the region lost 16 464 workers (-10%). There were only five territorial units where growth was detected, such as in Uzhhorod Raion (+22.8%, +1 997 persons) and Khust Raion (+6.3%, +336 persons). By contrast, there were four areas – Khust city (-32.6%, -2 181 persons), Berehove city (-29.4%, -2 240 persons), Perechyn Raion (-22.6%, -947 persons), Vynohradiv Raion (-22%, -2 847 persons) – where the value of reduction was more than 20%. In the Tiachiv Raion decrease (-11.2%, -1 227 persons) took place, but the volume of it was more moderate. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The territorial disparities are noticeable in the case of **average monthly salary**[31] of full-time employees too. In Transcarpathia the average monthly salary was 10 188 UAH in 2020, which was exceeded only by four territorial units. The highest payments in the regions were mainly in Uzhgorod city (11 187 UAH) and in its direct neighbourhood – such as Uzhhorod Raion (13 534 UAH) and Perechyn Raion (10 368 UAH) – which were the leading or pulling territories of the region. It is worth mentioning that Vynohradiv Raion (10 358 UAH) the average salary was greater than of Transcarpathian level, and it was the highest in the southern part of the region. The lowest wages were in the mountainous raions, especially in Svaliava Raion (8 244 UAH), Velykyi Bereznyi Raion (8 270 UAH), Khust city (8 301 UAH) and Khust Raion (8 647 UAH). In the

[30] Number of full-time employees 2020: http://www.uz.ukrstat.gov.ua/statinfo/dohodi/2020/pracivniki_rajon_2020.pdf
[31] Average monthly salary of full-time employees 2020: http://www.uz.ukrstat.gov.ua/statinfo/dohodi/2020/zarplata_rajon_2020.pdf

Tiachiv Raion the monthly wage was 9 306 UAH, which was below the regional level but it was favourable than in the mountainous raions. Due to the inflation, the value of the salaries has increased since 2015. The percentage of the increase was the highest in Uzhgorod Raion (94.4%), Irshava Raion (84.8%), Khust Raion (72.1%) and Tiachiv Raion (71.8%), where the volume of change was more than 10%-point compared to the regional level (60.2%). The less affected areas by inflation (salary increment) were the Velykyi Bereznyi Raion (45.2%) and the urban areas, such as Berehove city (49.2%), Chop city (50.9%) or Khust city (51.4%).(State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The situation of **unemployment**[32] in Ukraine has always been worse than in the western neighbouring countries, but Russia's war against Ukraine further enhanced the unfavourable condition of the labour force. In absence of unemployment data, there is no possibility to analyse data under regional level. In 2020, the percentage of unemployment – by taking account of the population in working age – was 11% in Transcarpathia, which was over the national level (9.9%) by 1.1%-point. By contrast, in the year of 2014 the difference between the two data was negligible (0.1%-point) and what is more, Transcarpathia (9.6%) had a lower unemployment rate than the national average (9.7%). Taking into consideration the employment situation of **Solotvyno**, the **unemployment level is relatively low**. Unemployment is rather frictional and structural, and less connected to educational attainment or any other reasons. Unemployment is a limited challenge considering that many work abroad and are refugees abroad or have found work opportunities locally given enough workplaces in the Solotvyno area. (State Statistics Service of Ukraine)

As the previous data show, the position of the Solotvyno and the Tiachiv Raion is complex. It stands out from the underdeveloped eastern raions, but it cannot catch up with the economic core of the region. The rate of unemployment significantly rose when one of the main employers of the raion (the mines of Solotvyno) was shut down in 2010. Between 2008 and 2010 – when the two remaining mines were closed too – 600 people lost their job, since not just the factory and the salt mine did not operate anymore (Onencan et al., 2018). The two underground allergology hospitals also discontinued the operation by 2010 (Móga et al., 2019). The only good news with the mining closures was that the mines did not close at once, but it was rather a long process of 20 years downturn. Due to the elimination of the companies – which were related to salt mining – a

[32] Unemployment rate 2020: http://ukrstat.gov.ua/

depression started, because in Solotvyno the primary source of income was based on salt. Unfortunately, the closure of mines was not the end of the local economic crisis since the effect of the mines' subsidence and the potential environmental hazard frightened away new investors. Therefore, not just the lack of new economic actors causes a tough issue, but the existing local companies must struggle too with the bad publicity of the settlement's geological risk which can provoke further business closures. A potential of Tiachiv Raion is its labour force, because the raion is a leading force within the region according to the number of full-time employees. Nevertheless, this number has been decreasing (more vigorously than in the region), and in 2020 it shrunk under 10 000 workers. Additionally, the level of salary is another drawback of the raion, considering that it does not reach the regional level and the inflation is not under control.

The labour market of Solotvyno heavily depends on the fate of tourism related to salt. The **restructuring and shift in employment from industry to the tertiary sector** has been almost finalised. The available salt resource is a great opportunity for medical tourism to employ and give income to more inhabitants, but developments should be based on sustainability principles and should go hand in hand with the deployment of a permanent monitoring system. Considering the data, up to 2020 the number of employees in the healthcare sector has significantly risen in Transcarpathia (instead of the workforce of the industry sector), which has a close bond with the economic growth of the medical tourism sector in Solotvyno.

Conclusions

- It is less the level of unemployment but the structure of employment that causes problems and an unfavourable structure.
- Restructuring has been happening in employment with decreasing share of industry parallel with increasing role of health and social services, construction, and trade, among others.
- The labour market is very mono-structural with focus on tourism as the new main source of income after the collapse of the mining industry.
- The salaries and the income levels are rather low.

Recommendations

- The vulnerability of the employment sector can be tackled by supporting other activities than industry, which is still the main employer.

- Instead of many new workplaces the direction could be the development of activities of higher added value and potential income such as health care and health tourism, processing industry etc.

2.3.3. Salt mining industry

As partly addressed before, salt **mining was one of the key assets** of Transcarpathia which could induce the development of the Marmarosh Basin. The flourishing of Solotvyno was based on this natural heritage which made it possible to open nine mines around the settlement. The first six ones were operated in a shallow depth until the 1930s, while the other three reached deeper and functioned with higher risk. The seventh mine was closed in the Soviet era, but the Number 8. and 9. were active until 2008 and 2010 (Stoeckl et al., 2020). The reasons for the abandonment of the mines are several: the non-sufficient operation and the lack of maintenance induced collapse of support pillars and causing floods. The operating mines required a huge number of (mostly manual and some educated, technical) labour force with sufficient knowledge, but the arrival of the new dwellers set other demands too: better and enough housing stock, new institutions (educational, medical, administrative) regarding the different nationalities and broader functions and services. Owing to the huge potential of the mines overshadowing the rest of the potential sectors, the diversification of the local economy did not happen, which further enhanced the economic vulnerability of the local society. The economic crisis broke out in 2010 with the closure of the 8. mine. During the peak period of the late Soviet era, a total number of 1500-2000 employees worked for the mining company. In June 2022 only 50-60 people remained active in salt mining (interview with Mr Kocserha, 2022). Many facilities within the territory of the mining company have collapsed and almost completely disappeared (e.g., carpentry workshop, sawmill, a mining tower). Out of the remaining constructions, the former directorate building is the only one worth mentioning.

Solotvyno was not just hit by economic depression, but by **environmental disaster** as well. After the collapse of the industrial sector, tourism, and the forestry (with the construction) were the main sectors which could provide jobs for the local inhabitants. Even if the salt mines were closed, the remaining salt resource can attract many visitors and patients to Solotvyno. It is also important to preserve the mining heritage of the urban-type settlement because the equipment and the infrastructure still exist, and they belong to the cultural heritage of the region. Furthermore, as a border point, Solotvyno should utilize its favourable geographic location and minority groups to attract not just inland tourists but foreign tourists too.

Considering recent changes in a wider context and local circumstances, there is **a potential to restart mining** at a larger scale (interview with Mr Kocserha. 2022). With the war-related problems in the largest salt mine of Ukraine, at Soledar Salt Mine of Donetsk Oblast, which offered salt for many Eastern European regions, the role of the resources in Solotvyno have gained higher importance. Salt became a demanded product in the rest of Ukraine. The reopening of mines would create impetus for the development of the new industrial park as well, where a processing plant could be set up. Still, past, and present recommendations should be considered in case the mining activity is planned to be increased.

Conclusions

- Salt mining has a long tradition in Solotvyno given that the development of modern-day Solotvyno was based on mining in the first place. This also means that the situation of salt mining shapes the present and future of the local economy, and it is not secondary to what will happen to the sector.
- Mining as an industry has collapsed, but there is a chance to restart mining in Solotvyno further away from the older mines that would disturb the urban areas less.
- Partly because of salt mining tourism based on salt and salty lakes have emerged.

Recommendations

- It is a topic of further investigation to find out if it is environmentally and economically feasible to support the redevelopment of the salt mining sector. Strict monitoring should be deployed in case of positive answers.
- Mining can also be seen as a joint cultural heritage of the settlement and the wider region including the hromada of Solotvyno, which can support international tourism.
- Some of the former mining facilities and premises could be targets of innovative sports and recreational developments such as extreme sports, urban games, escape rooms, theatre etc. as well as interactive open-air and underground exhibitions. Risk assessment is a must here, however, before any decisions are made.

- Salt processing and products based on salt mining should be supported more compared to previous times meaning salt can be considered more than just a raw material to mine in large amounts.

2.3.4. Agriculture

Although **agriculture and forestry are not the main sectors in the economic structure of Solotvyno** and the Tiachiv Raion, they provide livelihood for people. Most of all the grazing and forestry are the common agricultural activities in the raion, but some vegetables and fruit-trees can bear the climate of the Marmarosh basin. Agriculture plays little role in wealth generation in the hromada of Solotvyno. Talking about the local sector, sheep farming can be mentioned with its typical cheese and curd products. There are few entrepreneurs who have a larger number of sheep. Larger companies in the agricultural or food sector are not known, rather local households keep some production for their own and low scale purposes mainly.

However, the environmental impact related to the salt mine issue has a great effect on agriculture too. The subsidences, the landslides and the expanding sinkholes have restricted the extension of the arable lands. Moreover, the shepherds and graziers – despite the risk of unexpected landslides – tend to use the surface of the abandoned mines, since these desert areas fit for grazing. But not just the arable lands' shrinking territory causes significant challenges for the farmers, but the contamination of the soil and the groundwater too. The inflow of untreated wastewater and the illegal disposal of the domestic waste spoil the quality of the arable lands. Furthermore, the accumulated saline water in the sinkholes is also a serious risk factor, since it can easily damage the ecologic constitution of the floodplain of the and the quality of the arable lands. The increasing chloride level of the irrigation water means a vast obstacle for agriculture not just in the Tiachiv Raions, but in the further river section in Transcarpathia, Romania and Hungary too.

The anxiety of the landowners and the affected farmers is not irrational since their livelihood could be at risk. In the interest of them, more attention should be devoted to the quality of the groundwater and the treatment of the saline water.

Conclusions

- Agriculture plays a less relevant role compared to industry or tourism.
- Agricultural activities are also under risk because of pollution and land movements related to former mining activity as well.

Recommendations

- A more comprehensive land use planning would be well advised to secure sustainable agricultural production.
- Local-regional product systems could be supported covering processing, storage, trade and labelling, marketing to diversify the economy and the income sources.
- Entrepreneurial skills could be improved to establish enterprises that generate more and diversified income for the local population.

2.3.5. Tourism sector

Tourism[33] provides great potential in Transcarpathia to boost the economy, since the region possesses many cultural and natural heritages. Unfortunately, these endowments are not fully utilised because of the Ukrainian – Russian conflict, which has kept away some of the foreign tourists from Ukraine since 2014. Before the COVID-19 pandemic (in 2019) the number of hotels and other places for temporary accommodation was 59 with 4 672 places, which were used by 102 410 persons. According to the data of tour operators and travel agencies most of the tourists in Transcarpathia were domestic in the year of 2013 (92.6%, 6 414 persons) and 2019 (98.6%, 7 968 persons) too. It means, the organised tourist portfolio of the region focuses on the domestic demands and does not utilise the geographical vicinity and cultural bonds with the neighbouring countries. Presumably, these tourist connections and relations still exist just without the involvement of the Ukrainian travel agencies. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

Focusing on the tourism sector of the urban-type settlement of **Solotvyno**, between 2002 and 2008 approximately 100 000 visitors came to Solotvyno annually (Móga et al., 2019). In the main

[33] Tourism indicators: http://www.uz.ukrstat.gov.ua/statinfo/turism/zasob_rozm.pdf; http://www.uz.ukrstat.gov.ua/statinfo/turism/tur_potoki.pdf

season a few years ago 3000 people stayed in the settlement at the same time, which increased to 4000-5000 tourists by 2021 (interview with Mr Kocserha, 2022). Tourism is still way too concentrated for three summer months. **Seasonality** is apparent as winter is characterised by low level of inflow. 90% of the tourists are coming from other parts of Ukraine. Vast majority of the guests are from western regions of the country, e.g., from Lviv or from the rest of Transcarpathia. In the last few years, the number of guests also rose thanks to the proximity to the closest popular ski resort, and local businessmen see opportunities in Solotvyno to expand their operations. (State Statistics Service of Ukraine - Main Department of Statistics in Transcarpathian Region)

The **growing number of guests** triggered the development of tourism infrastructure, namely accommodation and catering, and the hospitality sector. Solotvyno became a true recreational centre with hotels, bars, and other accommodation facilities. The infrastructure was built up spontaneously and it focused mainly on the Salt Lake Kunigunda which was divided by small dams to ensure the decent water level for the bathers (Stoeckl et al., 2020). Speaking of the accommodation facilities, during the summer main season sometimes even more than 2000 tourists are accommodated locally (interview with Mr Kocserha, 2022). As a relatively new phenomenon bigger and higher quality hotels are being built. A total number of more than 60 **accommodation** units operate; some of them host few dozens of tourists, while others are larger facilities. In addition, many other private accommodation units (family houses, flats) offer additional beds to the larger accommodations. **The sector provides additional income for the inhabitants too** since they can rent their free rooms or houses for the visitors. In the last ten-eleven years there is a shift from a “party district” to a recreational area, which results in less live music, bars, restaurants, non-stop partying and smaller spas, pools, health services. Unfortunately, Russia's war against Ukraine could halt the further improvement of this type of tourism in Solotvyno, which worsens the livelihood of the locals. Still, even in the summer of 2022 new tourism facilities were being built.

It should be underlined that it is strongly tied to **health tourism**, namely to the lakes and the hospitals. The use of salt (and salt lakes) for tourist purposes as developing resources in Solotvyno began in the 1970s, but it was enhanced mostly just in the 2000s, when mining could not employ as many people as before. Incomers bathe in the lakes formed in the former mining area, furthermore more and more fresh and saltwater pools have been established at the accommodation buildings as services. Local gift shops and groceries also benefit from the incoming tourists. Apart from economic development tourism plays an important role in employing local citizens who have limited other employment options in Solotvyno.

Two **hospitals** operate in Solotvyno which are important socio-economic assets of the settlement. The hospital, maintained by the oblast of Transcarpathia, treats 100 patients with asthma and respiratory diseases. In the national hospital 350 patients are treated. More than 500 people worked in the two hospitals making it an important sector of the settlement. It would impact the whole hromada if the hospital stopped its operations given that many intellectuals, doctors and other crucial local workforce and human capital can be kept by having these health care institutions. Since the health benefit of the underground chambers is of great importance, underground allergology hospitals were established which received patients not just from Transcarpathia, but from other parts of Ukraine mainland. After the closure and the instability of the mines, the hospitals could not use the chambers anymore. **There is still a great demand for hospital treatments connected to salt**, which is a huge potential for Solotvyno, if the whole situation is properly managed and controlled. Even with the closure of the salt chambers, the opportunity of medical tourism has remained, since the health benefit of the hospital treatments, the brine pools and the sludge were conformed, and the medical tourism has widened with **spa tourism**.

The spontaneous and uncoordinated management of the recreational area and the proximity of the abandoned mines cause hazards. The contamination of the sinkholes – by the illegal littering – has a direct effect on the water quality of the beaches. The incidental pollution of the water in the Lake Kunigunda would impair the reputation of Solotvyno and decrease the number of the future tourists. Unfortunately, due to the abandoned mines and the irresponsible behaviour of the locals, these **salt resources have been contaminated, which impairs the future potential of tourism.** To avoid this, it is crucial to create a well-working waste management system and to halt the illegal littering. Another hazard can be the unclosed territory of the mining area since the visitors frequently roam here between the sinkholes just because of interest or short cut. Furthermore, the **constant danger of landslide and subsidence deters the new investors and companies, as they do not want to invest in a risk zone**. In addition, there are some smaller scale land movements around the recreational area of Solotvyno too. Local businesses try to mitigate and react to these processes, however according to local sources no major movements occurred recently. What can be dangerous is the underground flow of water between the two parts of the settlement of Solotvyno, and the effect of such invisible waters is unknown yet. Few accommodation facilities are affected by the movements. Lightweight buildings are less threatened, and they can be relocated, which is favourable to avoid further damages. There are 3-4 smaller accommodation buildings which are affected the most, and where solutions must be found to tackle the threats.

The growth of the tourism sector cannot be achieved without preventing the spread of pollution. The local salt resource is the most important value of the area, and currently it gives the brand of Solotvyno. However, if this geological resource is polluted further, Solotvyno will not be able to utilise this special endowment anymore. It is important to highlight that the mere existence of salt is not sufficient for sustainable economic and social development, there should be good quality of services, accommodations, leisure activities, medical treatment and decent infrastructures and equipment, which can ensure the basis of qualitative tourism. Besides this, the preservation of the former industrial heritages is also desirable since these facilities can introduce the history of the settlement. To support Solotvyno becoming an integrated tourist attraction on the market, the hromada needs to build up a unified brand, which facilitates the partnership building among the actors of the local tourism sector. For instance, it is inevitable to develop an integrated destination management and a coherent product and service development, which fosters the establishment of quality tourism in the region. With these measures, Solotvyno will be able to represent itself at international level as well.

Conclusion

- Tourism has become a major sector that shapes the status of the whole hromada.
- There is a shift towards recreational and medical tourism.
- There is still strong seasonality during the year.
- Inland tourism dominates while foreign tourists are less attracted to Solotvyno.
- There is a need to create a more attractive environment by eliminating environmental hazards that also impairs local tourism experience.

Recommendations

- Support local people to be part of the sector by encouraging quality improvements for them to be involved in the accommodation sector as well in the selling of local products and souvenirs.

- Initiate contacts with spa towns of European expertise.
- Those kinds of investments should be supported which are further away from the risk zones, and which encourage the shift to quality tourism and the introduction of complex new health services and medical treatments.
- The sources of pollution and the spread of it should be localised to avoid contamination to make tourism impossible or at least less attractive.
- Sustainability in tourism should be increased to find a balance between further development of the sector and the quality of the environment.
- Only those new developments should be authorised which keep in mind the environmental hazards and risk (e.g. the contamination of water bodies, or collapse of buildings).
- Cultural diversity could serve the basis for additional tourism products and services.
- Cooperation with other mining towns in the wider region as well as with other destinations along the international river of Tisza could be improved.

3 Findings of REVITAL1 project

3.1 Outputs of the field-trips and experiences

Field visual monitoring observations have been performed to verify remote studies of the deformation of the ground surface (interferometric processing of satellite radar monitoring data), as well as to record the manifestations of hazardous geological natural and man-made processes within Solotvyno rock salt deposit and adjacent territories, i.e., data collection and analysis on karst development (sinkholes: geometric dimensions and frequency of occurrence, ground subsidence etc.). Examined and documented (photos, schematic drawings, coordinates):

– the slopes of the flood-control dam, which are intensively built up with recreational facilities;
– abandoned hydrocarbons storage area;
– zones of influence of facilities for the extraction of rock salt - mine fields and adjacent territories of the abandoned mines 8, 9 and the failure of mine 7;
– Black Moor area;
– Little Black Moor area;

– karst-suffusion phenomena along the old river Hlod, north drainage gallery, lake Eldorado.

Visual field observations showed that the processes of degradation of the ground surface continue. In particular, the body of the flood-control dam continues to be actively built up, with the clearing of woody vegetation, and the arrangement of open drainage of sewage water into a drainage trench (Fig.3 A).

Within the area of the Black Moor, further absorption of the «cape» in the centre of the lake takes place (Figure 3 B). There is also a gradual increase around the lake in the northwestern to south-eastern direction. There is a fresh gaping "through" (on both opposite walls) crack oriented in the southwestern direction of the country house near the lake. The concrete tray along the Hlod River is dry, partially deformed, and overgrown with blackberries. A new trench up to 1 m deep was dug parallel to the road.

Numerous active and grass-covered sinkholes, mostly round or elliptical in shape, sometimes elongated due to their merging, were established around the Little Black Moor (Figure 3 C, D). The sinkholes are mostly not deep, with a visible depth of up to 5 m. Some of the sinkholes contain water and woody vegetation. The most disturbed part is near the railway mound, where there is a large active sinkhole with steep slopes above the drainage tunnel No. 7 (elongated due to the merging of several sinkholes) and a few individual sinkholes. The weakened zone of the elongated group of sinkholes is stepped, has 8 ledges clearly expressed in the relief on both sides, 0.5-1.5 m high, up to 3 m wide. Further, along the slope, there is an open narrow concrete drainage tray, 0.5 m deep. The Glod riverbed is traced by sinkholes.

Figure 3 A. The body of the flood-control dam continues to be actively built up, with the clearing of woody vegetation, the arrangement of open drainage of sewage water into a drainage trench (Photo 2020-03-16)

Figure 3 B. A newly formed karst sinkhole near a waste deposit on the eastern side of the Black Moor (Photo 2020-03-17)

Figure 3 B. Advancement of the south-eastern edge of the Black Moor (Chornyi Mochar) southwards to the landfill (Photo 2023-04-09)

Figure 3 C. Trough-shaped subsidence zone complicated by karst sinkhole near the southern slope near the railway bank (Photo 2020-03-17)

Figure 3 D. Karst-suffusion sinkholes in the mine № 9 eastern flank. General view (Photo 2020-03-17

Figure 3 E. Newly formed pits along the southern edge of the mine No. 7 sinkhole (Photo 2023-04-09)

Figure 3 F. New sinkholes to the west of mine funnel #7 (Photo 2023-04-10)

Figure 3 G. Recreation centre “Panorama” (new building) with sinkholes above the mine workings of mine No. 8 in the background (photo by Oleg Naumenko, https://hotel-panorama.com.ua/photos/)

Conclusions

- **On the territory of flooded and non-working (abandoned) mines, there is an expansion of the subsidence area and a gradual flattening of the slopes around karst craters and sinkholes. At the same time, the existence of karst-suffosion sinkholes with vertical walls is an indicator of the continuation of active karst-suffusion processes.**
- **In difficult economic conditions (military aggression of Russia, especially its acute phase from 2022 and to a certain extent COVID-19), the population of Solotvyno finds opportunities and resources to implement projects for the development of tourist infrastructure. There is an involvement in use, for building territories where vertical displacements are recorded. For balneological purposes, brine is pumped out of the sinkholes of mine No. 7.**

Recommendations

- **Create the conditions/system for the use of natural resources, for health tourism (medical, rehabilitation, recreational) within limits that do not pose additional risks to life and do not have negative consequences for the environment (primarily the spread of pollution). Consider legalising the use of brines for balneological purposes.**

3.2 Results of ground deformation mapping

3.2.1 Evaluation of surface movements

Archive data of the EU ENVISAT satellite system from the years 1992-2000 and 2002-2010 were used to monitor changes in surface movements in space and time. The mine ruptures with the largest surface movements can be linked to the latter period.

Surface movements can be described by the velocity vector of vertical displacements. In our case, the following values can be used to characterise the risks of displacement (specifically subsidence) expressed in mm/year to protect the structures.

For a value of -2.5 - +2.5 mm/year, the risk=0 (no risk)

In case of -5 - -2.5 mm/year, the risk=1 (medium risk)

In case of -15 - -5 mm/year, the risk = 2 (high risk)

In case of -25 - -15 mm/year, the risk=3 (very high risk)

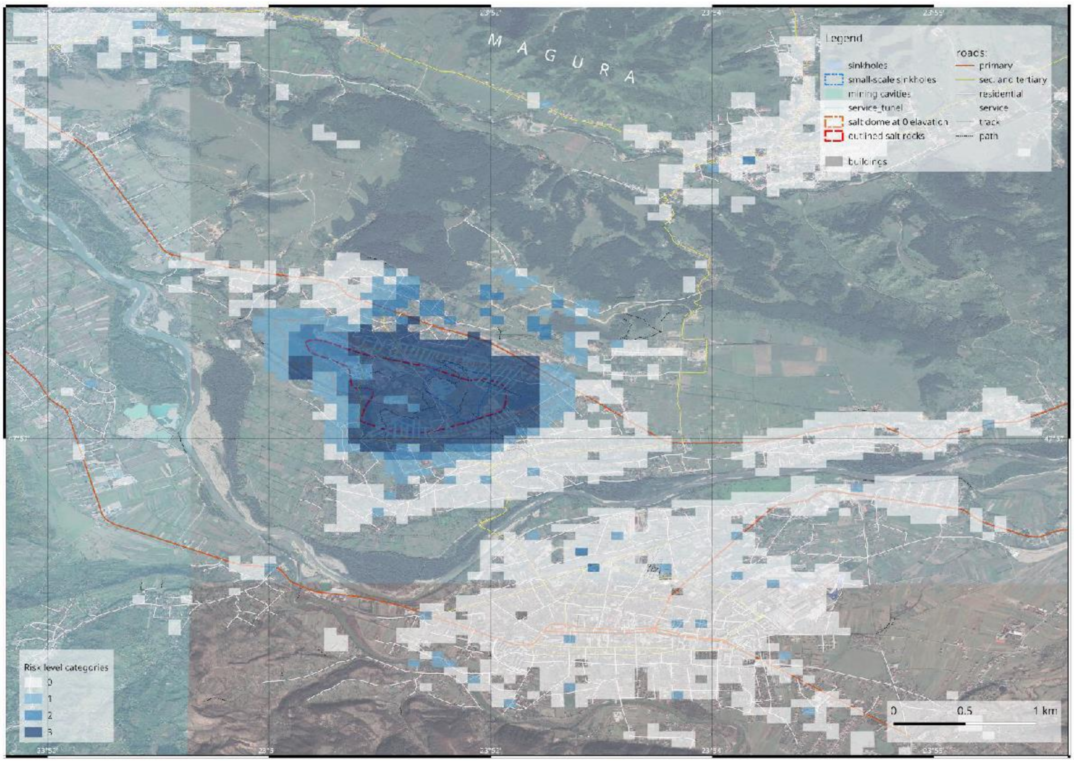


Figure 4 Risk map of land subsidence measured based on ERS data between 1992-2000 *(DatElite Ltd)* Legend: grey=0 (no risk), light blue=1 (medium risk), medium blue=2 (high risk), dark blue=3 (very high risk)

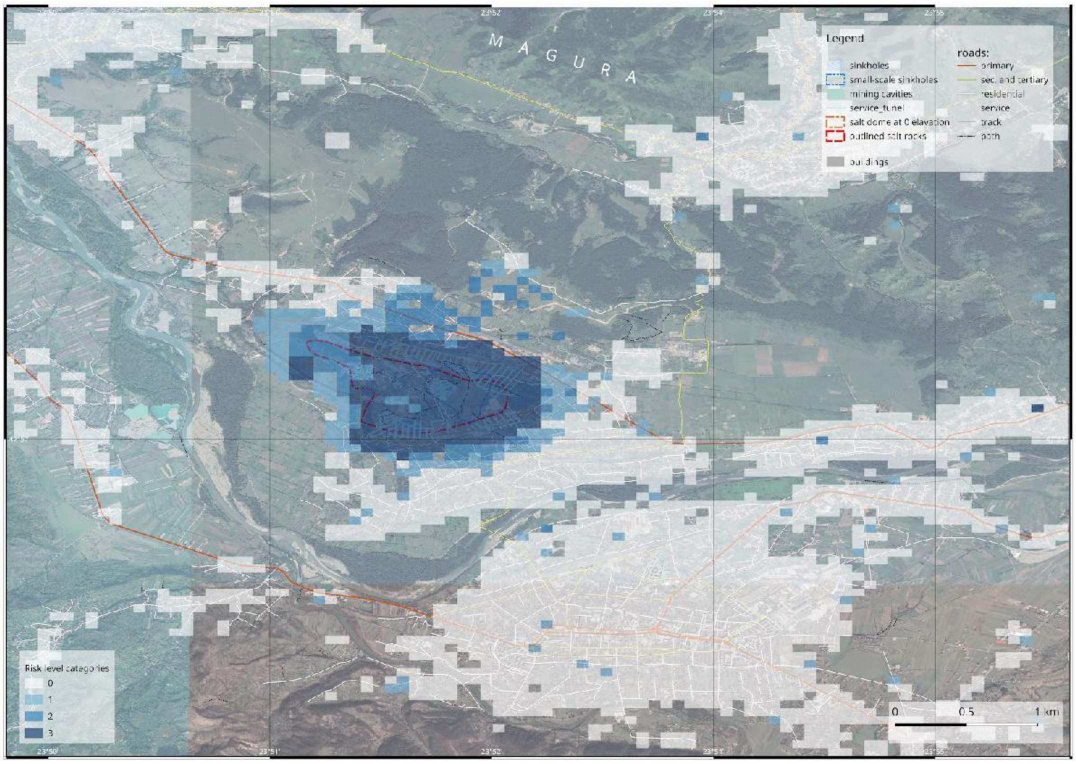


Figure 5 Risk map of land subsidence measured based on ENVISAT data between 2002-2010 *(DatElite Ltd)*
Legend: grey=0 (no risk), light blue=1 (medium risk), medium blue=2 (high risk),
dark blue=3 (very high risk)

Based on both figures above (Figure 4, 5), **there is no significant difference in land subsidence between 1992-2000, and 2002-2010 and and 2014-2021**. In both periods, it is clearly visible that **the very high-risk area is the former salt mine, the salt ponds, and the several hundred-meter strips bordering them** if it affects built-up areas. **This means subsidence of up to 25 mm/year** (obviously, this shows higher values in the vicinity of the ruptured craters). **The most endangered utility provider is the electrical distribution network plant located around Mine 9 (near Shaft 10) in the NE part of the very high-risk area.**

Based on E. Szűcs et al. (Evolution of surface deformation related to salt-extraction-caused sinkholes in Solotvyno (Ukraine) revealed by Sentinel-1 radar interferometry 2021, Nat. Hazards Earth Syst. Sci., 21, 977–993, 2021, https://doi.org/10.5194/nhess-21-977-2021) the evaluation of data from the **EU Copernicus SENTINEL-1 satellite between 2014-19, the rate of subsidence reached 30 mm/year.** As the recent project result identified a same value (DATelite Ltd, 2021)

This means that the intensity of subsidence increased slightly between 2014 and 2019, but there is no knowledge or measurement that this has changed.

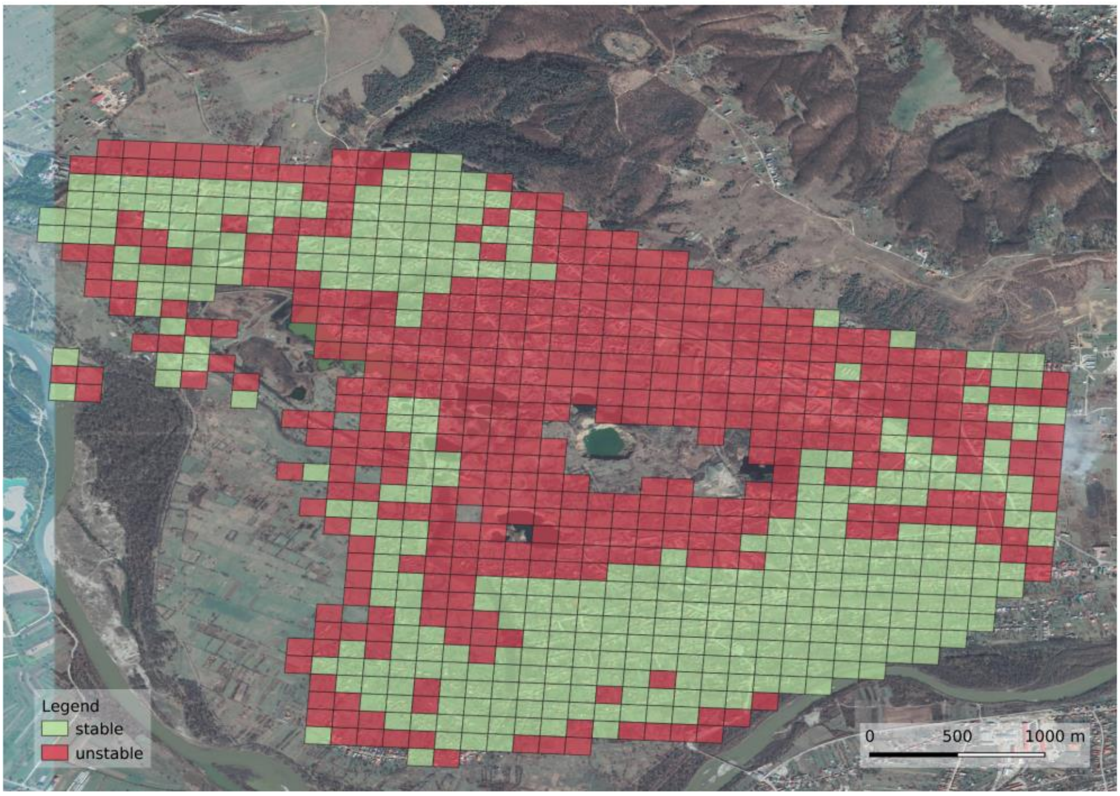


Figure 6. Stability map of Envisat scatters between 20014-2021 (DatElite Ltd)
Legend: green=stable, red=unstable

According to the indirect evidence of water chemistry tests, **the subsidence process progresses asymptotically to the new equilibrium state, higher subsidence values are most likely no longer expected.**

InSAR measurements revealed the spatial and temporal distribution of historical surface deformations Solotvyno in Ukraine. Through the analysis of interferometric data, it helped to understand the nature of the Solotvyno salt dome surface deformations from the 1990s to the end of 2000s. ERS and Envisat SAR imagery archives covering the above-mentioned time frame have been processed and interferometric deformation history of the area was investigated concluding **the results** listed below:

- The central part of Solotvyno and adjacent southern slopes of the Magura were detected as fast-moving distinct surfaces during both decades, while other surfaces remained permanently stable.
- Displacement rates were constant over time, velocity on the moving surfaces exceeded - 25 - -5 mm/y during both decades without significant accelerations and decelerations, representing a clear linear trend of subsidence.
- Displacement velocity decreased parallel with leaving the center of the salt dome.
- Only small-scale spatial changes of displacements were observed: movements shifted toward the north on the northern edge of the southern flank of the village.
- Risk levels were computed from interferometric and geological data, showing that high risk levels occur at the dome and surrounding area, while the level of risk decreases with the distance measured from the center of the salt dome.
- No significant spatial or temporal changes of risk levels have been found during measurements.
- Measurements were executed with sub-millimetre scale average precision.
- Interferometric scatterers are located over artificial structures, only a few scatterers were present on bare surfaces.
- Only a very few scatterers were found over the central area of the salt dome and other vegetated areas; establishment of a network of artificial scatterers (corner reflectors) or single reflectors could enhance the spatial coverage of interferometric scatterers here.
- **The results highlight a totally different situation in the Romanian part, as it was detected in Solotvyno. The whole territory of Sighetu Marmatiei presents a stable condition, and there are not any districts of the town, which shows a geographically recognizable pattern of surface movement. Scattered locations of few unstable points are detectable. It means that the revealed local instability most probably in connection with structural problems of a building, or slope conditions.**

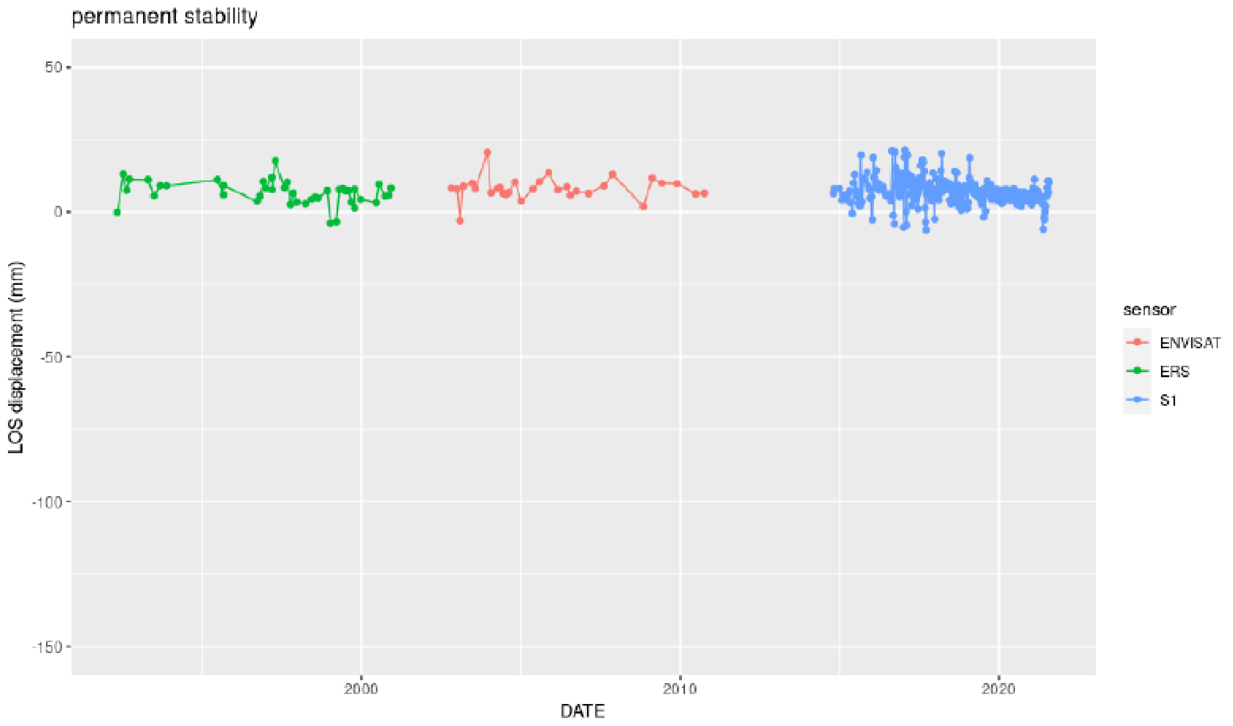


Figure 7. LOS displacements of grids showing permanent stability

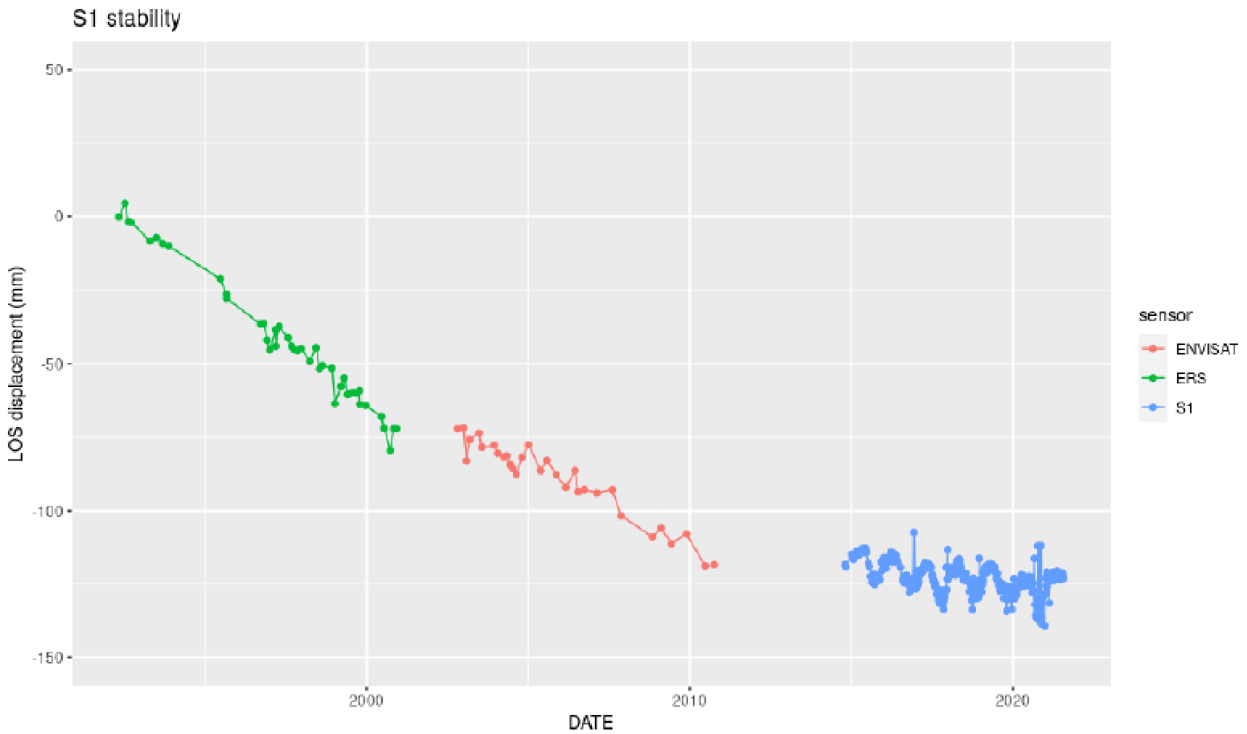


Figure 8. LOS displacements of grids showing S1 stability

SAR measurements clarified that the interferometric analysis of ERS and Envisat data provided a solid base for the successful processing and analysis of Sentinel-1 imagery, which could foster the deeper understanding of natural processes related to Solotvyno salt dome. To envision a prosperous future for the Solotvyno region, further investigation of the process is required over the hazardous area. **Using corner reflectors and InSAR technology an early warning system could be installed over the area. This InSAR-based monitoring system could improve the civil safety conditions quite a lot, and provides an objective, transparent surface deformation information for anyone throughout a web gis application. This application can be installed on local people's smartphones, and they will be able to receive direct information about their residential district.**

3.2.2. Results of ground deformation mapping

Interpretation of satellite images was carried out to establish the basic patterns of earth surface deformations for further assessment of risks associated with the development of hazardous natural and technogenic geological processes within the Solotvyno salt dome structure and adjacent territories.

Assessment of vertical displacements of objects and the ground surface was carried out using interferometric processing of satellite radar monitoring data by means of satellite constellations Sentinel-1A and 1B (DInSAR analysis data for 2016-2021 , SBAS approach, Copernicus EMSN-030, EMSN-064; PS+SBAS approach, Center of the Special Information Receiving and Processing and the Navigating Field Control, Ukraine). According to satellite radar monitoring by means of satellite constellations including Sentinel-1A and 1B and data processing techniques PS & SBAS. 2016-2021 studies performed by the Center of the Special Information Receiving and Processing and the Navigating Field Control, Ukraine.

Due to the use of a long time series of images obtained by Synthetic aperture radar (SAR), the errors of orbital data and the influence of atmospheric phenomena were effectively suppressed. The results of processing are digital maps with the accuracy of estimating of objects with an average vertical displacement speed of 2-4 mm/year using the PS technique, and 6-15 mm/year using SBAS.

The research area was 33 sq. km. The final information products (raster and vector) were created, which made it possible to analyze changes in spatial and temporal dimensions. Remote sensing radar data preparation and pre-processing operations were performed in ENVI software, SarScape modules, and thematic processing operations based on interferometry results (ArcGis software) was done.

Ground deformation mapping and monitoring by satellite (2018-2020)

Assessment of vertical displacements of ground surface was carried out using interferometric processing of satellite radar monitoring for the period from 06/25/2018 to 06/30/2020.

The values and areas of concentrated land surface deformations have been determined within the zone of anthropogenic and natural karst development, which is hampered by manifestations of hazardous geological processes (landslides, flooding, floods, etc.). According to the results of retrospective processing in the study area, the zones of concentrated deformations and the subsidence dynamics in the points of radar measurements were determined (Fig. 9). Areas of land surface subsidence with an average speed of vertical displacements from -6 to -94 mm/year were digitised using GIS tools. The assessment of anthropogenic hazards for Solotvyno salt dome structure and adjacent territories was given. As a result, 5 areas of intensive subsidence were identified. The largest subsidence of the ground surface is determined in zones №3 and 4 (Fig. 10). In the subsidence zone №4, the maximum average subsidence rate is –81 mm/year. It was determined that mines №7, 8, and 9 pose a threat to life safety in Solotvyno.

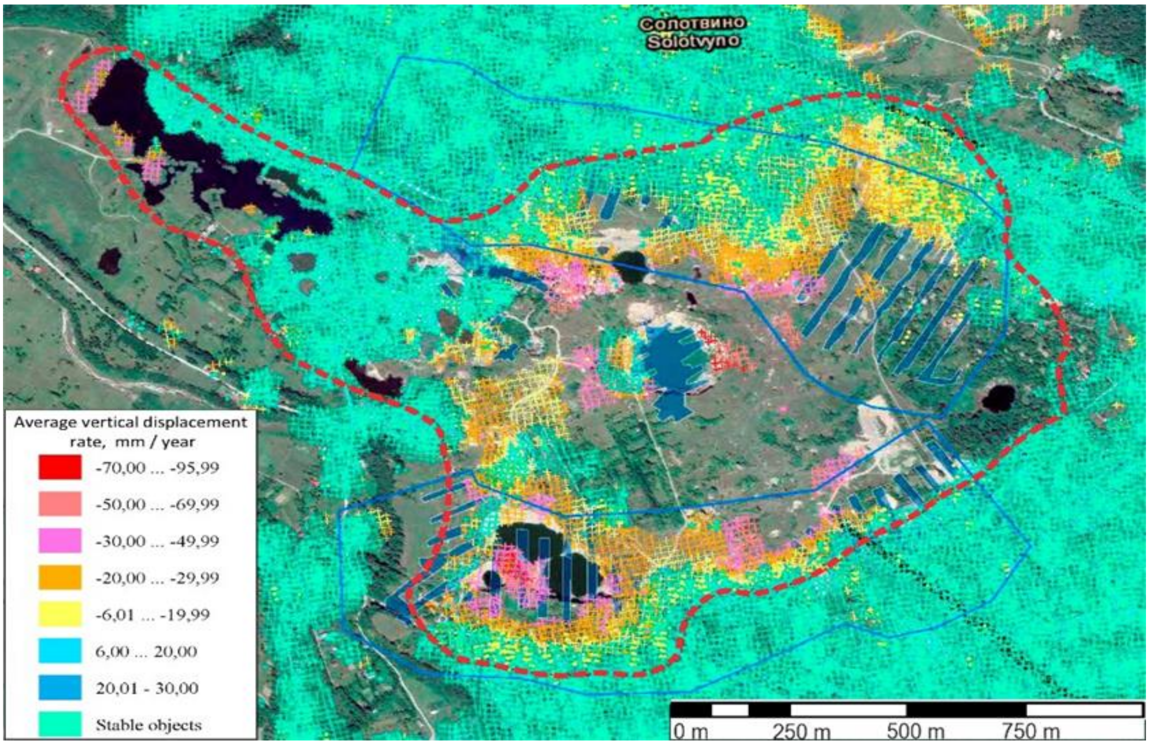


Figure 9 – Area of intense subsidence – delineated by red line (area with deformations of the ground surface with an average subsidence rate of –6 to –94 mm/year, PS & SBAS approaches)

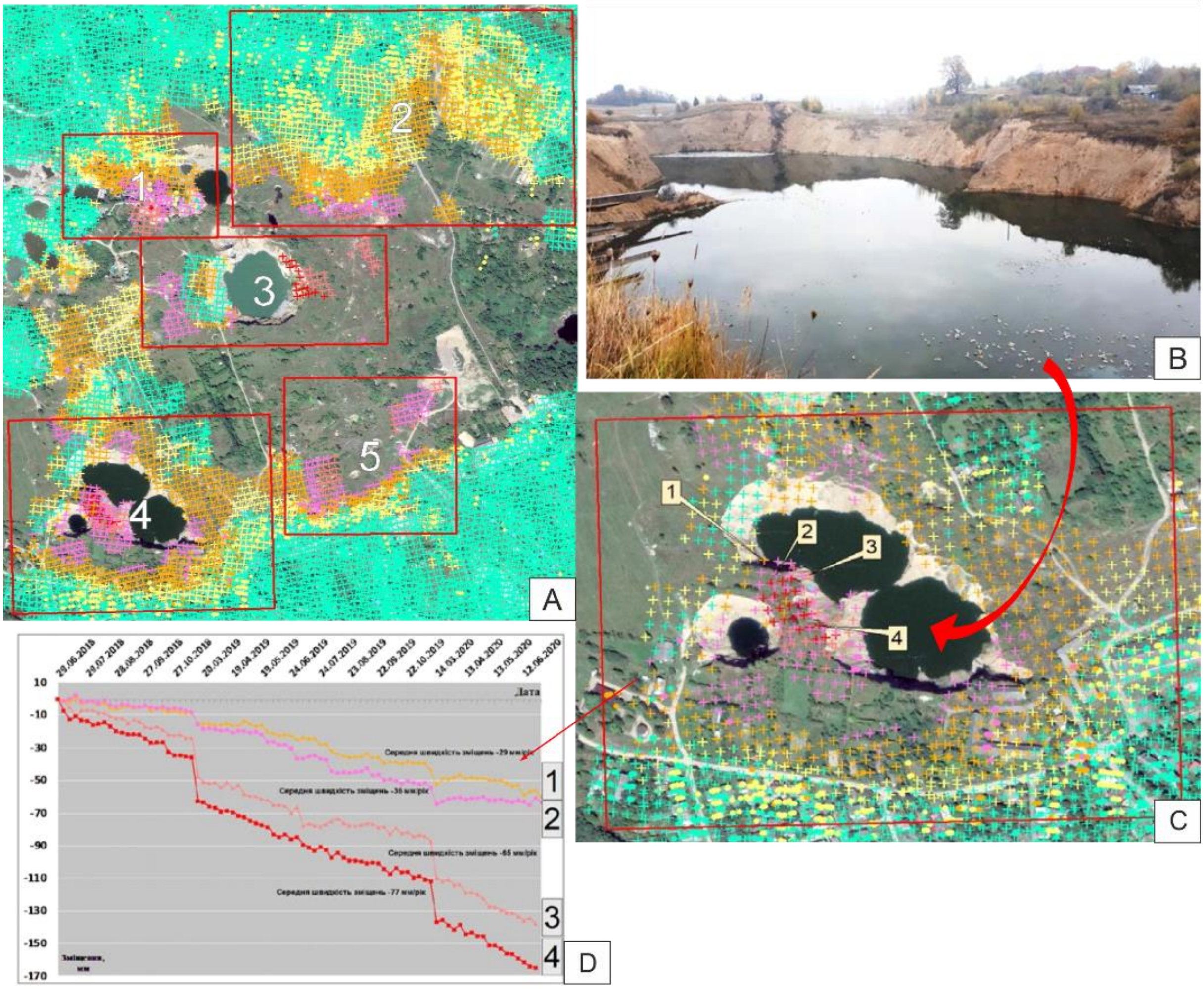


Figure 10. A – established zones of concentrated deformations; B – mine №8 western flank; C – geodynamic analysis of the subsidence zone №4 (western part of the mine №8 area); D – graph of vertical displacements for zone №4, the maximum average subsidence rate is –81 mm/year

Ground deformation mapping and monitoring by satellite (2020-2021)

According to the latest satellite radar monitoring data (for the period 06/30/2020-10/12/2021) the assessment of the vertical deformations of the ground surface, buildings, and facilities within the Solotvyno was done (Figure 11 A). (*Pakshin, M., Shekhunova, S., Stadnichenko, S., Liaska, I., 2021, The satellite radar monitoring for anthropogenic and natural geological hazards mapping within the Solotvyno mining area (Transcarpathia, Ukraine). European Geosciences Union «vEGU21». EGU21-8417.*

https://doi.org/10.5194/egusphere-egu21-8417)

As a result, 5 areas of intensive subsidence were identified (with an average subsidence rate from -6 to -126 mm/year) (Figure 11 B). It was established that the subsidence zones near the mine No. 7, 8, 9 are significant in area and each has a significant subsidence mould, in which the largest subsidence is determined in its centre, and, when moving away from the centre, the intensity of subsidence of the ground surface gradually decreases. **The territory of mine No. 7 and the western and eastern parts of the mine No. 8 area was identified as unsafe**.

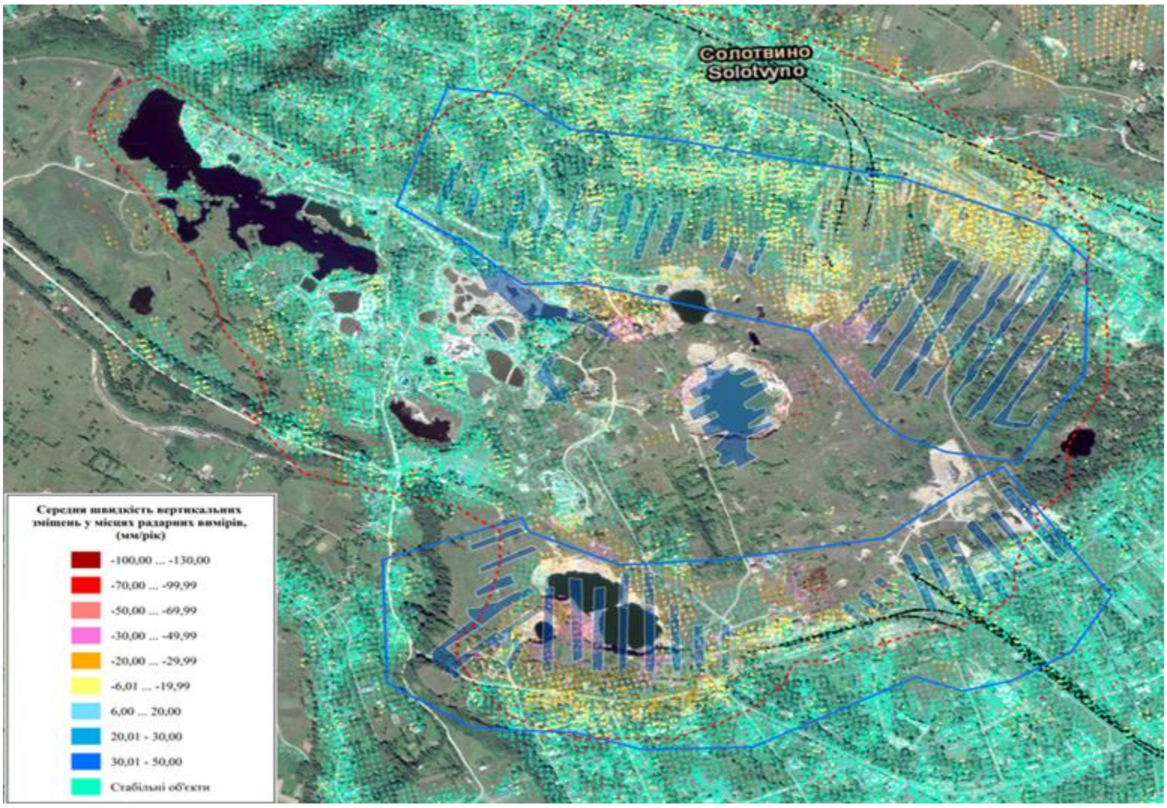


Figure 11 A. Overview scheme of the Solotvyno territory with radar measurement points and determination of ground surface vertical displacements values for the period 06/30/2020-10/12/2021. Zone of intense subsidence marked by red dash-dotted line

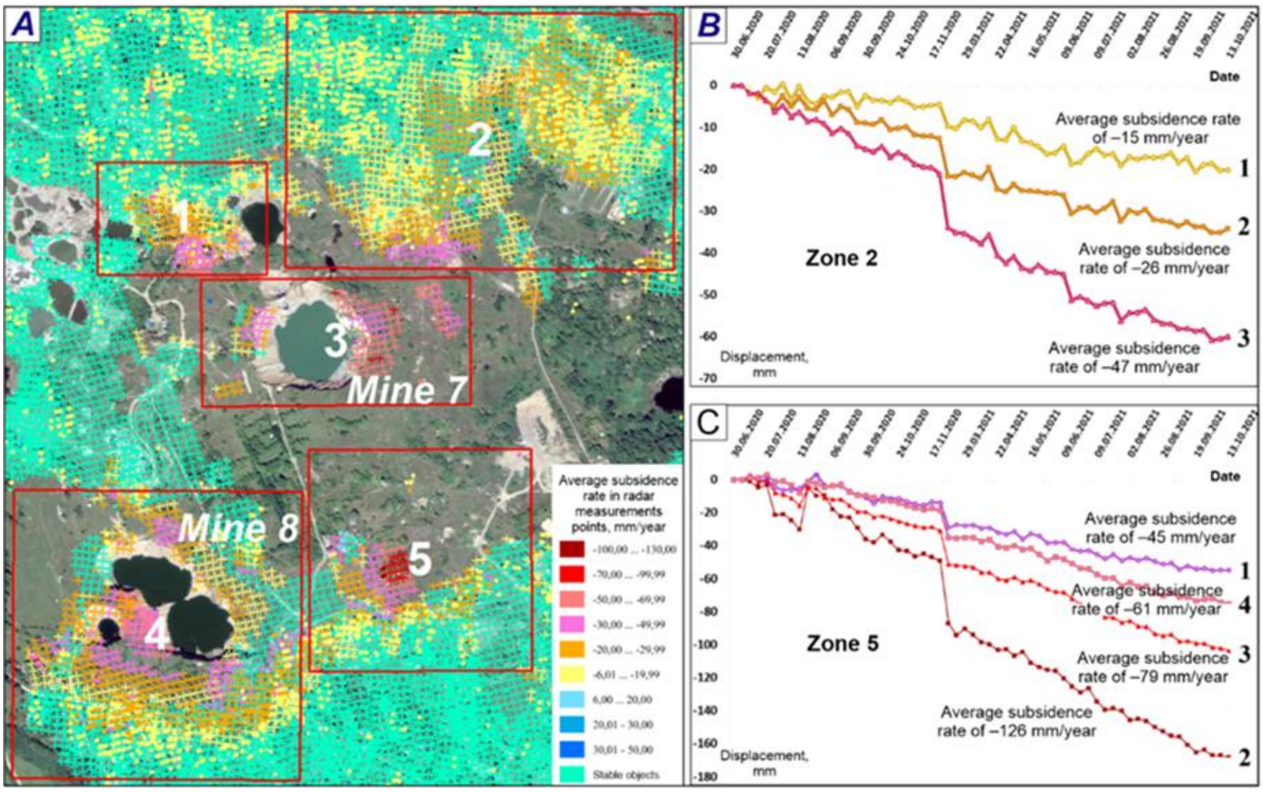


Figure 11 B. Assessment of ground surface vertical displacements using interferometric processing of satellite radar monitoring data (PS&SBAS) for the period from 06/2020 to 06/2021: A – zones of concentrated deformations; B – graph of vertical displacements for the zone of concentrated deformations #2, the maximum average subsidence rate is –47 mm/year; C – graph of vertical displacements for the zone of concentrated deformations #5, the maximum average subsidence rate is –126 mm/year (crosses of different colors mark observation points with different vertical displacement rates; the rate increases in order green, yellow, orange, lilac, pink, red. The rates correspond to the color in fig. 9 A)

Ground deformation mapping and monitoring by satellite for control objects (critical infrastructure objects)

Analysis of satellite interferometric data for Solotvyno settlement and adjacent territories was carried out to determine the ground surface vertical displacements for the period 1997-2021 due to long-term underground mining activities. Areas of detailed study - control objects sites (critical infrastructure facilities) were selected: 1 – power transmission tower; 2 – electrical substation, 3 – balneological resort facility; 4 – water supply pumping station; 5 – five-storey building; 6 – underground water supply facility. For each control object site graphs of accumulated deformations and the rate of ground surface displacement was plotted (Figure 12). For each of the sections, two graphs of vertical displacements were created for the periods 04/30/2016 - 06/25/2018 and 06/25/2018 – 06/30/2020 (*Shekhunova et al., 2021*, *The satellite radar monitoring of post-mining area (Solotvyno, Ukraine). Materials of the XV International Scientific Conference EAGE "Monitoring of Geological Processes and Ecological Condition of the Environment", 17–19 November 2021, Kyiv, Ukraine. Mon-21-075*, https://doi.org/10.3997/2214-4609.20215K2075).

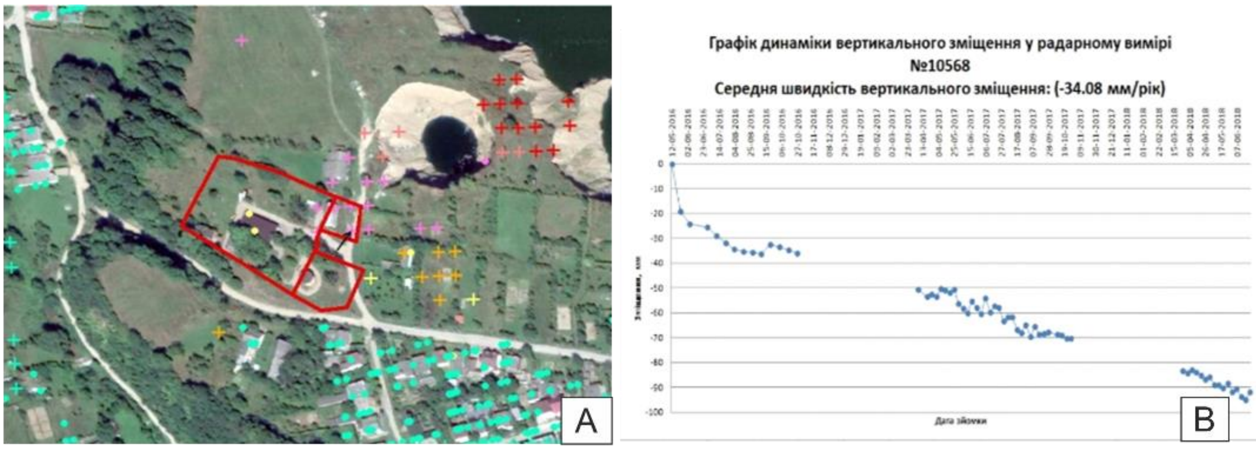


Figure 12. A – Control object Water supply pumping station; B – Graph of accumulated earth's surface deformations for control object Water supply pumping station (2016-2018) with average vertical displacement rate -34,08 mm/year

Based on the interferometric processing of satellite radar data, the frequency and scale of vertical displacements of the ground surface were estimated (Table 2). It was found that the highest values of surface deformation from –94.93 to –139.98 mm at vertical displacement rates from –34.08 to –67.54 mm/year were obtained for objects/sites (critical infrastructure facilities) located within the zone emergency mines, which is characterised by the most intensive development of karst-suffusion processes, which are associated with the formation of failures, landslides, landslides, and subsidence.

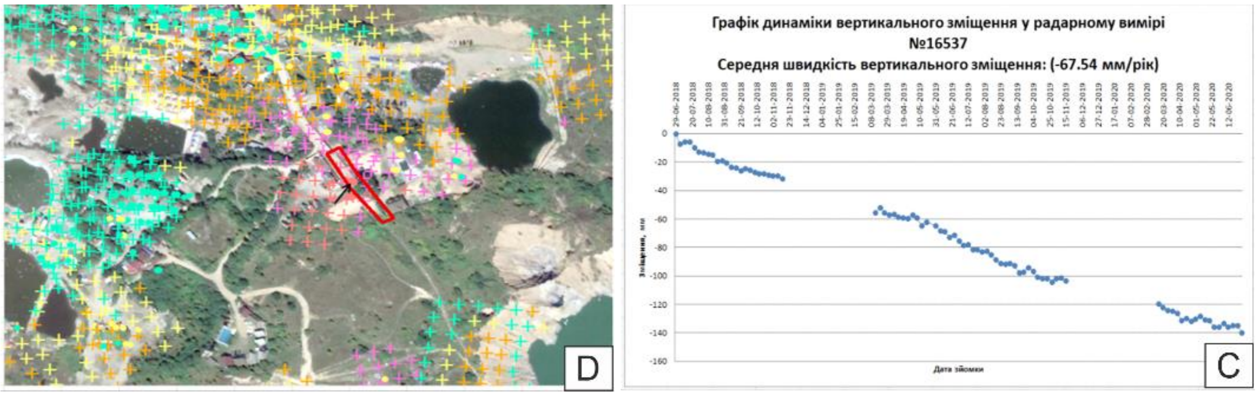


Figure 12. C – Control Object – Balneological resort facility; D - Graph of accumulated ground surface deformations for control object Balneological resort facility with average vertical displacement rate -67,54 mm/year

Table 2. Satellite radar monitoring data interpretation results on the ground surface deformation for control objects (*Shekhunova et al.*, *2021*, https://doi.org/10.3997/2214-4609.20215K2075)

№ of control object	Control object / Critical infrastructure	Technique (number of measured points per control object)	Vertical displacement, mm	Average displacement rate, mm/year	Time period	Zone	Probability, %
1	Power transmission tower	PS (1); SBAS (5)	-15.44	-3.81	2016-2018	7	20
		PS (2); SBAS (10)	-17.46	-2.79	2018-2020		
2	Electrical substation	PS (35); SBAS (4)	-25.46	-7.98	2016-2018	1	100
		PS (59); SBAS (45)	-27.52	-11.93	2018-2020		
3	Balneological resort facility	PS (1); SBAS (4)	-139.98	-67.54	2018-2020	1	100
4	Water supply pumping station	PS (2) SBAS (5)	-24.25 ... -94.93	-11.72 ... -34.08	2016-2018 2016-2018	1	100
		PS (8) SBAS (17)	-77.85 -43.56 ...	-22.29 -31.66 -20.18 ...	2018-2020 2018-2020	1	100
5	Five-storey building	PS (5); SBAS (2) PS (4); SBAS (10)	-13.21; -12.78 ...	-1.70 -0.27 ...	2016-2018 2018-2020	1(?) 2	50
6	Underground water supply facility	PS (2); SBAS (9) PS (2); SBAS (28)	-60.32 ... -69.38	-24.75 ... -31.59	2016-2018 2018-2020	15	50-75

Thus, as a result of analysis of the plotted graphs of accumulated ground surface deformations for control objects sites (critical infrastructure facilities) based on the satellite radar monitoring data (for the period 30.04.2016 – 30.06.2020), the assessment of the geodynamic subsidence state of these objects with the vertical displacements rates was carried out, new data were obtained on the parameters of the manifestation of hazardous natural and man-made processes in Solotvyno, their impact on critical infrastructure facilities was assessed.

Data on the ground surface vertical deformations frequency and scale are summarised and analysed according to satellite radar monitoring for the period 2016-2021

According to the results of retrospective processing in the study area, zones of concentrated deformations and the dynamics of subsidence in the points of radar measurements were determined (Figure 13). Based on the assessment of the vertical displacements data of objects and territories, obtained using interferometric processing of satellite radar monitoring data, it was determined that mines No. 7, 8 and 9 pose a threat to the technogenic safety of the Solotvyno settlement.

The detailed situational plan of the Solotvyno salt mine area and its surroundings with critical infrastructure objects and other facilities (including preschool and school educational institutions) located within or close to the zone of technogenic impact of salt mining operations and manifestations of hazardous exogenous geological process are shown in the Figure 14.

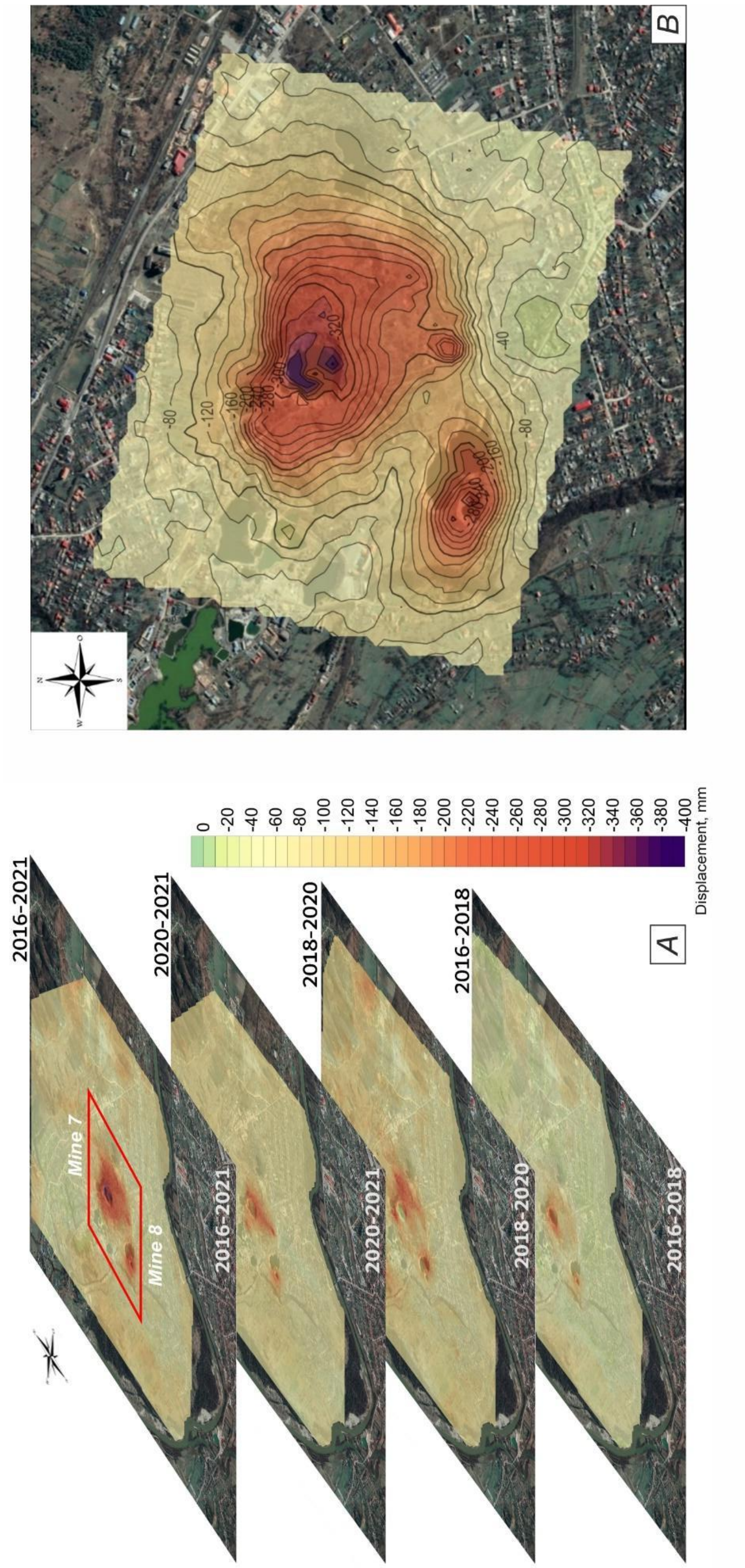


Figure 13. Dynamics of changes in the maximum vertical ground surface displacements

Figure 13. Dynamics of changes in the maximum vertical ground surface displacements

Based on provided studies results (field observations of hazardous natural and technogenic geological processes development, remote sensing satellite radar monitoring data analysis) the contour of zone of technogenic impact of salt mining operations and manifestations of hazardous exogenous geological processes in the Solotvyno settlement has been updated (Figure 14).

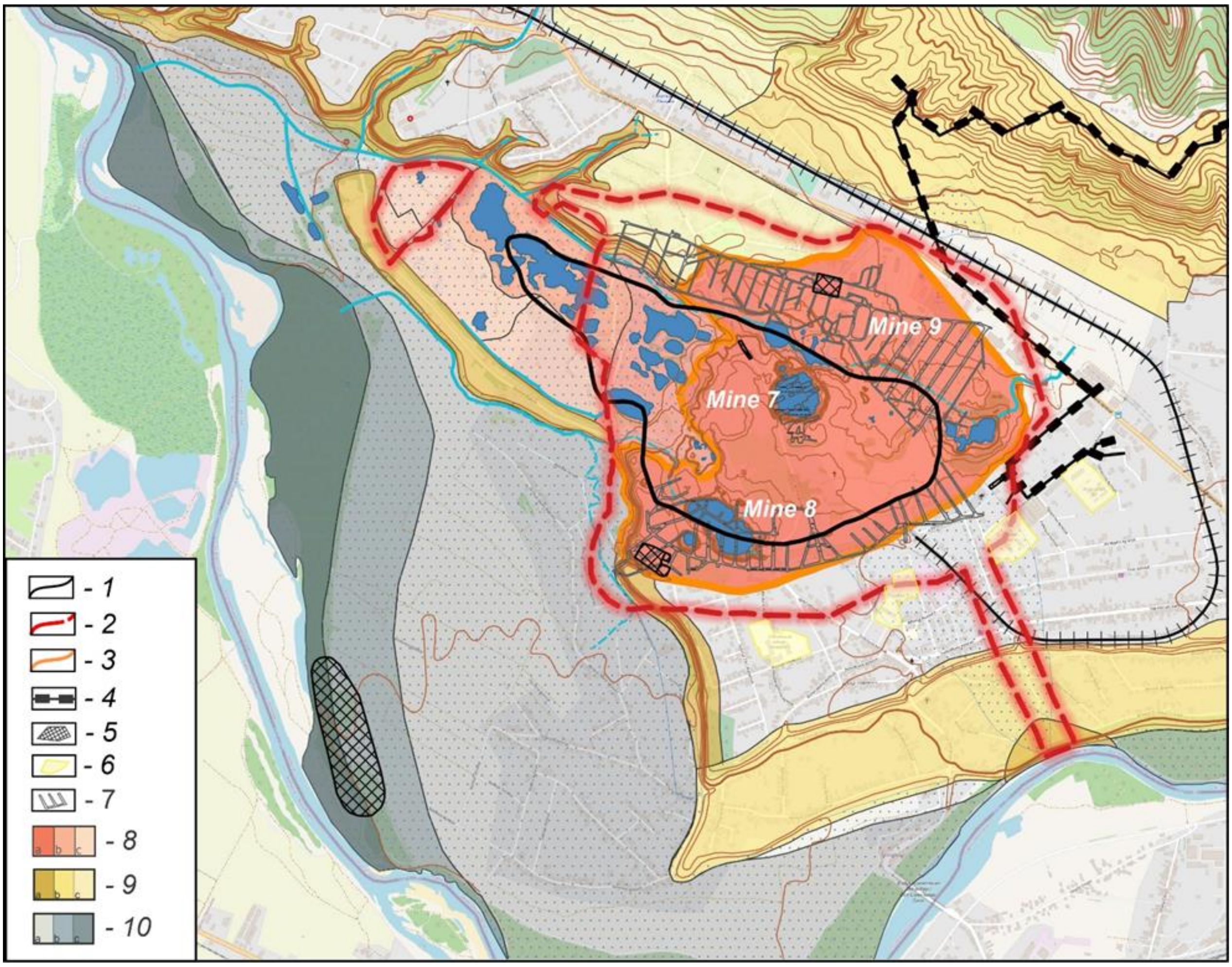


Figure 14. Situational plan of the Solotvyno salt mine area and its surroundings with zone of technogenic impact of salt mining operations and manifestations of hazardous exogenous geological processes: 1 – contour of the salt dome structure on the surface of alluvial sediments; 2 – the zone of technogenic impact of salt mines and development of the hazardous exogenous geological processes; 3 – the zone of active technogenic impact of salt mines and development of the hazardous exogenous geological processes; 4 – gas pipeline; 5 – critical infrastructure objects (power substation, water supply pumping station, sewage treatment facilities, landfill); 6 – preschool and school educational institutions; 7 – contours of mines. Risk of natural and natural-antropogenic hazards (8-10): 8 – karst processes: catastrophic (a), high (b), medium (c), low (d); 9 – slope erosion: high (a), medium (b), low (c); 10 – seasonal and flash floods: low (a), medium (b), high (a)

Conclusions

- **Patterns of the distribution of ground surface vertical displacements, which are fixed not only in the contour of mining operations but also beyond them, are revealed; the accumulated ground surface deformations in the areas of critical infrastructure facilities were assessed.**
- **The highest values of surface deformation from –94.93 to –139.98 mm at vertical displacement rates from –34.08 to –67.54 mm/year were obtained for objects/sites (critical infrastructure facilities) for the period 2016-2020, located within the zone emergency mines, which is characterised by the most intensive development of karst-suffusion processes.**
- **Based on the assessment of the vertical displacements of ground surface, obtained using interferometric processing of satellite radar monitoring data for the period 2016-2021 , the values of the accumulated deformations of the earth's surface reach -385.12 mm, it was determined that mines No. 7, 8 and 9 pose a threat to the technogenic safety of the Solotvyno settlement.**
- **Considering the complicated geoecological situation, development and functioning of the permanent complex monitoring system for the Solotvyno salt dome structure and adjacent territories is the priority objective.**

Recommendations

- **Use the Assessment of vertical displacements of objects and the ground surface using interferometric processing of satellite radar monitoring data in a monitoring system.**
- **To verify remote data, use field observations and geodetic studies.**

3.3 Geophysical and geological survey

3.3.1 Geophysical survey

The geophysical survey campaign has been carried out with the aim of extending the geological mapping of the Solotvyno salt mine area and to supplement the near-surface geophysical data of the region with several measurements from the southern side of the river.

Several methods were used: multielectrode geoelectrical tomography (ERT), Very Low Frequency Radio-magnetotellurics (VLF-RMT), Horizontal Loop Electromagnetics (HLEM), gravimetric and seismic measurements. Among the applied geophysical methods, the most detailed and undisturbed results were obtained with electrical and electromagnetic measurements. The interpretations of the salt mine area's geology and structure was effectuated on base of these data, which were also the input parameters of the 3D geologic and hydrodynamic models.

The two methods are widely used in the detection of geological structures based on their electrical properties, measuring the electrical resistivity of the various rocks in the analysed subsoil. Thus, layers with different electrical resistivity (e.g. clayey with law resistivity and high resistivity sandy bads) can be separated. After processing the raw data, it can be generated the distribution of specific electrical resistivity along the sections which characterises the underground space as a real distribution of physical parameters.

Due to the resistivity contrast between different rock types, the ERT method is a practical tool for mapping subsurface inhomogeneities, but at the same time, the overlap of the characteristic resistivity values of different materials must be considered when interpreting the data. The specific electrical resistance of different rocks varies in a relatively wide range, depending on several parameters. The most important of these parameters include water saturation, compactness, fragmentation, and mineral composition (Table 3).

Common Materials	Cited Resistivity Values (Ωm)				
	Loke (2002)	Gibson and George (2003)	SEGJ (2004)	Ewusi (2006)	AGI (2008)
Clay	1 – 100	1 – 100	1 – 300	1 – 100	10 – 100
Sand	10 – 800	50 – 1050	1 – 1100	30 – 1050	$600 - 1 \times 10^4$
Lateritic Soil	----	----	----	120 – 750	----
Gravel	$600 - 10^4$	100 – 1400	20 – 7000	100 – 1400	$600 - 1 \times 10^4$
Mudstone	----	----	----	20 – 120	----
Siltstone	----	----	----	20 – 150	----
Limestone	80 – 6000	$50 - 10^6$	----	----	$100 - 1 \times 10^6$
Shale	20 – 2000	----	3 – 200	$20 - 2 \times 10^3$	----
Sandstone	10 – 5000	$1 - 7.4 \times 10^8$	10 – 700	200 – 5000	$100 - 1 \times 10^3$
Granite	$5000 - 10^6$	$100 - 10^6$	300 – 40000	$3 \times 10^2 - 10^6$	----

Table 3. Resistivity ranges for some rocks (Loke 2002; Gibson and George 2003; Society of Exploration Geophysicist of Japan (SEGJ) 2004; Advanced Geosciences Incorporated (AGI) 2008).

During acquisition, 34 ERT profiles with a total length of 24,787.5 m and 2 VLF-RMT profiles with a total length of 2 km were measured (Figure 15.). With the help of the measurements, it was possible to define the topography of the oldest sedimentary complex, the spatial extent and thickness of the fluvial sediments, and the "hydraulic windows" in the pallah, as well as mine chambers that were not filled with water could be detected on the sections measured above the mine. The research depth was 100 m.

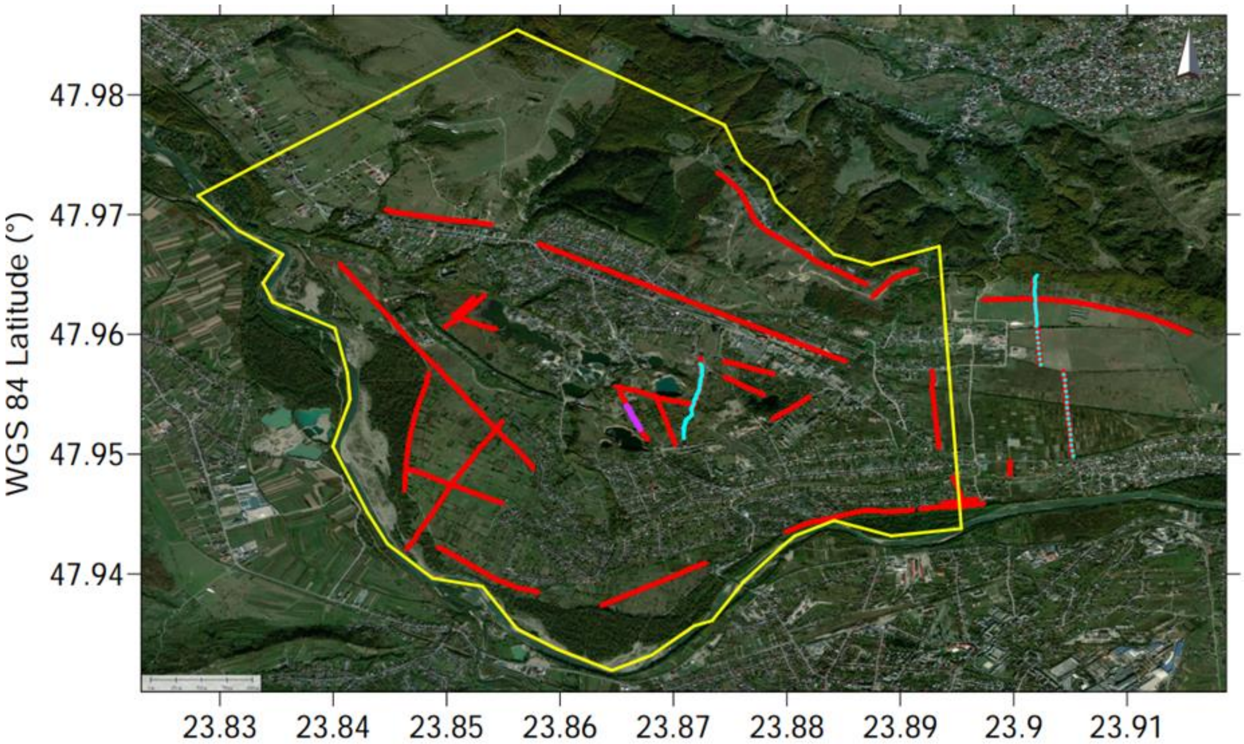


Figure 15. Overview map of the area with the survey lines. Yellow polygon represents the area of interest. Red, blue and cyan lines represent ERT, HLEM and VLF-RMT measurements.

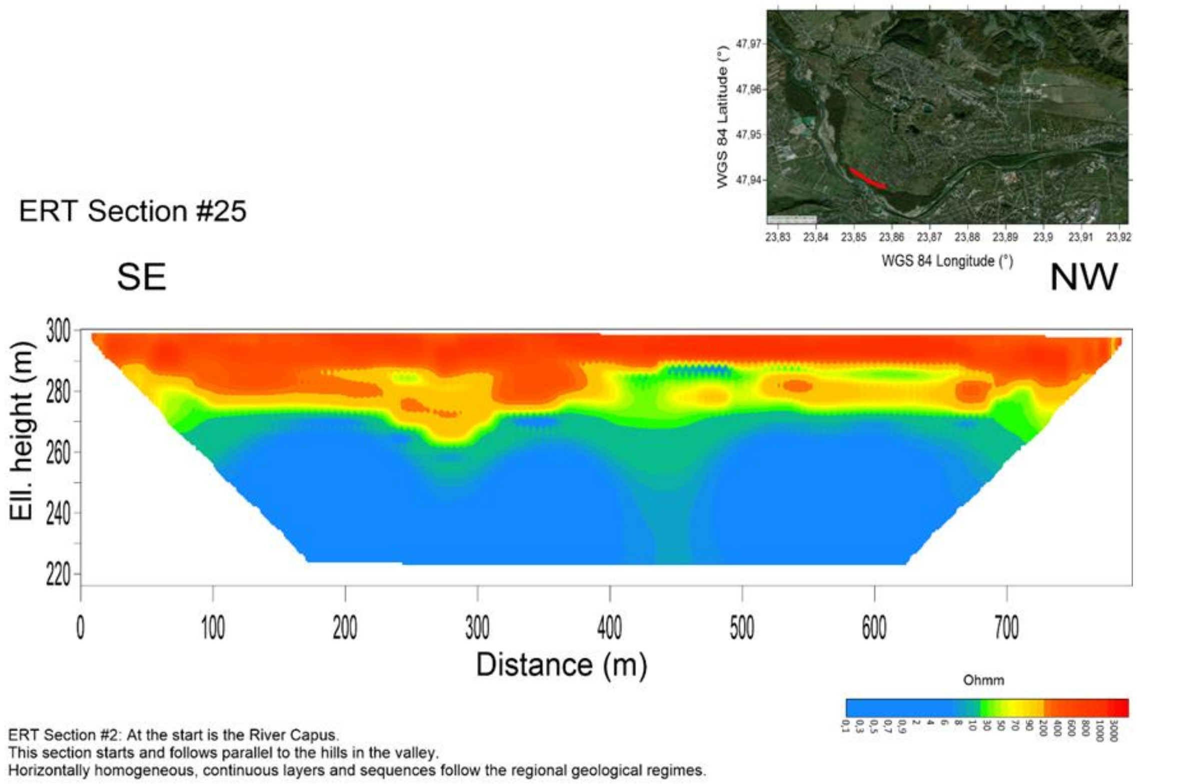


Figure 16 The distribution of specific electrical resistivity along the ERT-25 profile, situated in the 's floodplain.

The geological interpretation of the measured geophysical profiles will be detailed in chapter 3.3.2.

Along the geoelectric profiles measured in the Tisza floodplain, three resistivity ranges usually appear (Figure 16): a very high one (500-700 Ohms) in the upper 20 m, a slightly lower one (30-100 Ohms) down to a depth of 40 m and in a depth of nearly 100 m, very low resistivity values are displayed. Knowing the approximate local geologic conditions, this can be interpreted as the fact that in the upper third of the section there are coarse-grained fluvial sediments characterized by high resistivities (gravel, cobble graduating into sand), while below this there are clayey deposites characterized by low resistivities, probably the older sedimentary complex.

On the sections measured around the salt mine (Figure 17), a very low resistance range (1-10 Ohmm) appears under a layer of varying thickness of 5-15 m, with a high resistance (90-200 Ohm), in which there are angular spots characterized by very high values (4000-5000 Ohm). In these cases, low resistivity values may indicate saline-clay layers, and high resistivities included in this may indicate the presence of voids (mine galleries).

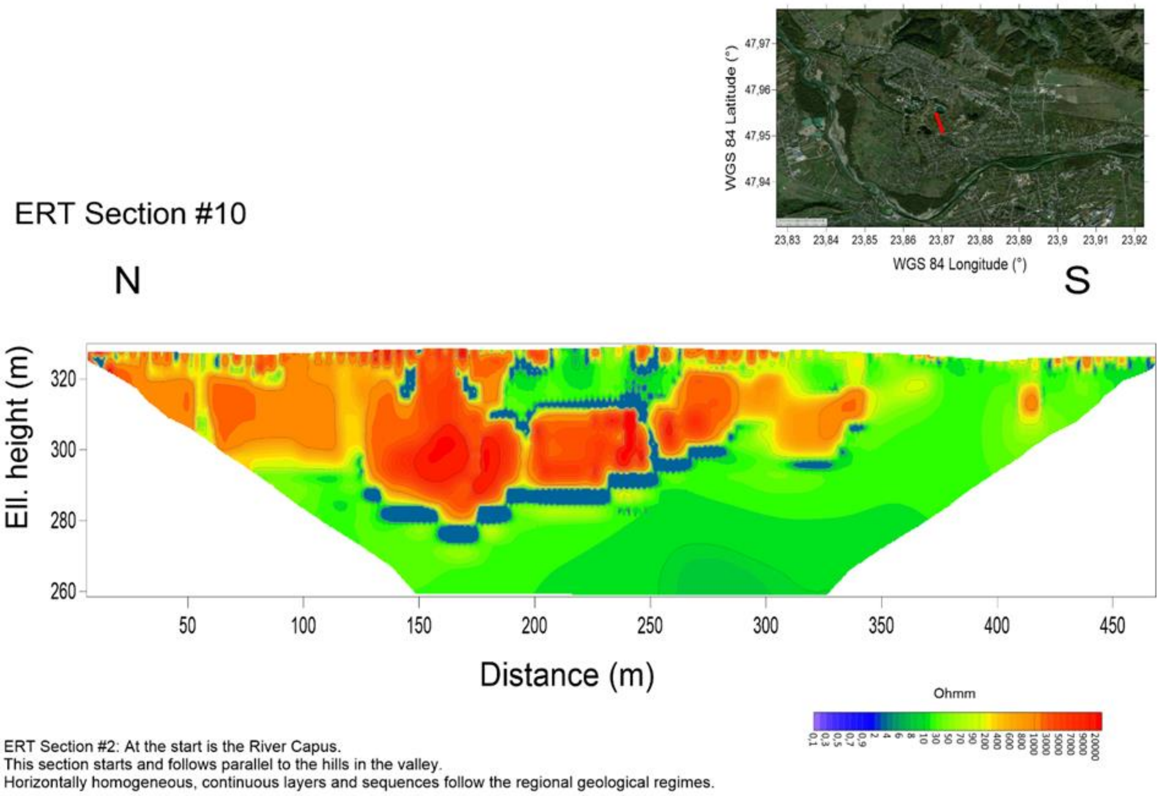


Figure 17 The distribution of specific electrical resistivity along the ERT-10 profile, situated in the salt mine area

Two main resistance ranges usually appear along the sections measured perpendicular to Mount Magura (Figure 18): a higher one (150-250 Ohms) at the foot of the mountain, a lower one (25-100 Ohms) on the higher terrains. The coarse-grained sediments characterized by higher resistance values (Tisza alluvium, gravel sands) are wedged out of the clay marl and tuff complex that builds the mountain.

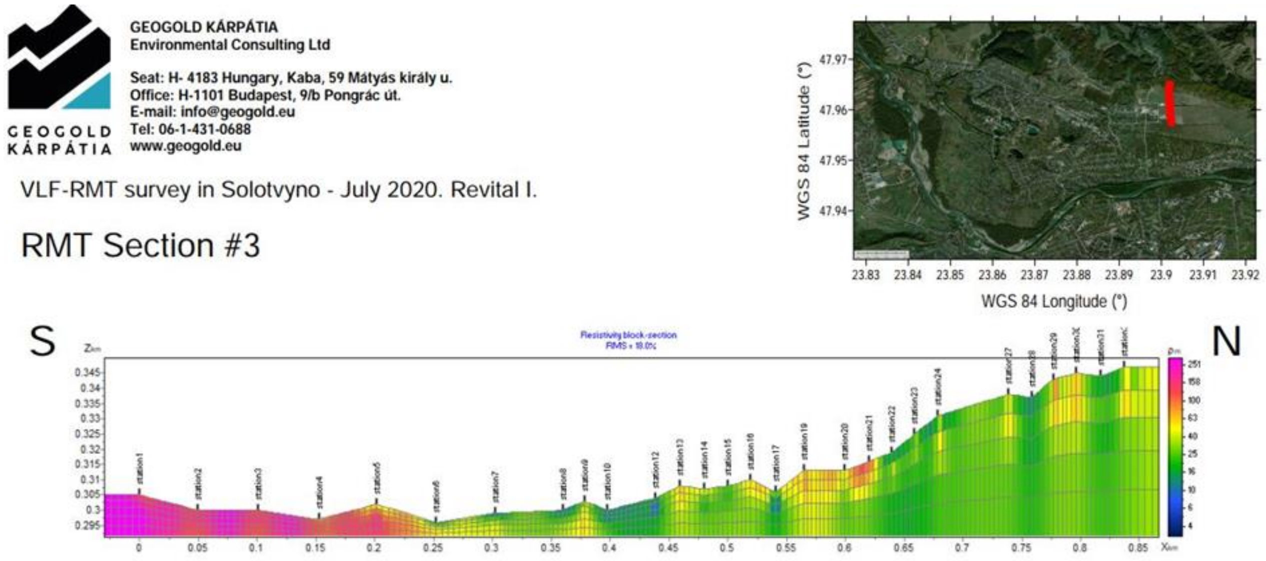


Figure 18. The distribution of specific electrical resistivity along the RMT-3 profile, situated in the piedmont area of the Magura-mountain

In the resistivity profile measured in Romanian part, parallel with River (Figure 19) the continuous upper 4 m is the artificial dike structure, it is well distinguishable from the underlying layer with significantly higher resistivity values (400-600 Ohmm). This unit is interpreted as the gravel terrace, correspondingly with the sections of the Ukrainian side. Below the gravel terrace a few metres are composed of more sandy deposits graduating into clay. The lower 5-10m of the profile shows low resistivity values (5-10 Ohmm), correspondingly with other sections of the riverbed it is interpreted as clayey deposit, characterising the profile down to 100m.

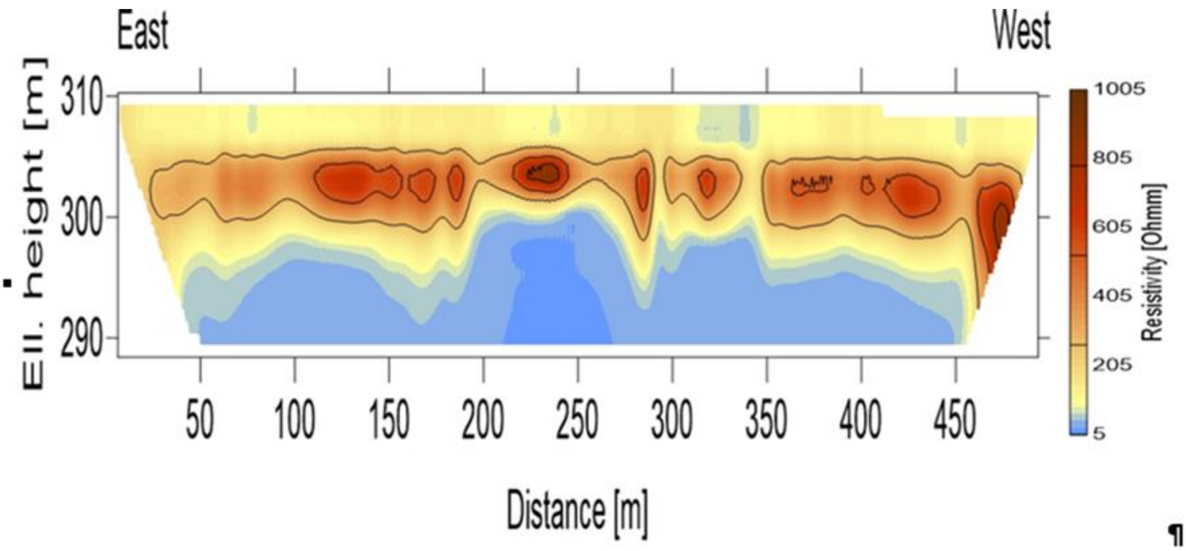


Figure 19. The distribution of specific electrical resistivity along the ERT profile from Sighetu Marmaţiei

3.3.2 Geological survey

The Neogene molasse-filled Transcarpathian Basin lies between the arc of the Carpathians and the Pannonian Basin. It is separated from the Folded Carpathians and the Pannonian Basin by NW-SE trending major structural lines. The depression is divided into smaller structural units by NE-SW trending fault systems. The boundaries of the depression can be defined by the Pieniny Klippen Belt, the Peripannonian structural line (Merlics – Szpitovszkaja, 1965), and the Hernád fault line to the Solotvyno fault line.

The Central Zone of the Transcarpathian Basin (Chop-Mukachevo Plain-, and Sighetu-Marmatini (Solotvyno)-basins) is the largest structural unit of the depression. It consists of brachyanticlinals, eroding salt diapirs (Solotvyno, Husztsófalva-Talaborfalva), cryptodiapirs (Beregkisalmás, Ilosva, Técső, Husztköz, Kökényes) and magmatic intrusions (Nagydobrony, Verbőc) (Sakin, 1976; Glusko – Kruglov, 1986; Lozinjak – Miszjura, 2010). The local Miocene sedimentary sequence consists of sandstones and mudstones overlain by volcanic tuffs and rests on the Ukrainian Precambrian shield of volcanic and metamorphic rocks. The rock salt is mostly white with grey clay layers containing gypsum-anhydrites (Hryniv et al., 2007). The salt crystallized as a fluid structure halite due to metamorphism. The river terraces testify to the Neogene (23-2.5 million years ago) uplift that covers the surface of the salt dome. The engineering properties of the overlying sediments (high permeability) affect the natural salt karst.

The Solotvyno rock salt deposit is in a subducted block in the south-southwestern extension of the Dibrovskaya and Solotvyno anticlines in the central zone of the Transcharpatian Basin. According to the nature of the structure, the supra salt plain is close to the brachyanticlinal fold with a salt core. The thickness of salt in the anticlinal core is approx 2000 m. The Solotvyno salt dome (Bosevs'ka and Hruscsov, 2011) is of remarkable size, with a surface area of approximately 1 million m2. It is elongated and pear-shaped, oriented in a northwest-southeast direction. The greatest depth of the salt body is about 2 km, while its width varies between 200 and 800 m at the westernmost and easternmost parts (Figure 20, Figure 21).

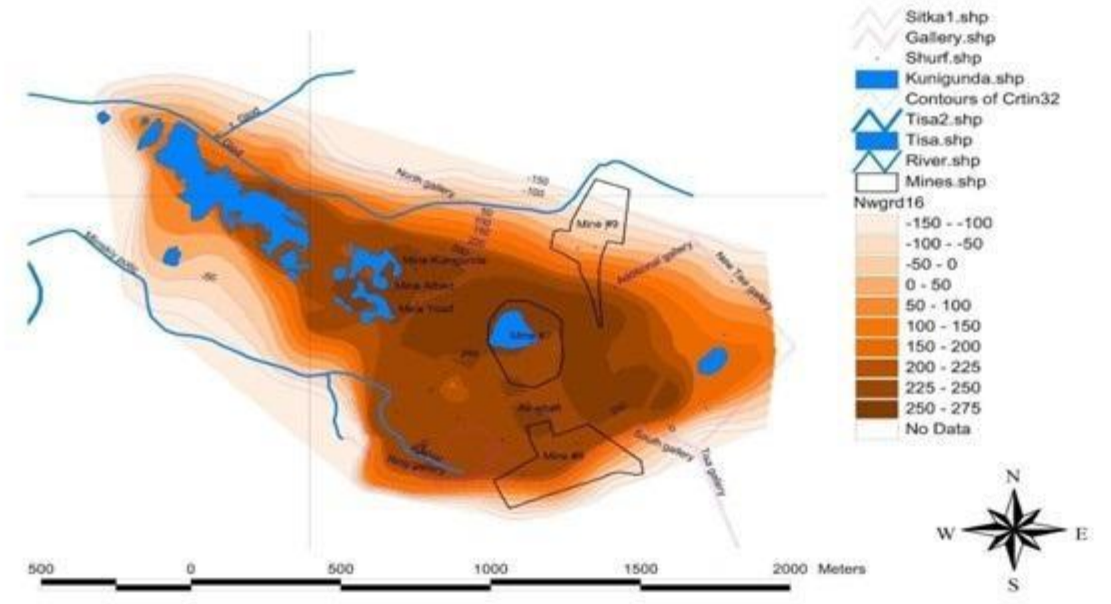


Figure 20 Map on the extent of the salt dome with lakes (fresh and salt), creeks, dewatering galleries (double lines light purple colour), and mines according to ABSL

Courtesy of the Institute of Geological Sciences of the NAS, Ukraine (From the article 'Lithological model of the Solotvyno Salt Dome Structure suprasalt complex', S.B.Shekhunovaet al., 2021, Collection of Scientific Works of the Institute of Geological Sciences NAS of Ukraine, vol. 14. https//doi.org/10.30836/igs.2522-9753.2021.245822)

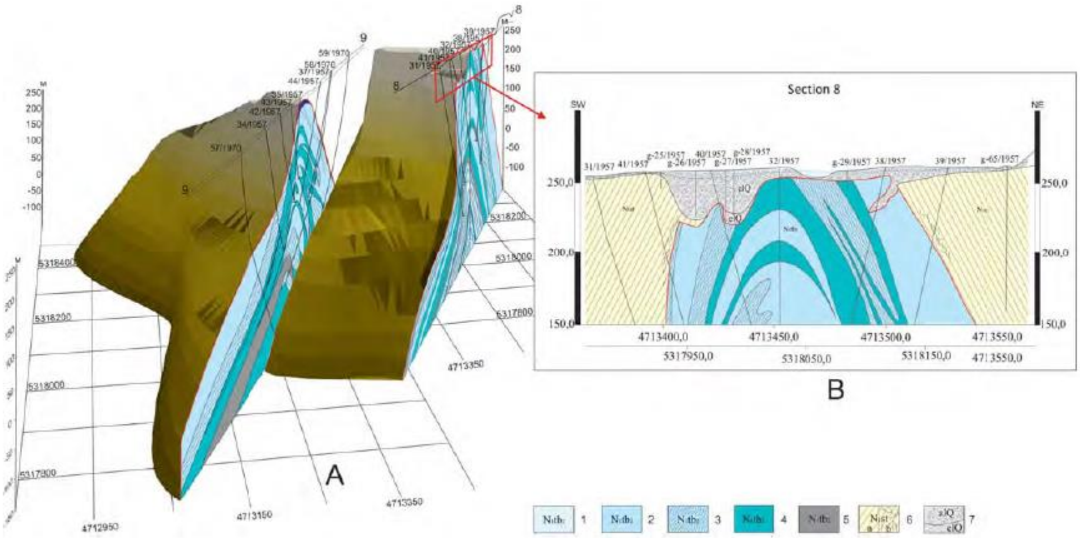


Figure 21 Lithological cross-section on the internal structure of the Solotvyno salt-dome with different salt content layers.

Legend: 1) white rock salt NaCl>= 98.2%, 2) white and light grey rock salt NaCl>=97.5%, 3) light grey and grey rock salt NaCl>=97%, 4) grey rock salt NaCl<97%, 5) clay and mudstone (A part), 6) mudstone, sandstone and tuff, 7) Quaternary sediments and below salt-clay (palah)

Courtesy of the Institute of Geological Sciences of the NAS, Ukraine (From the article 'The integrated geological model of Solotvyno structure as a tool to assess geoecological sustainability of Solotvyno rock-salt deposit', S.B. Shekhunova et al., 2015,Collection of Scientific Works of the Institute of Geological Sciences NAS of Ukraine, vol. 8, 233-250. https://doi.org/10.30836/igs.2522-9753.2015.146791)

Originally, the karstified salt dome was a genetically covered karst body protected from any contamination. The presence of impurities results in characteristic karst processes (both the formation of cavities and swallow holes) in the salt. The clay-rich salt residue, if not damaged, forms a natural protective layer called "palag" or "pallah" in some places, and the different forms of crystallization affect the geomechanical properties of the salt.

During the centuries, due to the salt rock excavation made first on the surface, and later, due to the development of mining and borehole techniques to the deeper ways, the protecting layers (palah) partly destroyed and disappeared. Because of these activities, the surface of the salt dome became open, contacting directly with the air humidity and precipitation, moreover

is closer contact with the flowing surface and shallow groundwater, too, and the salt karstification processing has started here. Sinkholes, dolines, craters, and finally the disruption of the mines have been coming into play, and all these phenomena are the consequences of the salt dissolving.

After finalisation the processing of the geological data and assessment of the geophysical measurements and information it has become clear, that **the alluvial terraces of the Tisza River covering each other reached the slopes of the Magura Mountains, moreover they also covered the relatively higher positioned salt dome but not as thick way like other places.**

In the West and South-west part of the area is a large alluvial floodplain (Figure 22) with all significant elements: clay, sand, and coarse-grained gravel. The thickness of the gravel terrace is gradually changing with respect to the distance from the river (Figure 23). This can be noticed also in the East parts and South-east part of the area.

On the Magura, the clay and sand layers are very heterogeneous with some gravel parts, but mainly the clay formations are significant. At the bottom of the Magura the first aquitard layer can be identified that has significance in the area's surface waters. In the mine area the pallah (shallow marine environment salty clay) is present with indicators of salt (Figure 24).

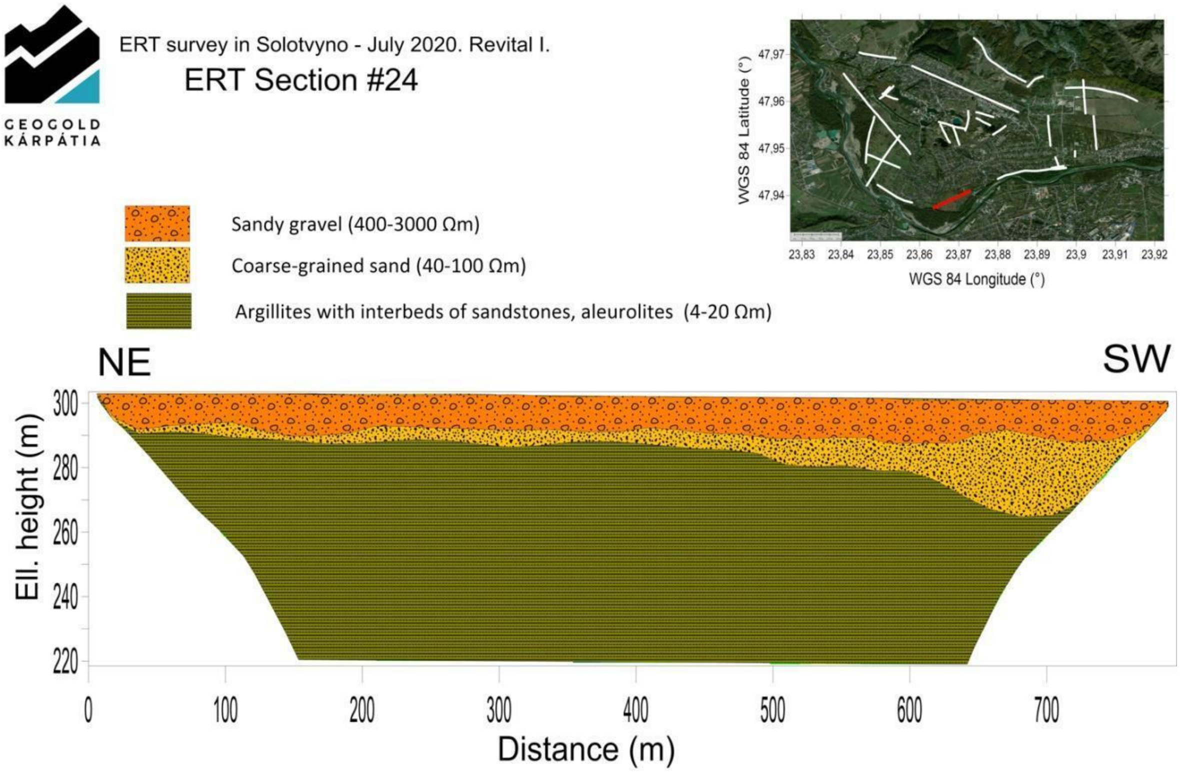


Figure 22 Alluvial floodplain in geological cross section

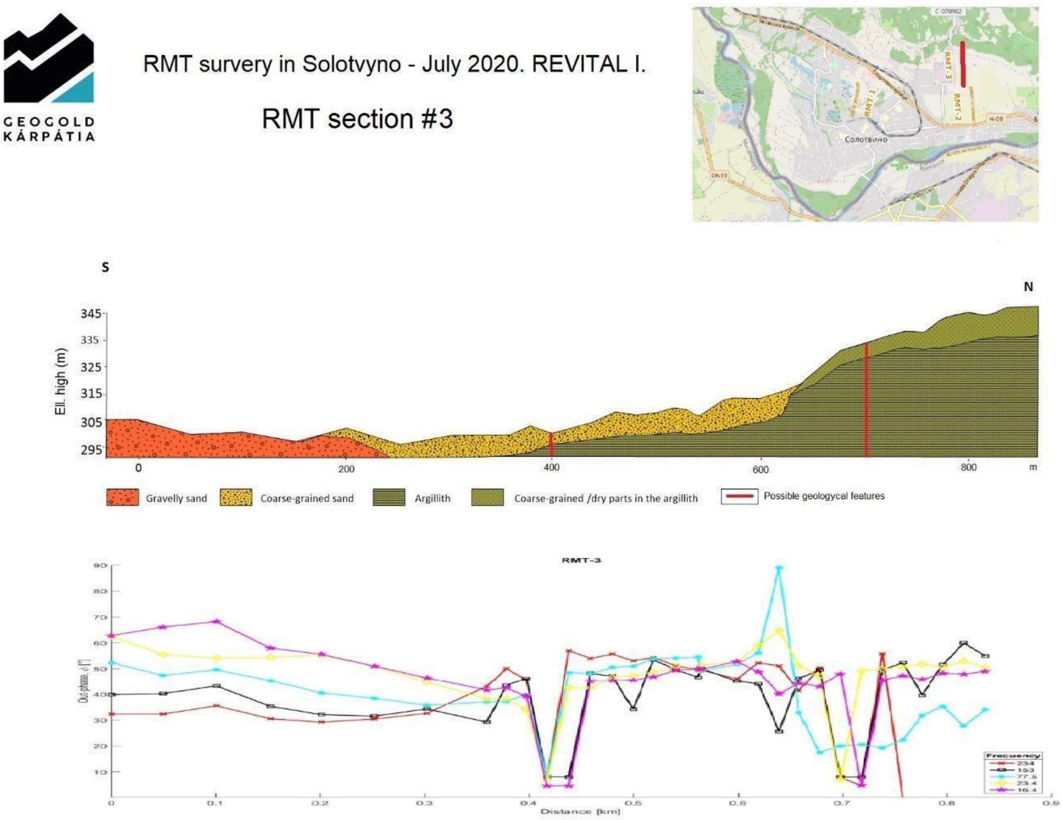


Figure 23. Geological cross section where the alluvial deposits thinning near Magura mountain

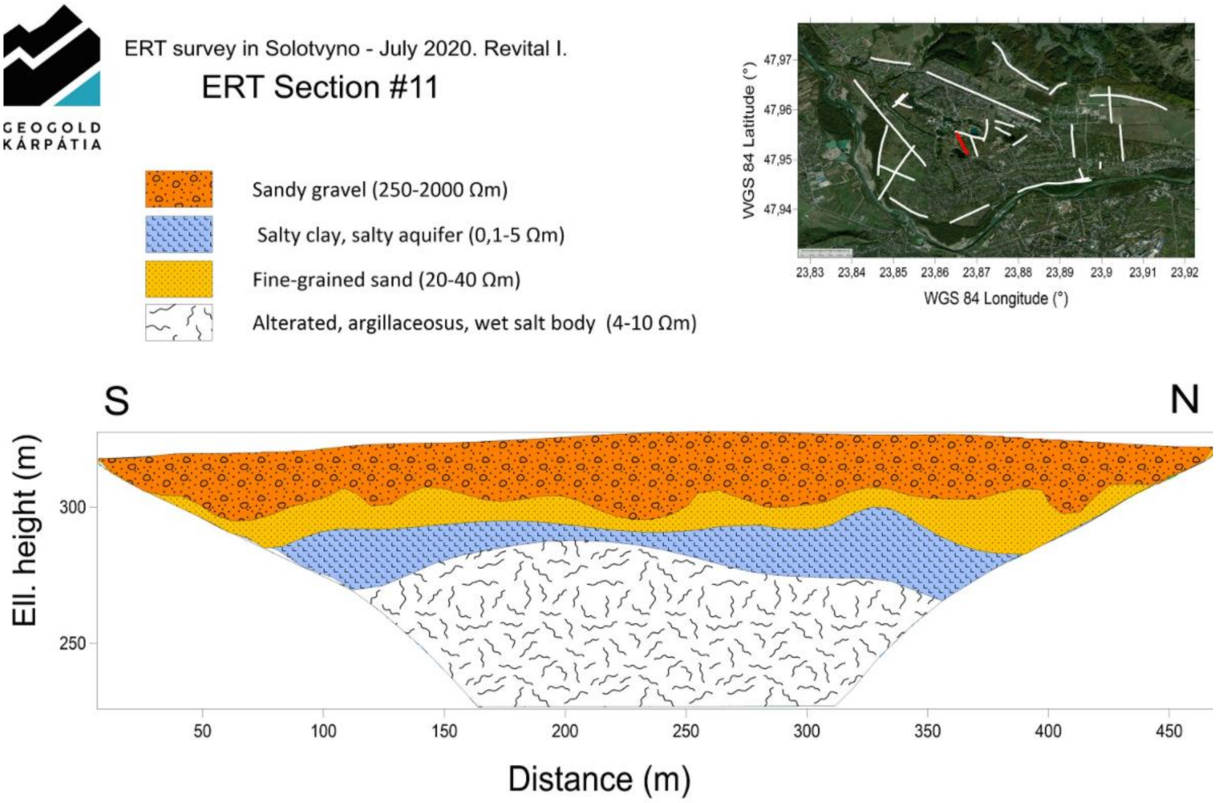


Figure 24 Cross section above the mining area, represents pallah and salty complex

Based on archive geological, geophysical, and borehole data the alluvial surface model has been done in 3D (see Figure 25), and the salt dome has been also done in 3D under surface (see Figure 26). The 3D surface model created for the project can be run in any modern web browser. In this way, the model is easier to share and use because it does not require any special software on the computer, and most currently used operating systems (Windows, OSX, Linux) and devices (PCs, tablets, phones) can display it. In this case, online access is provided, but the model can also be run without an internet connection.

For optimal use, a personal computer with an up-to-date browser installed (e.g., Microsoft Edge, Google Chrome, Mozilla Firefox, Opera) and an internet connection is required. The model is stored and shared on GeoGold Ltd. WebGIS server (https://www.geogoldmap.tk/). To access it, the user must have login credentials (username: geogoldvendeg; password: vendeg1234), and then the 3D model can be invited through the map interface.

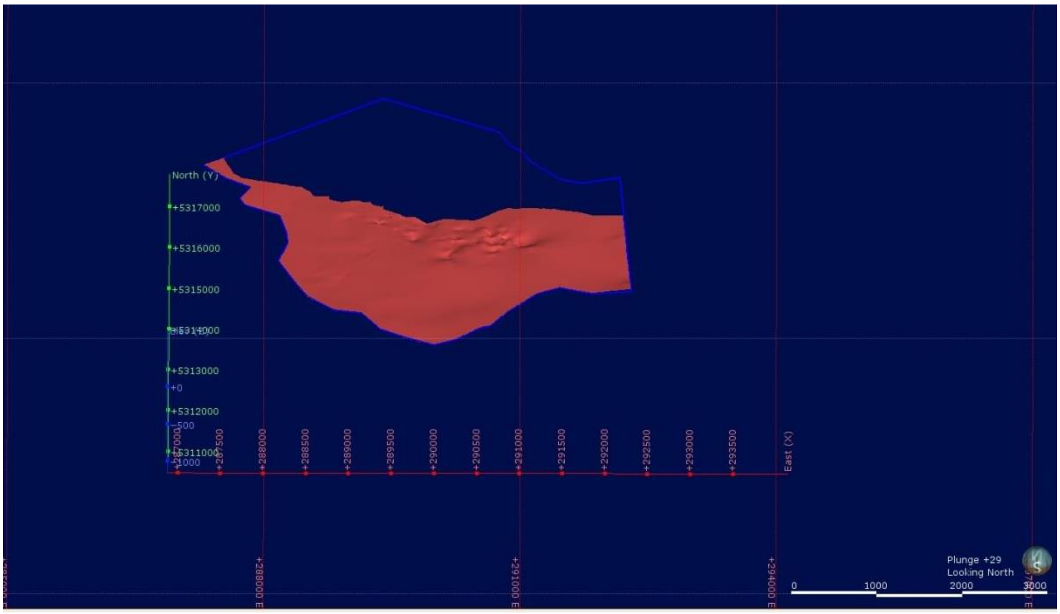
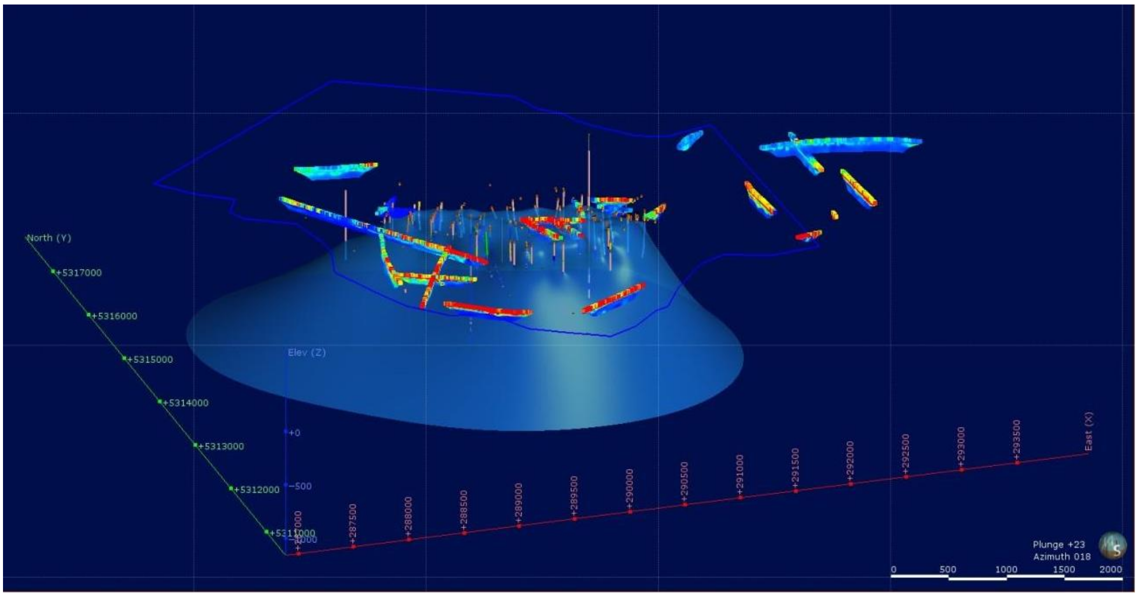


Figure 25

3D alluvial surface model of Solotvyno and its surrounding area (Tisza River is lining the southern borderline of the model). Craters and sinkholes are well visible at the former mining area *(Geogold Ltd)*



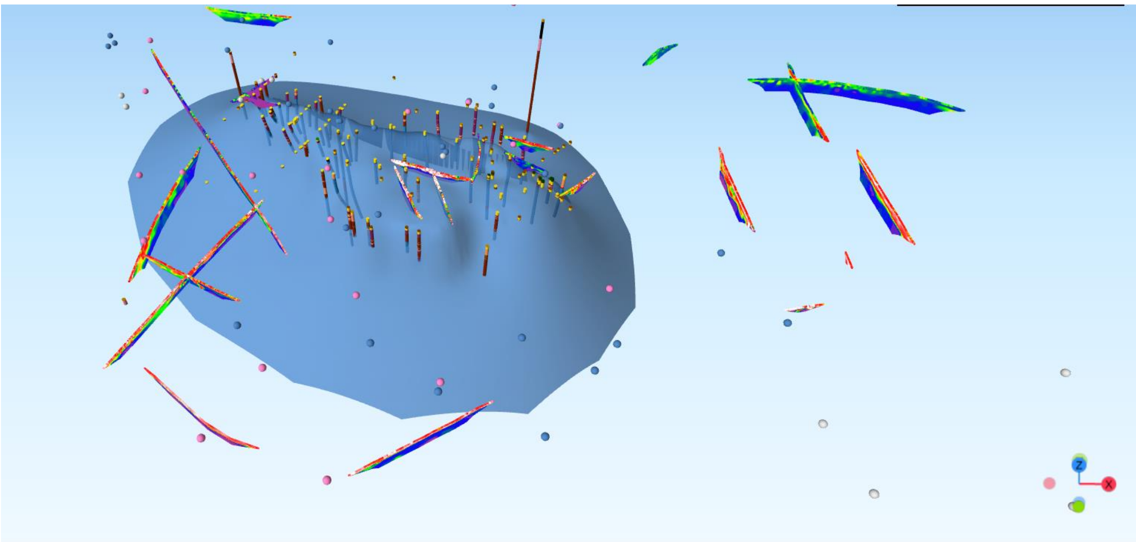


Figure 26

3D model of the salt dome with the path-lines of the geophysical measurements, and boreholes *(GeoGold Ltd)*

3.3.3 The effects of the salt-mining to geology of the area

The problems of the mining activity, which has been operating for hundreds of years, mainly started in the 60s and 70s. As the volume of salt extraction increased from 0.5 million tons per year to 1 million tons per year using explosives in deep mines, the amount and speed of harmful phenomena also increased. **Forced blasting extraction also increased the number of environmental disasters, the causes of which can be classified into three main groups.**

1) **Disruption of the natural water-tight layer near the surface (a layer of salty clay a few meters thick below the Quaternary cobble-gravel-sand alluvial sediment layer, locally known as 'palah') because of mining activity and research drillings.**
2) **Complete lack of maintenance of the drainage gallery system (the dewatering system at an average depth of 30 m, which surrounds the cultivated mine area and aims to drain the groundwater of the Quaternary cobble-gravel- sand layer near the surface, located above the 'palah' layer that provides the natural protection of the salt dome) created about a hundred years ago. The absence of gallery and dewatering**

management started in the 70s, continuing with the incorrect handling of the resulting problems and the lack of further prevention.

3) **Use of improperly performed and forced blasting procedures to increase salt production.**

Consequences:

a) Water intrusions into mines

b) Formation of cracks and mine lakes that penetrate to the surface

c) Detectable annual ground level subsidence of 1-2.5 cm/year

3.4 Hydrogeological measurements

The continuous dissolution of the Solotvyno salt dome is influenced by the replenishment of fresh water, the amount and intensity of precipitation (especially the accumulation of winter precipitation), the flow of natural waters coming from the direction of the Magura mountain range, as well as anthropogenic effects, mainly water withdrawals and wastewater introductions.

The salt dome in a prominent position divides geomorphologically the region into two, from the salt dome to the Magura Mountains to the North, and from the salt dome to the Tisza to the South. The slope from the Magura Mountains to the mine area is 5-7.5%, so the rainwater flowing from here attacks the mining area. The resolution of protecting against water was a gallery dewatering system, which was created more than a hundred years ago at an average depth of 30 m. The dewatering system, which was built several kilometres long, surrounding the cultivated mining area, has not been in operation for decades.

From the mining area to the Tisza, the terrain falls significantly from here it is only 1% on average. The leakage path of the saltwater leaking from the mine is thus significantly longer (2-4 years) despite the very good water-conducting capabilities of the Quaternary alluvium (Tisza floodplains) (k^{-}=100-200 m/d), - excluding the immediate impact of shock waves following mine collapses on the Tisza, as it was result in chapter 3.6 (Hydrogeologycal measurements).

Collapsed mines, through this long leakage path, burden the Tisza in smaller quantities, but constantly, the salt load of which is, at the same time, significantly increased by the introduction of the used salty water of the salt lakes operated for the purpose of tourism into the Tisza, concentrated through the Glod and Izvor stream and other artificially created drainage ditches.

The Black Moor, located near mines 8 and 9, occupies a special position in the region. This is a 'so-called' "crater lake" with a large surface area filled with water, the water of which, based on temperature measurements, is partially continuously filled with fresh water, and partially filled with salt-mineralized water through some contact with the salt rock, and which shows an increasing value towards the depth of the lake (see Figure 27).

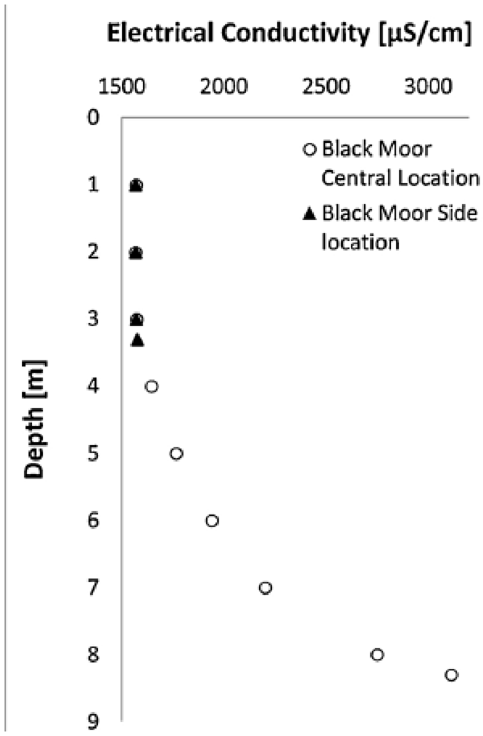


Figure 27

The E(lectrical) C(onductivity) profile measured near the water surface of the Black Moor and at the bottom of the crater lake in 2016 (The UX-1 robot also measured this between 150-470 m in the Shaft 10 in 2021) *(from the Article 'The hydrogeological situation after salt-mine collapses at Solotvyno, Ukraine' L.Stöckl et al, 2020, Journal of Hydrology, vol. 30, 100701. pp. 1-16.* https://doi.org/10.1016/j.ejrh.2020.100701*)*

The Black Moor may have a hydraulic connection with the collapsed mines that cannot be directly detected and proven by measurements during the project, but there is a lot of indirect evidence of it. Thus, for example, some research drillings were previously carried out in or near the crater, which reached the salt dome and thus could cause a hydraulic "short circuit" between the thus opened mining area and the lake. In addition, the water intrusion in the Mine 9 was also at the extraction point closest to the Black Moor, in a shaft (anyway, Mine 9 had to be closed in 2008, together with the allergology hospital operating at a depth of around 300-350 m). According to residents (oral history), the lake emptied down twice (at the end of 2005 and in the spring of 2006) and then refilled up. During the emptying, the crater lake sank more than 10 m and thus the surface of the lake also increased. These draining events show that the Black Moor is affected by the continuous dewatering and the salt production events that were still taking place in Mines 8 and 9 at the time (e.g. continuous pump dewatering in the two still-operating mines, with which the inflow of water accelerated), could have come into contact with Mine 9 (closed in 2008 due to water intrusion) and Mine 8, which were still operating at the time. The latter (Mine 8) ruptured further and collapsed in 2007-08 because of further salt dissolution processes, and then it had to be abandoned in 2010.

Figure 28 Map of the studied salt dome area with lakes (fresh and salt), creeks, drainage system (GeoGold Ltd.)

That is why the crater created by the collapse of the Mine 8 is more spectacular, because the mine, which was opened in 1886, in accordance with the production habits of the time, was designed as a hall (larger or smaller but hall), and the top of it was only about 50-70 m from the surface. The water entering such a large hall(s), in the case of a hydraulic connection, could find big places, which could explain the sudden, and rapid suction, and discharge of the Black Moor.

Based on the archival mine maps collected from the Mine Directorate in Solotvyno, the farthest excavation chambers of the Mine 9 went under the Black Moor, and in the case of Mine 8, the most distant excavations also approached the crater-lake within 100 m (see Figure 28).

The water break-in of Mine 9 without creating a crater lake could only have happened because the more modern small-chamber excavation technique of the "Wieliczka" type (Wieliczka salt mine near Krakow, Poland) was used here and the excavations took place at a depth of 300-450 m. According to the robot-driven survey conducted by the University of Miskolc, the chamber branches at this depth completely collapsed and filled with water, without any visible consequences reaching the surface.

3.4.1 Shallow groundwater and the Tisza River survey

3.4.1.1 Examination of the flow of near-surface waters in area

During the project, a well-group consisting of 15 piezometer wells was established (wells marked MON), in which regular/continuous water level and water chemistry test measurements were carried out for a year. Private residential wells of similar depth (6-15 m) were also included in the measurements (a total of 8).

The tests based on the measurements also covered the detection of seasonal differences. Figure 29 clearly shows the broad N-S groundwater flow starting from the slope of the Magura Mountains, which suddenly changes direction and turns E-W when it reaches the former mining area. This is true for most of the flowing water, but a smaller part of the flowing water avoids the mine area and flows towards the Tisza, keeping its flow direction almost N-S.

The waters maintaining the E-W direction of flow pass through the ruined surface mine areas, there they locally distort the flow picture by entering under the ruined surface and then continuing the flow in the west direction towards the Tisza.

The flowing picture has **three results**:

1) **The MON piezometer wells have been well designated, serving as the basis for the future near-surface water monitoring network**
2) **it proved that the main regional flow direction of near-surface waters started from N and then changed to E-W**
3) **During the summer, low-water period, all flowing water goes to the Tisza.**

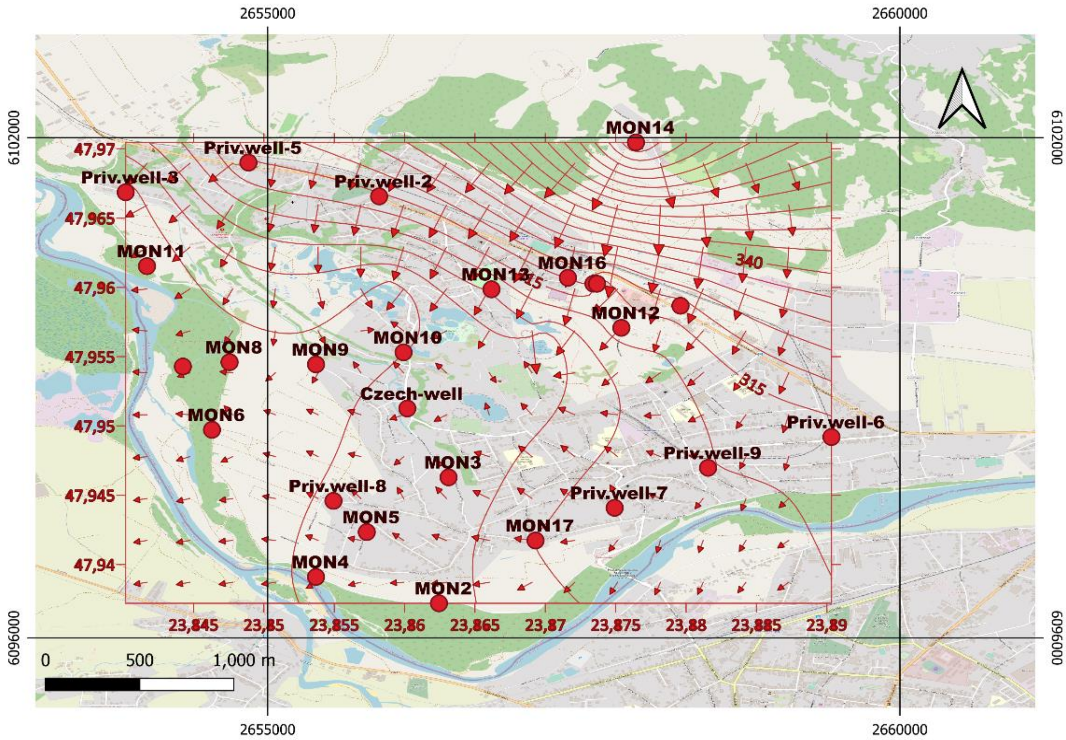


Figure 29 A map on the development of groundwater flow directions in the low-precipitation July of 2020 *(Geogold Ltd)*

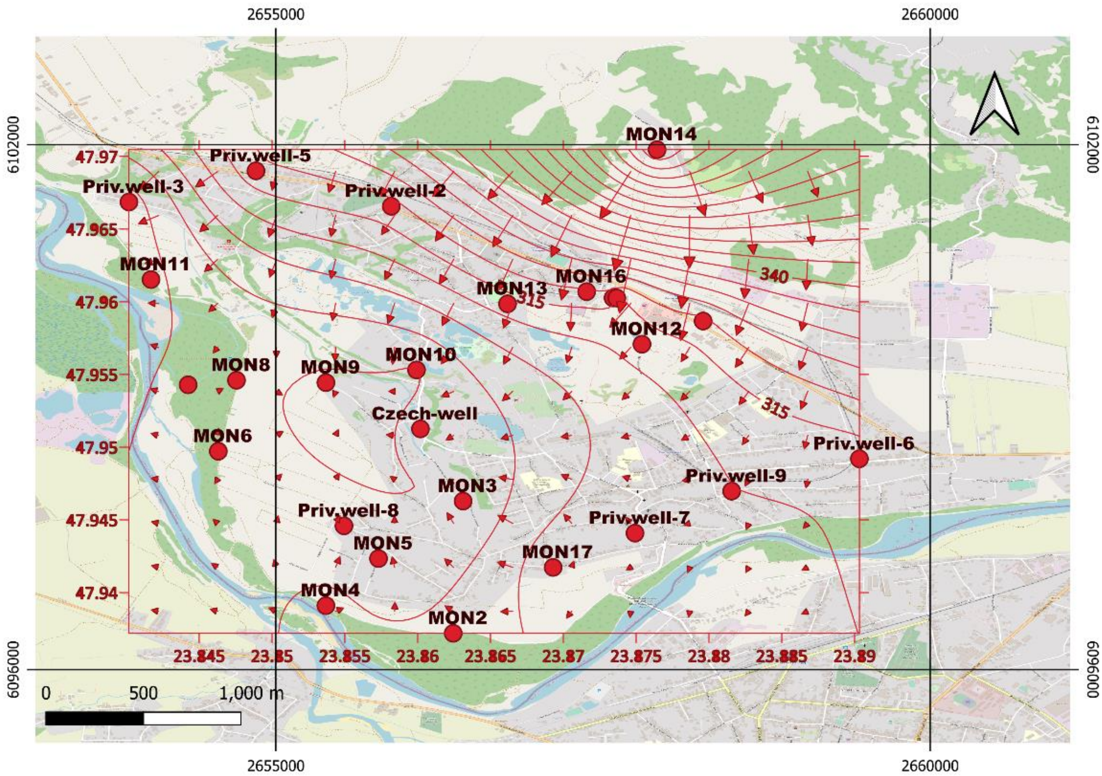


Figure 30 Groundwater flow map in February 2022 *(Geogold Ltd)*

The flow pattern changes slightly in the wintertime when it is more flooded. The main flow directions remain, but from the south-southwest direction of the Tisza, the flow pattern can be seen turning back toward the mine area. In other words, during the flood season, the former mining area is attacked by the mixture of near-surface waters pushed back by the Tisza and the waters of the Tisza (hyporheic zone) (see Figure 30).

The effect of the high-amplitude price wave descending on the Tisza was also investigated.

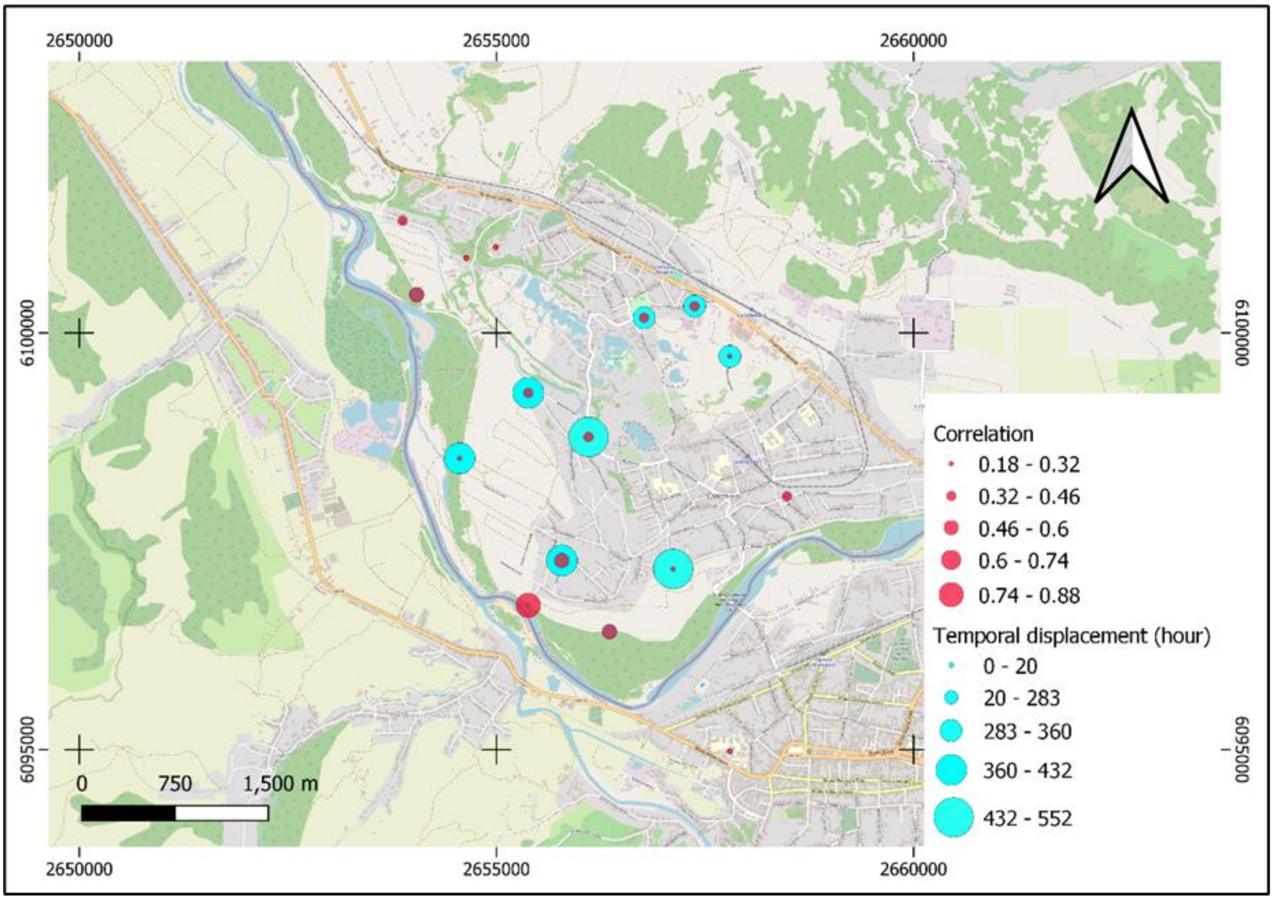


Figure 31 Connection between flood event in Tisza river and measured water level in wells

In summary, the results of the pressure wave tests carried out between 2021.06.2021 and 2022.05. show that the groundwater stored in the sediments along the Tisza is connected to the Tisza, even if the water level at the given observation point is higher than the nearest point on the Tisza. This may be since in the upper and higher stretches of the Tisza, water infiltrated in the bank sediments flows longitudinally along the river in a K-NW direction, and the propagation of the pressure wave is also seen at higher altitudes (including in 20-30m deep wells at the foot of the Magura). The specific value depends on the distance from the river and the geological structure.

The Tisza no longer has any influence on the water levels in the well Mon-14 on Mount Magura. At this observation point, the water level in the well (356.55mbf) is significantly higher than the Tisza water level (95 metres difference).

The effect of a high amplitude flood wave on the Tisza River was also investigated. From the time series of water levels sampled hourly during the flood event from 12.12.2021 to 02.02.2022, it can be deduced that the Tisza has a wide range of coastal areas under its influence, where pressure waves reach the observation points in a short time, depending on the geological structure.

The connection between wells is even closer than between river and groundwater monitoring points. This implies that some points in the groundwater aquifer, drained simultaneously in a short time after a flood event.

3.4.2 Chemical measurements (Black Moor, craters, shafts, alluvium connecting to the Tisza River)

Some basics regarding water chemistry parameters:
Typical EC values for natural waters:
rainwater: 50 µS/cm
river water: 200-300 µS/cm (e.g. non-saline sections of the Tisza River)
drinking water: 500-600 µS/cm
slightly salty water (mineralized freshwater): 1000 – 1800 µS/cm
seawater: 52 000 µS/cm (35 g/l salinity, mainly NaCl)
saturated salt water: 100 – 150 mS/cm (salinity above 50 g/l, saturation can be increased by raising the temperature)
fully saturated salt water: 230 – 250 mS/cm (max. 358g of salt can dissolve in 1l of freshwater)

A fully saturated salt solution means a salt solution of 26.4%, so the salt content of 1 l of fully saturated salt water (density 1358 g/l) is 264 g of salt.

The water chemistry processes taking place in the region were examined in several time planes to detect the change or the unchanged of the processes.

1) Measurements carried out in September 2016, during the EU Advisory Mission (published by L. Stöckl et al. 2020, Journal of Hydrology, Elsevier)
2) Tests measured by Geogold Ltd in 2020-21
3) Depth tests performed by the UX-1 robot of the University of Miskolc (in Shaft 10)

3.4.2.1 Examination of the Black Moor

The Black Moor, as mentioned at the beginning of the hydrogeological summary, played and plays a key role in the development of regional processes.

The EC values measured (see Figure 12,13) below the water surface (at a depth of -1 - -3m) of Black Moor (while each mine is in a higher topographic and hydraulic gradient position, at an average height of 309 m ABSL):

EC= 1550µS/cm (2016.09.) Stöckl et al.(2020)

EC= 1425µS/cm, Cl= 234mg/l (2020.06.) Geogold Ltd

EC= 1530µS/cm, Cl= 352mg/l (2021.11.) Geogold Ltd

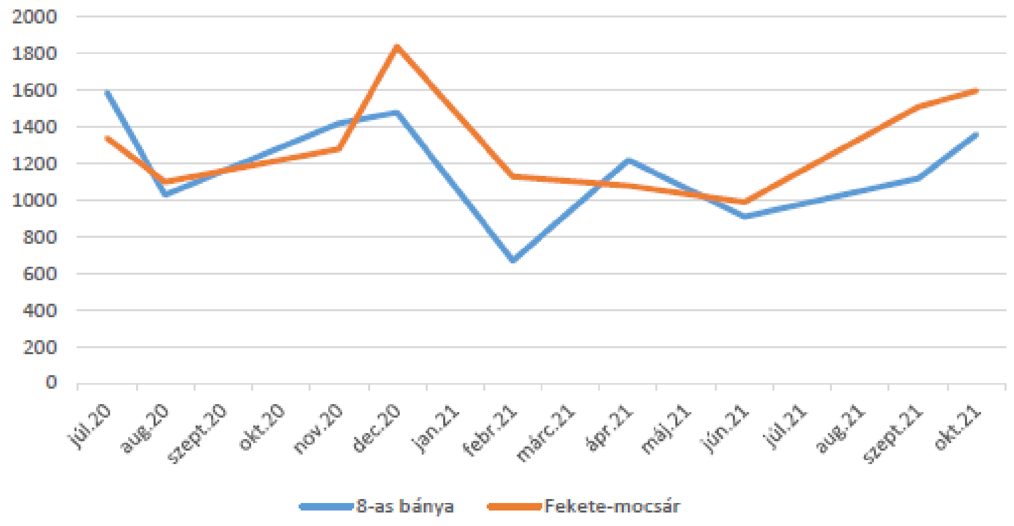


Figure 32 EC (µS/cm) values measured near the water surface in 2020 - 21 *(Geogold Ltd)*
Legend: Crater Lake of Mine 8(blue), Black Moor (orange)

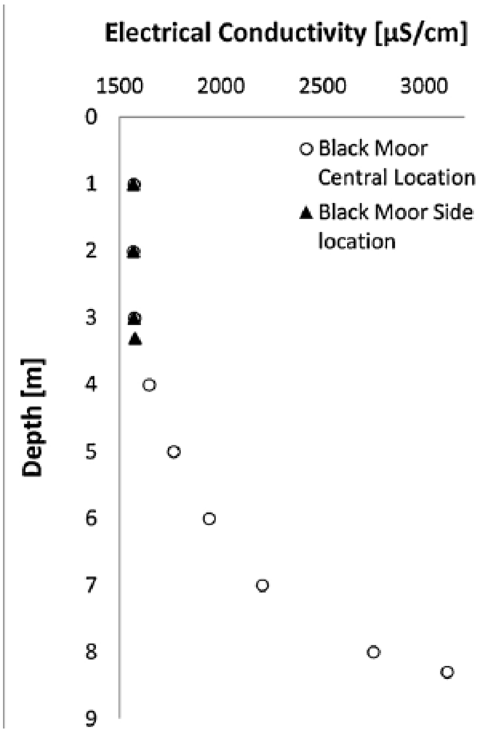


Figure 33 The EC profile measured near the water surface of the Black Moor and to the bottom of it in 2016 (*L.Stöckl et al, 2020, Journal of Hydrology)* The UX-1 robot also measured this between 150-470 m in Shaft 10 in 2021

The EC values measured near the surface of the Black Moor, therefore, agree with Stöckl's measurements (2016).

The EC values measured near the surface of the Black Moor- lake, therefore, seem to have practically not changed in 5 years. This apparently shows a state of equilibrium.

At the same time, the EC value measured at the deepest point of the Black Moor (at a depth of -8 m) is: EC= 3110 µS/cm *(09.2016) Stöckl et al.*

This value is the same as the average (3200 microS/cm) of the values measured by the UX-1 robot between 150 and 470 m in shaft 10. Based on this, **we can assume a hydraulic connection between the Black Moor - lake and Shaft 10 of Mine 9.** To prove this, water painting was also done, however, the dye injected on the surface of the lake (salt as a tracer was out of the question here, only fluorescents) has not yet appeared in Shaft 10, presumably due to the still (apparently motionless) and higher density salt water in the shaft. in the great depth between 150-470 m, and above.

3.4.2.2 Examination of crater lakes

The crater lakes were created because of the ruptures of the former mines. After the ruptures, they were filled with water within a short time, mostly from water that entered the mine (which later concentrated because of the salt solution), and to a lesser extent from the rain that flowed into it, as well as municipal wastewater.

Regarding the change and examination of the water quality of the crater lakes (created at the site of Mines 7 and 8), it is worth noting the following:

Different from freshwater, salt water (brine) is primarily stratified based on the difference in density.

Seawater has a density of 1.036 g/cm³ (corresponding to a 3.5% salt solution), if the salt solution has a density of 1.164 g/cm³ (corresponding to a 14% salt solution), the fully saturated salt solution (can't be more than that without residue dissolve) has a density of 1.360 g/cm³ (26.5% salt solution). This is the explanation of the fact that in Shaft 10, from about 150 m, the higher density salt water (EC= 2200-3200 µS/cm), - practically motionless -, and above it the lower density, less salty water, or almost freshwater is located, which, on the other hand, moves easily. This can be said for the EC data of most measuring points (above a drinking water type with EC = 500-600 µS/cm, a few meters or a couple of 10 m deeper a seawater type EC = 50-60 mS/cm, and below them, the saline solution is already saturated EC = 100 -250 mS/cm).

To reach saturation, fresh water needs a shorter or longer residence time in the saline medium; during this time, it carries out its salt-dissolving, salt-karstification/cavitation and thus destructive processes. The processes of salt karst formation slow down as they approach the saturation state, and due to the difference in density, this is gradually true for the deeper layers. On the other hand, the less dense waters flowing near the surface move easily and try to reach their equilibrium state, which in their case means a state close to saturation. This means continuous salting. In other words, **stabilised conditions have most likely occurred in the depths, the same is probably not true near the surface, and thus further surface movements are expected**. **However, their intensity will decrease asymptotically over time**, unless some sudden natural change occurs (e.g. extreme rainfall event, earthquake, etc.). But additional surface movement can be caused by unregulated salt water withdrawals from salt lakes formed above the broken mining areas, as well as significant leaks in water utility networks.

According to the literature, **Mine 7** was closed in 1953, and decades have passed since the subsequent crater formation. Since, of the last three mines, the lid of the salt dome is the closest here to the surface (some 10 m), **the water-filled crater lake** is in direct contact with the lid of the salt dome, and **thus the lake is completely saturated with salt and thus in a state of equilibrium.** This was already confirmed by the on-site measurements in 2016 (see Figure 34).

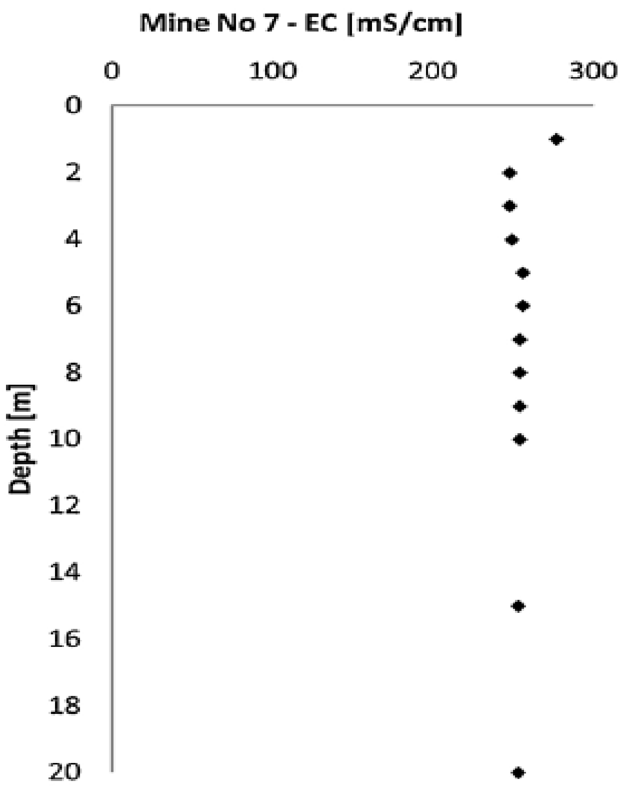


Figure 34

EC depth profile in the crater-lake of Mine 7 in 2016 *(Stöckl et al, 2020)*

In 2016, the EU Civil Protection Team's Advisory mission experts did not even risk the direct water chemistry test, instead, they sampled the Shaft of Mine 8. According to Figure 15, the water on the surface of the shaft has a salt concentration corresponding to seawater (EC= 50 – 60 mS/cm), then the salinity, after reaching the transition zone between the depth of 8 – 16 m, reaches the full EC= 250 – 270 mS/cm saturation state.

The water chemistry EC tests show that the crater lake formed at the site of Mine 8 has not yet reached its equilibrium state either from a static or water chemistry point of view. In addition, the crater - lake also receives a continuous water supply thanks to the residential wastewater inlets, so it is capable of further desalination.

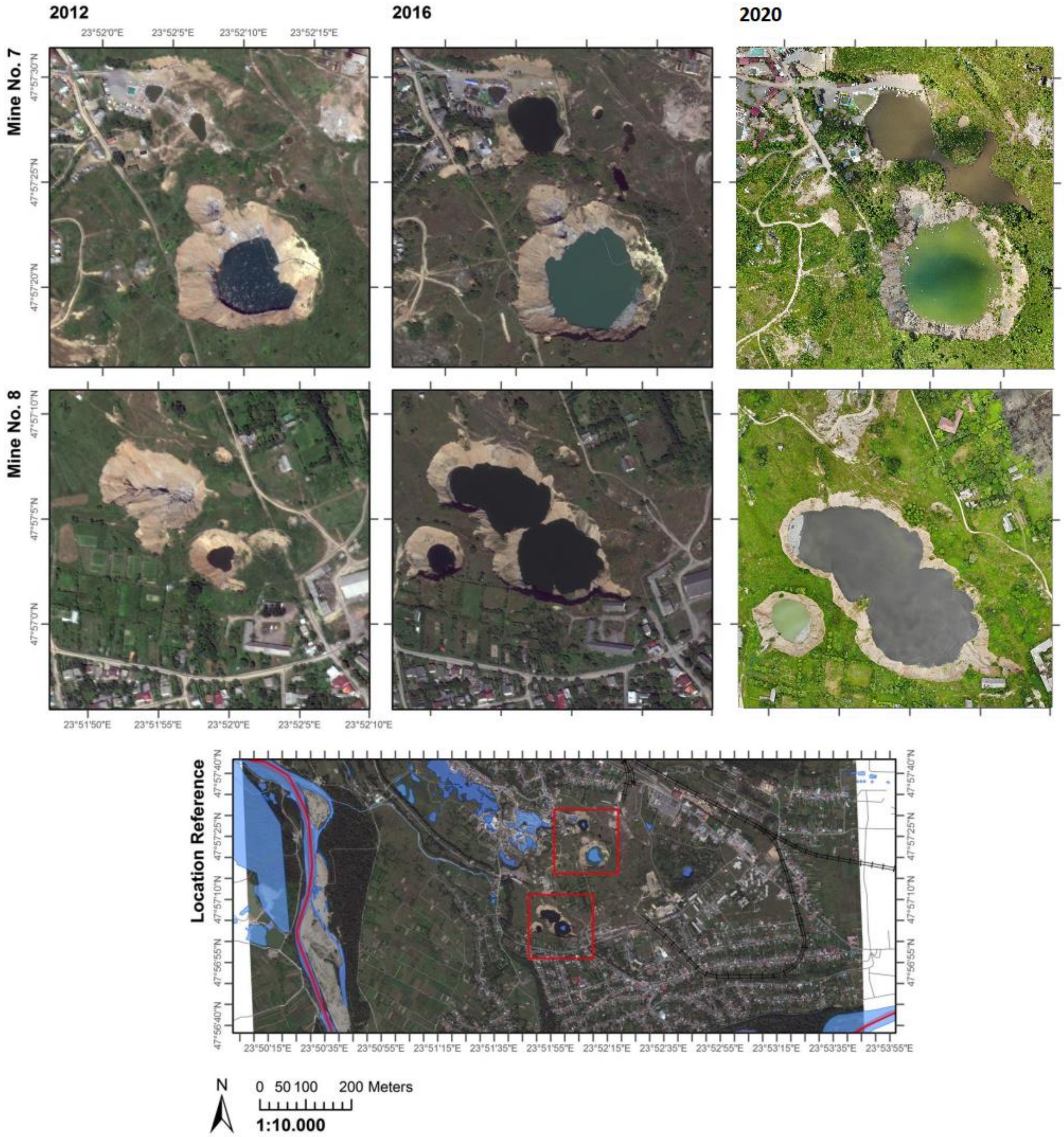


Figure 35 The evolution of the craters of Mine 7 and 8 rupture *(GeoGold Ltd. in Stöckl et al, 2020)*

3.4.2.3 Examination of mine shafts

Shaft 8

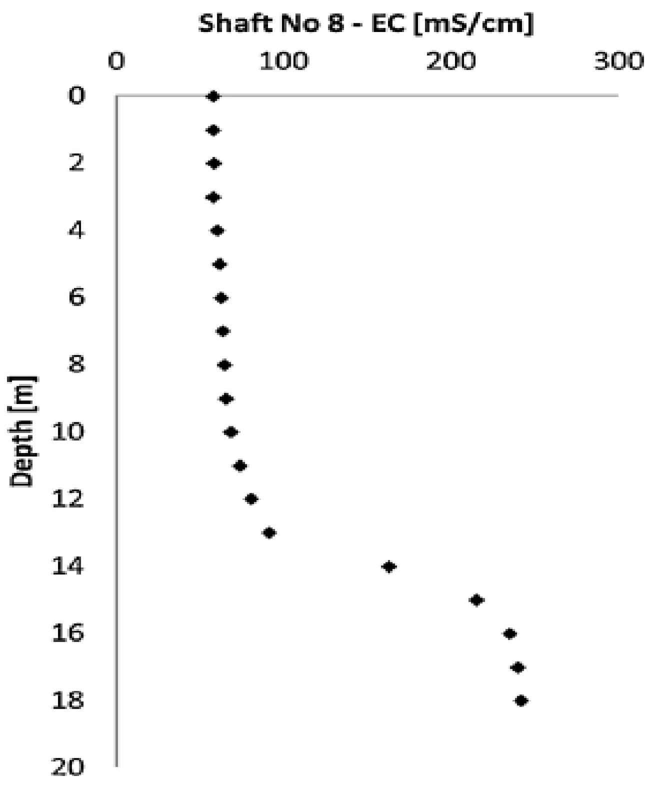


Figure 36 EC depth profile in Mine Shaft 8 in 2016 *(Stöckl et al, 2020)*

ShaftMine 8 shows the most spectacular and intense intrusions (see Figure 36).

It finally collapsed in 2010 and has been unstable, and difficult to access and measure ever since. Based on the conductivity measured on the crater -water surface, EC= 1280µS/cm, Cl= 262 mg/l (November 2021), it belongs to the category of slightly saltwater/mineralized freshwater based on Geogold's measurements.

Shaft 10

Currently, only the former transport shaft (Shaft 10) of Mine 9 (closed in 2008) can be measured along its entire length to a depth of 506 m. In 2016, the shaft of Mine 8, which could still be measured, also collapsed.

According to the EC measurement carried out in September 2016 up to about 200 m, it increases from EC=500 µS/cm to EC=650 µS/cm in the upper few metres, and then approx. Between 10 and 150 m, this value stabilises. At a depth of 198 m (this was the maximum depth at the time due to the short measurement cable), the EC increased to 2180 µS/cm (see Figure 37).

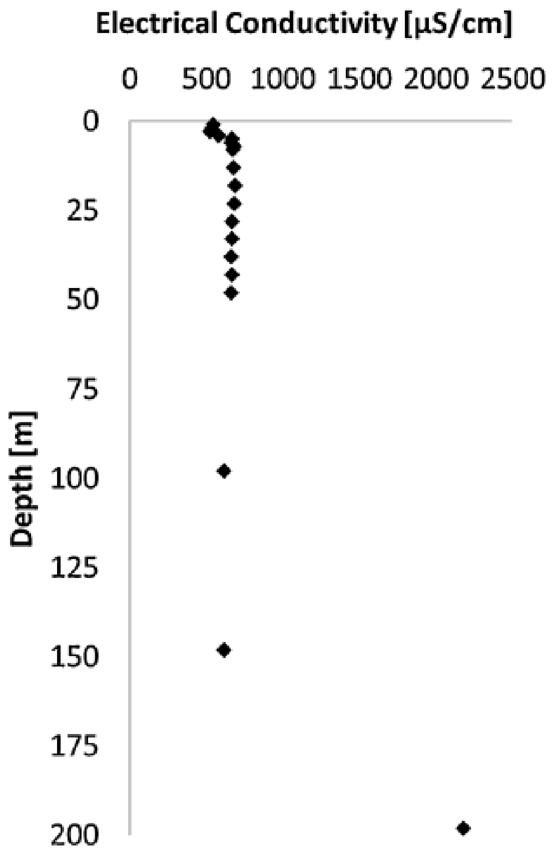


Figure 37 EC depth profile in transport Shaft 10 of Mine 9 in 2016 *(Stöckl et al, 2020)*

The 2016 EC measurements were rechecked, and the results were extended to the entire section of Shaft 10 by the UX-1 robot deployed in the late autumn of 2021. The remote-controlled floating device is also suitable for water quality measurements and water sampling, among other things. The EC profile taken by the robot confirmed the 2016 measurements and even extended the depth limit of the measurements below 500 m.

Based on the measurement profile, the electrical conductivity in the upper 10-130 m, the water layer of the shaft shows an almost constant value of EC=400-450 µS/cm (the measurements in 2016 showed a value of EC= 500-650 µS/cm). Between 130 -140 m, in the transition zone, a rapid increase in conductivity can be observed. From 140 m to a depth of 506 m, EC=3250 µS/cm is also almost constant (see Figure 38).

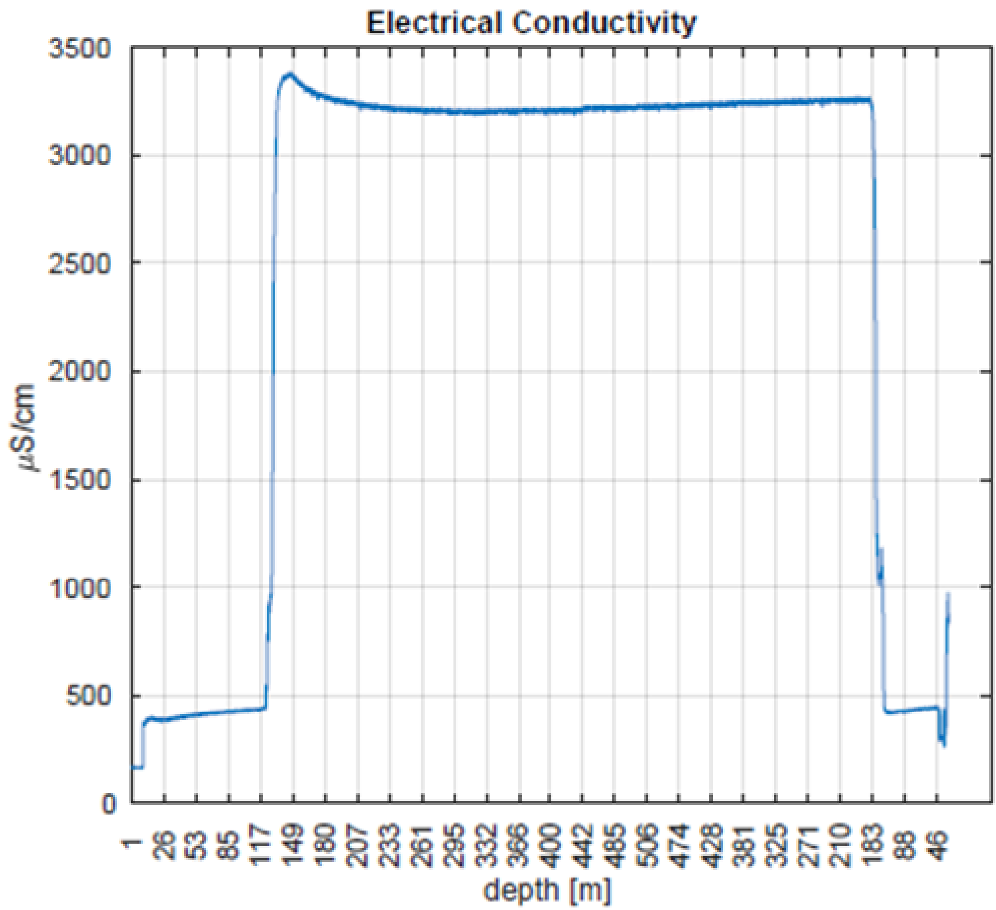


Figure 38

Evolution of the EC values along the entire length of Shaft 10 according to UX-1

(University of Miskolc)

The change in temperature profile values measured by the robot shows almost the same profile curve. In the upper section of Shaft 10, up to a depth of 130 m, the temperature is constant t= 8°C. In the transition zone between a depth of 130–150 m, the temperature shows a constant rise to 24°C and then remains unchanged until the bottom of the Shaft 10(506 m) (see Figure 39).

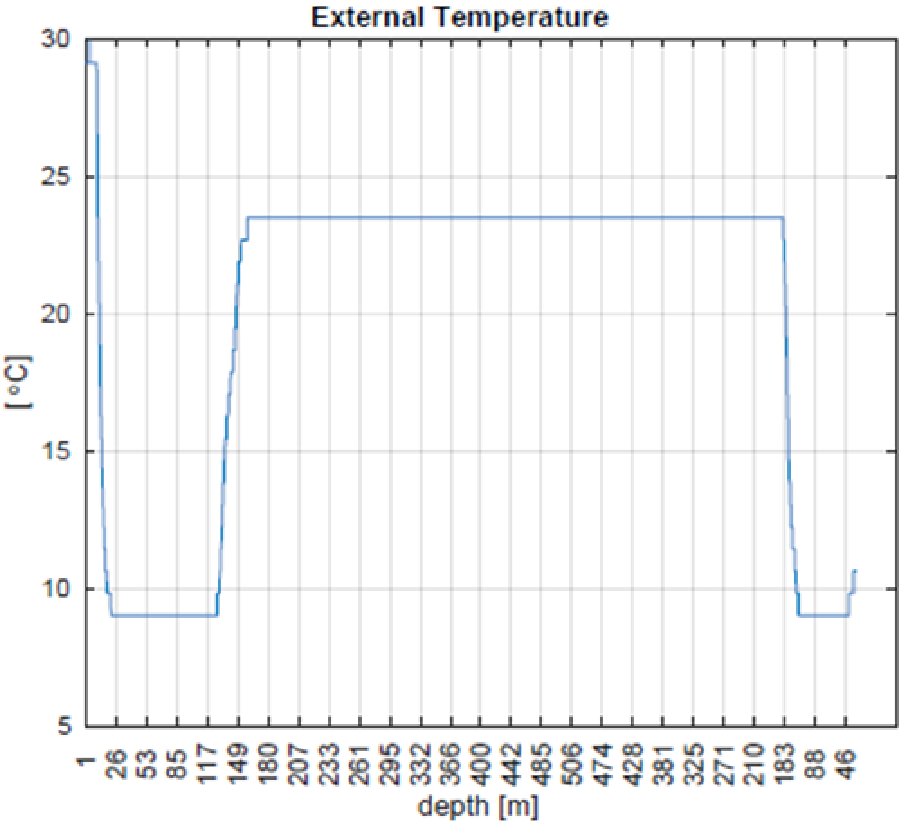


Figure 39. Evolution of the temperature values along the entire length of Shaft 10 according to UX-1 *(University of Miskolc)*

The pH of Shaft 10 shows a gradually decreasing value between 10 and 9.5 in the depth between the surface and 143 m and then decreases to a value of around 8.5 from 143 m, which is constant up to a depth of 506 m stays.

In summary, the EC measurements, since 2016, show **that fresh water is being accessed in the Shaft 10**. The value EC=500-650 µS/cm, in 2016, was reduced to EC= 200-400 µS/cm based on the robot measurements in 2021, which changes to EC= 400-450 µS/cm in the zone between 10-130 m (in 2016, a value of 650 µS/cm was measured in 150 m). At a depth of 130-140 m, a transitional mixing zone can already be seen (the value of EC= 450 µS/cm increases to a value of 3200 µS/cm), which came higher compared to the minimum depth of 150 m registered in 2016.

The robot measurements in 2021 show a constant value of EC= 3200 µS/cm from a depth of 140 m to the bottom of the shaft, which is a conductivity of approx. EC= 1000 µS/cm is higher than the EC= 2180 µS/cm measured in 2016 in 198 m.

Slow salt dissolution takes place in the depths to reach a state close to saturation. The saturation process is not yet complete.

The above is also confirmed by the temperature profile measured in the shaft. The value of low-conductivity fresh water at t = 8 C° rises to t = 24 C° after the transition zone of 130-150 m and remains constant until the bottom depth.

The mine shafts located hundreds of metres deep are practically impassable due to the collapses detected by the robot. At the same time, shaft 10 is statically stable and provides additional measurement options for investigating water chemistry changes at depth.

3.4.2.4 Examination of near-surface waters flowing in the alluvium of the Tisza floodplain

The near-surface water flows in the floodplain of the Tisza River require a separate attention, and that is why part of the monitoring wells marked MON were created here, right on the floodplain next to the Tisza. The floodplain of the Tisza River near-surface waters flow towards the land during floods and towards the river when the water level is low. This back-and-forth flow, which is mainly linked to the seasons, keeps the (relatively lower salinity) waters coming from the river and the higher salinity groundwater coming with a slow flow from the broken mining areas in constant motion. During floods, the waters of the Tisza River threatened/threatens the mining area (this is why the 'Czech' dam was built in the 1930s, which nowadays requires a complete overhaul), while in the event of a low water level (albeit slowly) salty groundwater burdens the Tisza (the In addition to the used salt lake waters led to the Tisza, which in summer, with low water levels, represent a greater load on the Tisza River).Therefore the sodium ion concentration therefore increases in the summer samples.

It has been already mentioned the prominent role of the Glod stream (F 16 water chemistry measuring point) in the salt load of the Tisza. The Glod Izvor watercourse shows a direct salt load to the Tisza through the watercourse.

At the same time, the piezometer wells MON 4, 6, 8 and 11 show the near-surface saline groundwater flow (Figure 40). The main direction towards the Tisza from saline groundwater is shown by MON 11 (Figure 41). That is, the main direction of the flow of saline groundwater from the mine area is E-W. This is an important finding, supporting the groundwater flow map (see Figures 40 and 41).

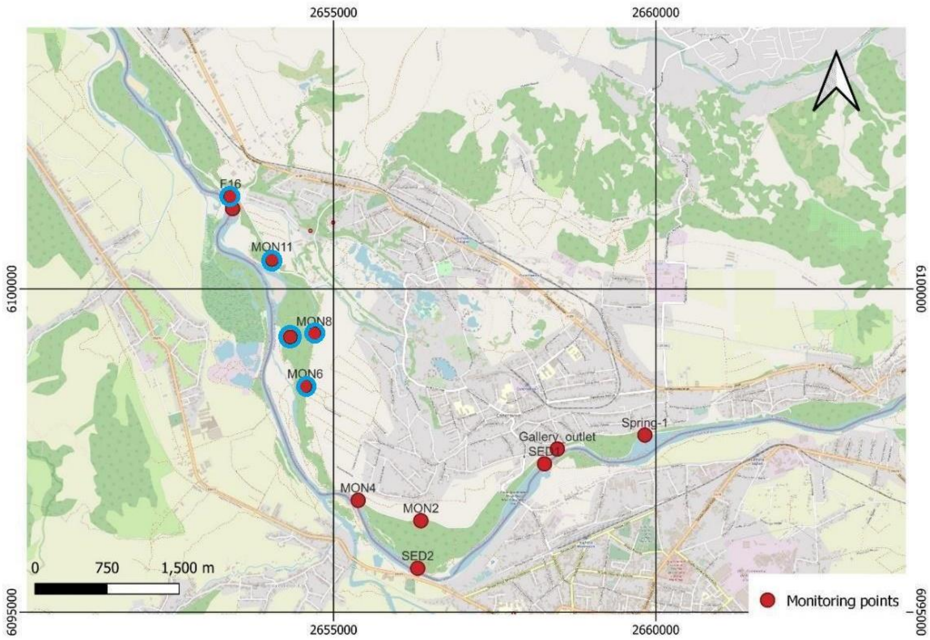


Figure 40 Blue circles shows monitoring points with a typically higher salt load - F16 point is the Glod stream *(Geogold Ltd)*

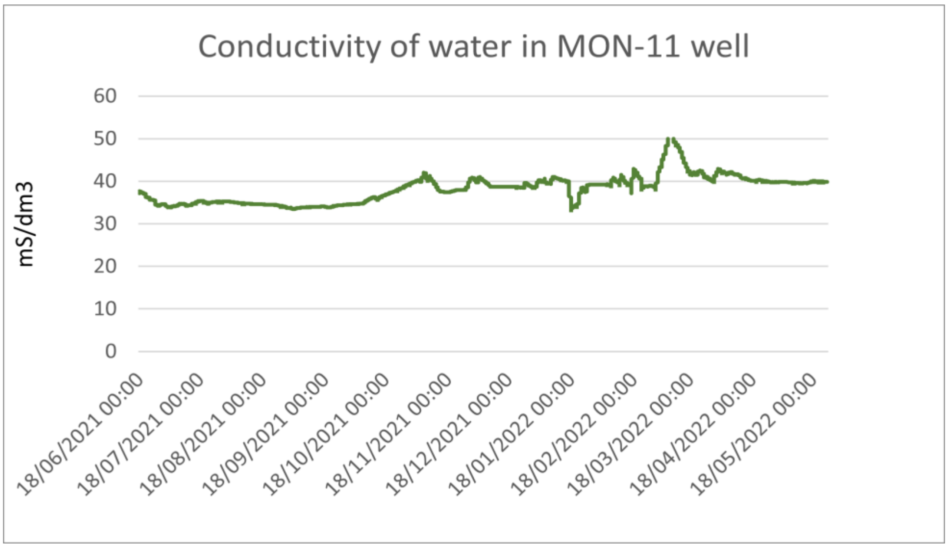


Figure 41 Annual (June 2021 - May 2022) change in the EC values of the MON -11 piezometer well *(Geogold Ltd)*

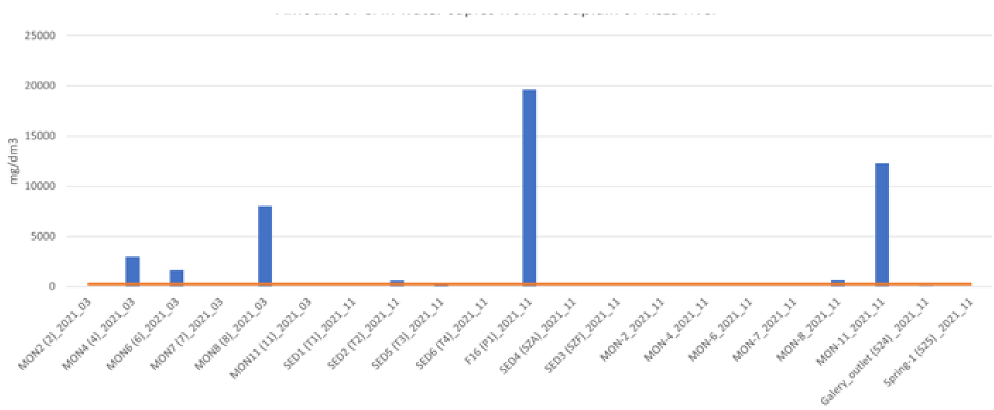


Figure 42

Cl-concentrations measured along the Tisza floodplain *(Geogold Ltd)*

During large floods of the river, the water seeps towards the salt body and causes serious damage, where the waterproofing layers are missing. Such incidents occurred in 1998, 2001 and 2007, further destroying the already attacked and destroyed mine area.

From the pressure wave test results, between 2021.06.-2022.05, it can be concluded that the underground water stored in the sediment along the Tisza is connected to the Tisza, even if the water level measured at the given observation point is higher than the nearest point on the Tisza. The reason for this may be that in the upper and at the same time more elevated sections of the Tisza, the water infiltrated in the coastal sediment flows along the river in an E-W direction, and the propagation of the pressure wave also appears at higher altitudes.

In Sighetu-Marmatiei there were quality measurements too. According to the classification PSS-78 the salinity of all tested water samples is less than 0.5 ppt, so the tested waters around Sighetu-Marmaţiei are classified as fully fresh waters for the whole study period. As a result of the salinity studies carried out during the project period, it can be concluded that in Sighetu-Marmatiei and its surroundings are not affected by salt pollution from the nearby Solotvino salt dome.

3.5 Results from the applied UX robot technology

With the help of the UX-1Nepo diving robot the UNEXMIN Georobotics Ltd. to produce 3D maps, capture high-resolution video footage in the Solotvyno mining area and evaluate the results of the dives. In addition, the robot carried out water sampling and water parameter measurements (electrical conductivity, pH, oxygen fugacity, temperature, pressure). The main expected outcome of the work was to better understand the potential subsurface sinkholes beneath the Solotvyno municipality and to complete the information needed for modelling the local groundwater flow system.

The UX-1Neo diving robot (**Figure 43.**) contains a total of six cameras that record images in the visible range (RGB images). These cameras are also used to record laser scans (SLS). Due to their dependence on the visible range, SLS systems are sensitive to water clarity. Obstructions such as floats, objects and water turbidity reduce performance. Other factors, such as salinity, do not affect quality.

Figure 43. The UX-1Neo robot at the entrance of the Ventilation shaft 9

In addition, the Multibeam sonar system (M3) and two scanning sonars produce point clouds from sound waves. The sound propagation velocity in water is used for calibration. It is therefore sensitive to large changes in sound propagation due to the different composition of the water. The data collected by sonars are little affected by small obstacles such as particles floating in the water.

The UX-1Neo is equipped with an on-board pressure sensor for depth estimation. A pressure increase of 1 bar corresponds to a depth increase of 10 m. It should be noted, however, that these values refer to fresh water. In the case of saturated solutions, depth estimates may be somewhat inaccurate due to the higher density and therefore higher pressure of the solution. These errors can be on the order of 10% in saturated aqueous environments.

During the first missions, it became clear that the salinity of the water changed dramatically with depth. The change in high salinity greatly alters the performance of underwater devices, including the UX-1Neo robot. Underwater vehicles are carefully calibrated to the environment in which they operate, considering buoyancy and sensors. In ventilation shaft 9, this meant a maximum depth of about 60 metres. This is because, although the robot can be adapted to the saltwater environment in field conditions, the extra weight of more than 20 kg installed makes it impossible to move the robot in freshwater, so it cannot be manoeuvred past any obstacle in the shaft. In Shaft

10, an additional 20 kg of weight was required to enable the robot to operate in high salinity zones. As there were small obstacles in the dive path that made the dive difficult, the lowering of the weighted robot in the freshwater at the top of the shaft had to be solved separately, which required the construction of a special robot-controlled cage. However, in a freshwater environment, to slow the robot's rapid descent and to protect the technology, a special cage was built to allow the robot to explore all accessible areas up to the maximum pressure range of 47.5 bar (in this case to a depth of 435 m).

3.5.1. Results of the dives

A total of fourteen dives were performed in the two shafts, three in Ventilation shaft 9 and eleven in Shaft 10. In total, more than 2 million photographs, 6 TB of video footage and 400 GB of other sensor data were recorded. During the dives, 8 water samples were collected in Shaft 10 and continuous water parameter measurements were taken along the entire length of the shaft and in the side passage at -81 m level. Due to the blockages in the shafts, only the man-made structures were visible, so no multispectral measurements of geological and mineralogical use were recorded.

Figure 44 - 3D model of shaft 9

In total, dives were carried out in Shaft 10 on three different dates: in June 2021, November 2021 and early December 2021.

During the dives in June, the water was turbid and opaque up to a depth of about 80 m near the surface, making navigation difficult. We were able to explore the shaft to a depth of 315 m and to measure the various water parameters up to the bottom of the shaft, 506 m, using a separate robotic unit.

During the June dives, a lateral entrance was discovered at 306 m depth, but this was blocked by a grid, wall, and debris (**Figure 45**).

During November, the shaft was mapped to a depth of 435 m (47.5 bar), which is the theoretical endpoint of the robot's dive depth. In total, there are 3 levels of access, of which only the access at 366 m is open from the shaft.

At the beginning of December, the robot was able to reach 55 m during the side passage mapping, but the passage was blocked (**Figure 46**), so it was not possible to continue with the robot. Based on the robot's images, the first 55 m of the side passage is covered with concrete, its walls are undamaged, and the metal frame does not appear to be corroded (**Figure 47**).

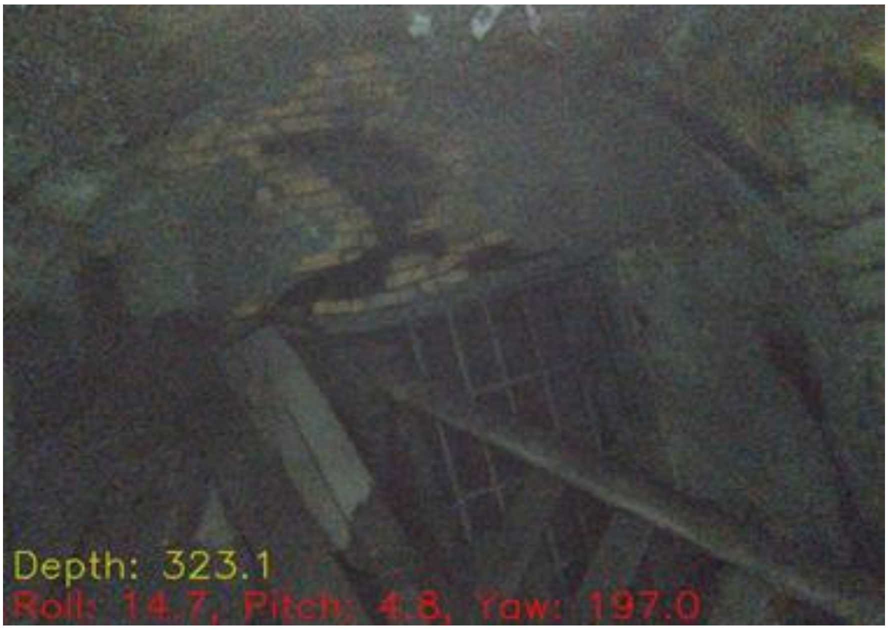


Figure 45 The entrance to the 306 m side passage is in shaft 10. The depth in the picture differs from the actual depth due to the difference in water density.

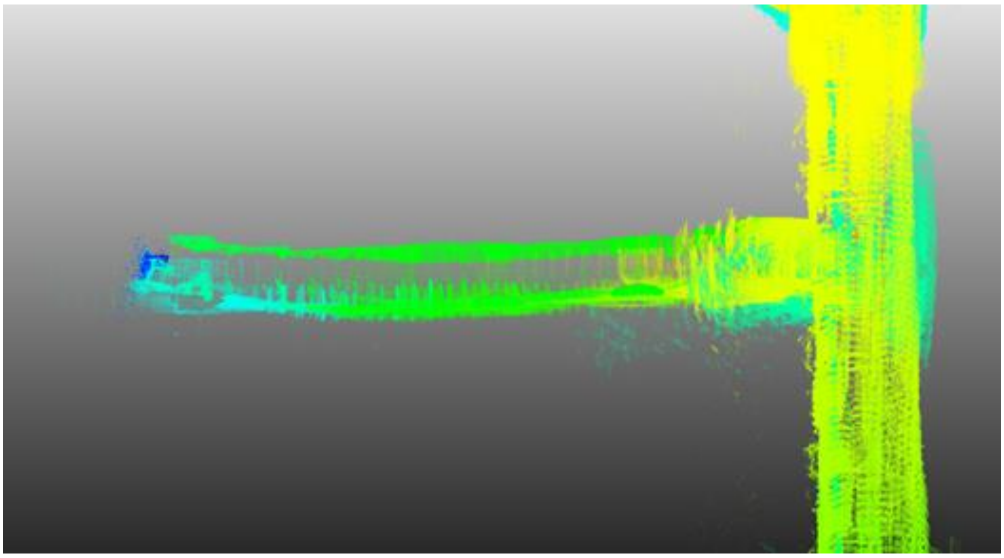


Figure 46 3D image of the side passage of shaft 10 at a depth of 366 m, blocked 55 m from the entrance

Figure 47 - Visual image of the side passage at 366 m. 1. front camera view of the entrance; 2. front camera view of the concrete entrance; 3. side camera view of the concrete side of the entrance; 4. side camera view of the shaft and the safety cage; 5. side cam

Above each of the three entrances in Shaft 10, ~10 m above the entrance, there is a service cavity of about 3 m.

During June 2021, the water in the upper 30-40 m of Shaft 10 was turbid and almost completely opaque. Visibility for the robot's cameras was only 25-30 cm. At a depth of ~40 m, the water was almost completely clear, with only small sediments floating in the water disturbing the view. This is probably due to the complete covering of the shaft and the fact that the body of water has remained undisturbed for months.

In June 2021, increased suspended particle counts were observed in the water in the transition zone of Shaft 10, in the 135-145 m depth range, due to sediment from the disturbed surface accumulating above the dense, thick saline water body. Visual evaluation of images taken at this time is almost impossible due to poor visibility. In the images taken in November and December 2021, this phenomenon is no longer visible, which is also due to the closure of the shaft roof and the fact that the accumulated particles have successfully settled to the bottom of the shaft over the months that have passed.

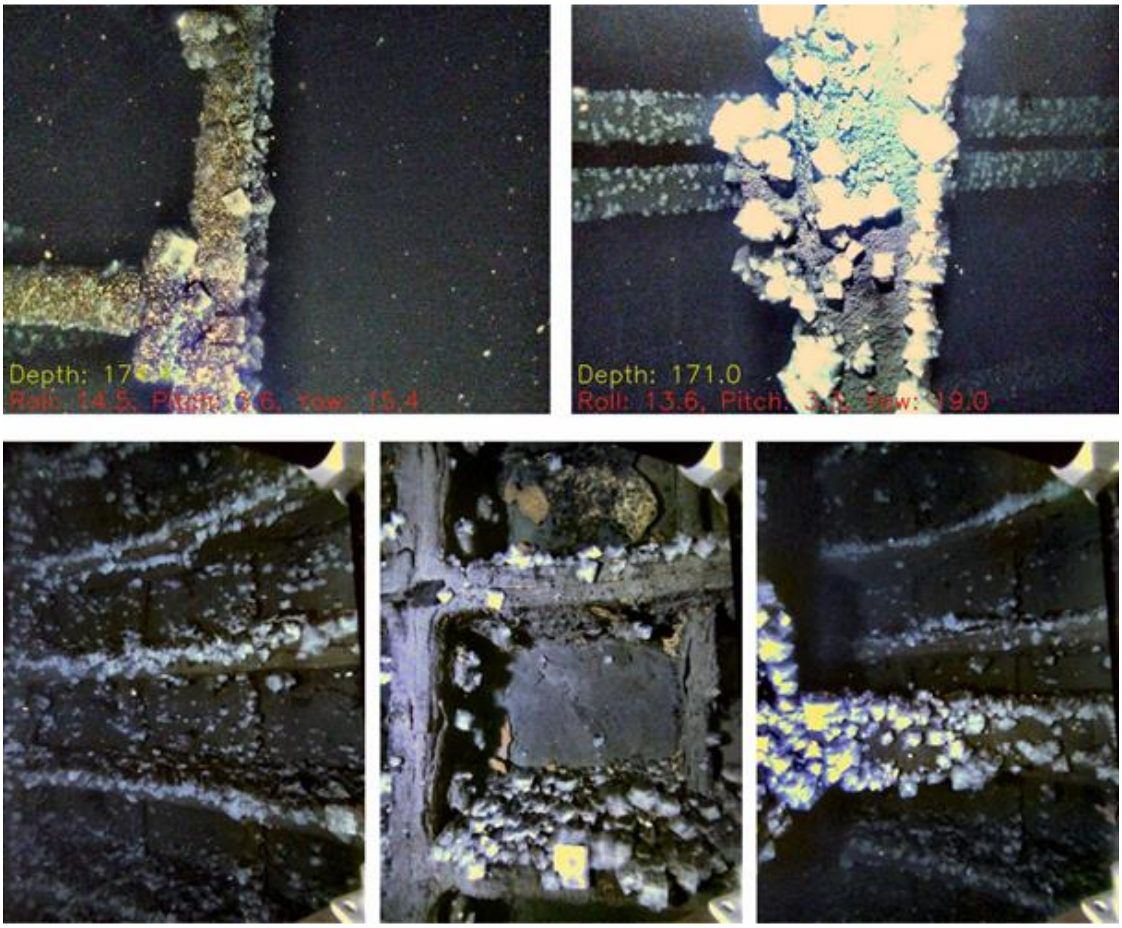


Figure 48 - Salt crystals observed on the wall of the shaft

3.5.2. Structural condition of the Ventilation shaft 9 and Shaft 10

Structurally, few conclusions can be drawn about the state of the mine as a whole, as limited data are available. Both shafts appear to be structurally good. The same cannot be said for the side tunnels and beyond. Photographs of the entrance to the tunnel at a depth of 306 m indicate that the built environment, except for the concrete lining, is in poor structural condition.

The gate and the wall above it are structurally unstable. The 55 m long accessible side passage at -366 m is in a stable condition, but the origin of the blockage is unknown. The sonar images clearly show that the sidewall of the passage is stable after the blockage, but the condition of the cover cannot be clearly inferred from the data. It can be assumed that debris flowing in the direction of Shaft 10 after the water ingress forms a barrier in the shaft, but the blockage could also have been caused by the collapse of the cover. However, it remains unclear from the data collected to what extent this has affected the condition of the salt cavities further down the mine.

In the saturated saline water body observed below 145 m, salt crystal formation is observed on the shaft wall and metal beams in the shaft at a depth of 158 m.

Despite the onset of halocline at 145 m, the intense crystallization observed at 158 m (Figure 39) may be due to seasonal halocline variation, which was not observed between June and December 2021. The most likely explanation is that the halocline level varies from time to time, but never deeper than 158 m. Thus, salt crystals formed above this level are redissolved when the freshwater system reduces the halocline level.

Ventilation shaft 9 and Shaft 10 are located at approximately the same elevation at the surface, saturated brine begins at a depth of ~60 m in ventilation shaft 9 and at a depth of 140 m in shaft 10. Thus, there is a pressure difference of 1-1.5 bar between the two shafts. This value assumes limited permeability between the two shafts, which is partly evidenced by the blockages we observed in the side passages.

Both shafts appear to be structurally good, but the same cannot be said for the side tunnels and beyond.

3.6. Hydrogeological / hydrodynamic modelling

3.6.1. The preliminary hydrodynamic model of the Solotvyno rock salt deposit

At the first stage, the preliminary hydrodynamic model of the Solotvyno rock salt deposit was created. The results of modelling of occurrence and increasing of water inflows into the mine shafts of Solotvyno deposit due to salt leaching, the formation and development of a karst aquifer under a layer of dense Quaternary clay, which also partly degraded are considered and generalised. Many years before the industrial development of salt this Quaternary clay reliably protected the integrity of the salt dome body of the Solotvino deposit from its destruction by the fresh underground waters of the Quaternary water-bearing complex. Due to the leaching of salt by fresh water, primarily in the network of remains of discontinuous tectonic disturbances under layer of Quaternary clay, karst cavities formed, ceiling over some of which collapsed over time with the formation of karst funnels in the terrain, which became effective conductors of fresh water from the Quaternary alluvial complex in Tortonian karst aquifer.

Original archive data (geological, geophysical, hydrogeological) of the study area (Solotvyno rock salt deposit and adjacent territory within Solotvyno settlement) served as the main source of initial data for the natural conditions' schematization for the hydrogeological modeling. Elements of the integral geological model of the Solotvyno salt dome structure previously developed at the IGS NASUwere used as a prior geological information (*Shehunova et al., 2015*).

The constructed hydrodynamic model includes:

- Model scheme of sediments transmissivity of the Quaternary water-bearing complex within studied area (as of 2000);
- Model scheme of transmissivity of Tortonian aquifer complex within Solotvyno salt deposit area;
- Model scheme of specific leak-permeability of layer of dense salt over mines of Solotvyno deposit at the beginning of 2000;
- General ways of groundwater movement of Tortonian (karst) aquifer inside 3D space of Solotvyno rock salt deposit after flooding of mines of №8 and №9 under influence of hydraulic gradient (Fig. 49).

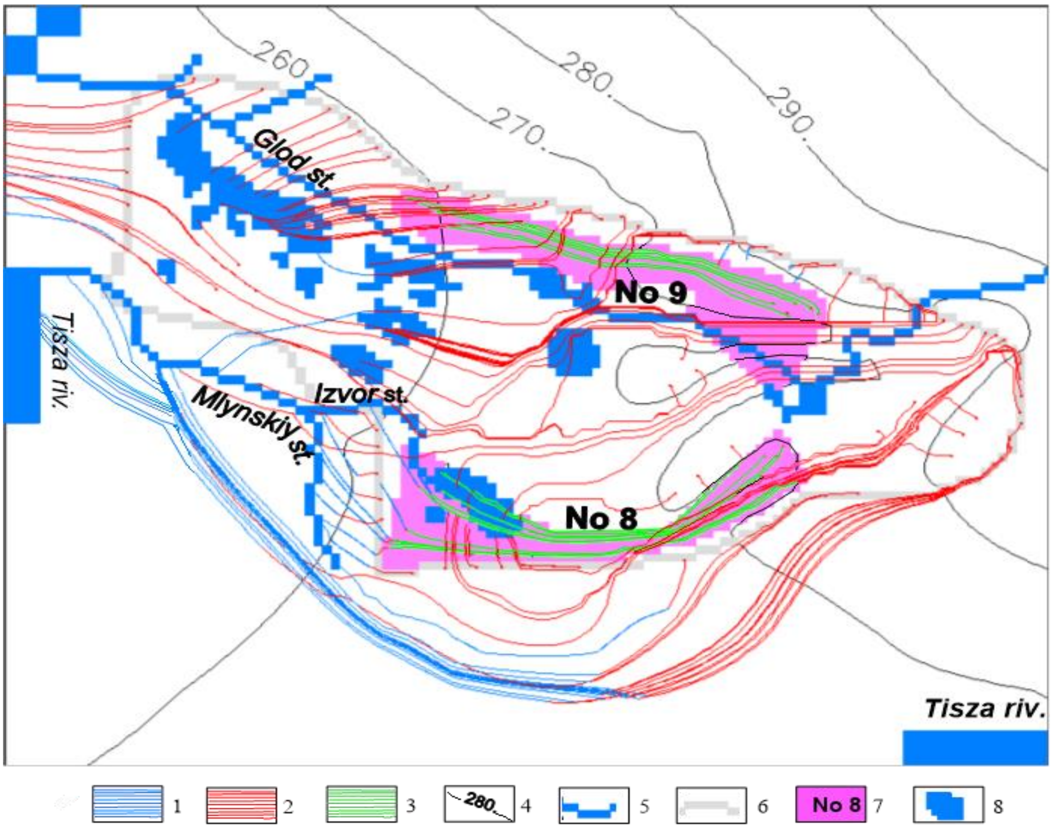


Figure 49. General ways of groundwater movement of karst aquifer inside three-dimensional space of Solotvyno salt deposit after flooding of mines of №8 and №9 under influence of hydraulic gradient: 1 – flowlines in Quaternary aquifer; 2 – flowlines in Tortonian aquifer; 3 flowlines in inundation underground cambers of №8 and №9 mines; 4 – isopiestic line, m; 5 – model hydrological network; 6 – conventional border of salt deposit dome; 7 – area of №8 mine; 8 – saline lakes, and large present-day and ancient fall-through karst funnels *(Stetsenko B.D., Shekhunova S.B., V.M. Shestopalov, Yu.F. Rudenko, Stadnichenko, S.M. (2021) Hydrogeological problems of the Solotvyno rock salt deposit and their analysis using modeling (Ukraine). Collection of Scientific Works of the Institute of geological Sciences NAS of Ukraine, 14 (2). DOI: https://doi.org/10.30836/igs.2522-9753.2021.245937)*

Calculation of the water balance of Quaternary and Tortonian aquifers shows the significance of the latter for the formation of water inflows into the mines of the Solotvyno deposit, especially during the period when it was completed, when the water inflows, contrary to the opposition of the miners, became excessively large for safe operation of the field. With the termination of exploitation of the deposit and the flooding of its mining operations, the problems of the Solotvyno deposit did not end, because the process of salt leaching continues due to both natural (faults) and man-made favourable conditions for the inflow of fresh water into contact with the salt body.

It should be noted that the obtained schemes of hydrodynamic parameters of the Solotvino deposit model, according to previous studies, are not only approximate, but also outdated, given the fact that over the 10-year period after the cessation of salt mining at the Solotvyno deposit, the hydrogeological conditions here have noticeably changed towards further destruction of the salt deposit through leaching processes.

Based on the obtained hydrodynamic modelling results, there is a potential for in-depth detailing: updated geological data (lithological composition of rocks, thickness of sediments covering the salt body, presence of macro-scale paths of anomalous migration (tectonic disturbances).

Thus, considering the difficult water balance of the studied area, it is recommended to take into account all possible tectonic disturbances, which may be ways of underground water (brines) flow between aquifers.

3.6.2. Improvement of constructed hydrodynamic model of the Solotvyno rock salt deposit using GIS

3.6.2.1. Detailed model of the the Solotvyno salt dome structure overlying sediments

To improve a basic integrated geological model and hydrodynamic model of the groundwater exchange system, the processing and analysis of the original archive data of Quaternary sediments geological sections of 395 wells drilled within the Solotvyno rock salt deposit for the period from 1922 to 1982 was performed.

For environmental state assessment and subsequent monitoring of the development of hazardous geological processes within the Solotvyno rock salt deposit, an integrated lithological model of the salt dome structure was created. The model includes consistent mathematical models of the boundaries and thickness of the sedimentary formation overlying the salt body built using GIS technologies based on the values of individual points (wells), including:

- Model of gravel-pebble rocks thickness above the Solotvyno salt dome structure (Figure 50 A);
- Model of the thickness of "palah" above the Solotvyno salt-dome structure (Figure 50 B);

- Model of the total thickness of overlying rocks above the Solotvyno Salt Dome structure (Figure 50 C);
- Model of the Quaternary sediments (palah & gravel) bottom surface (Figure 50 D).

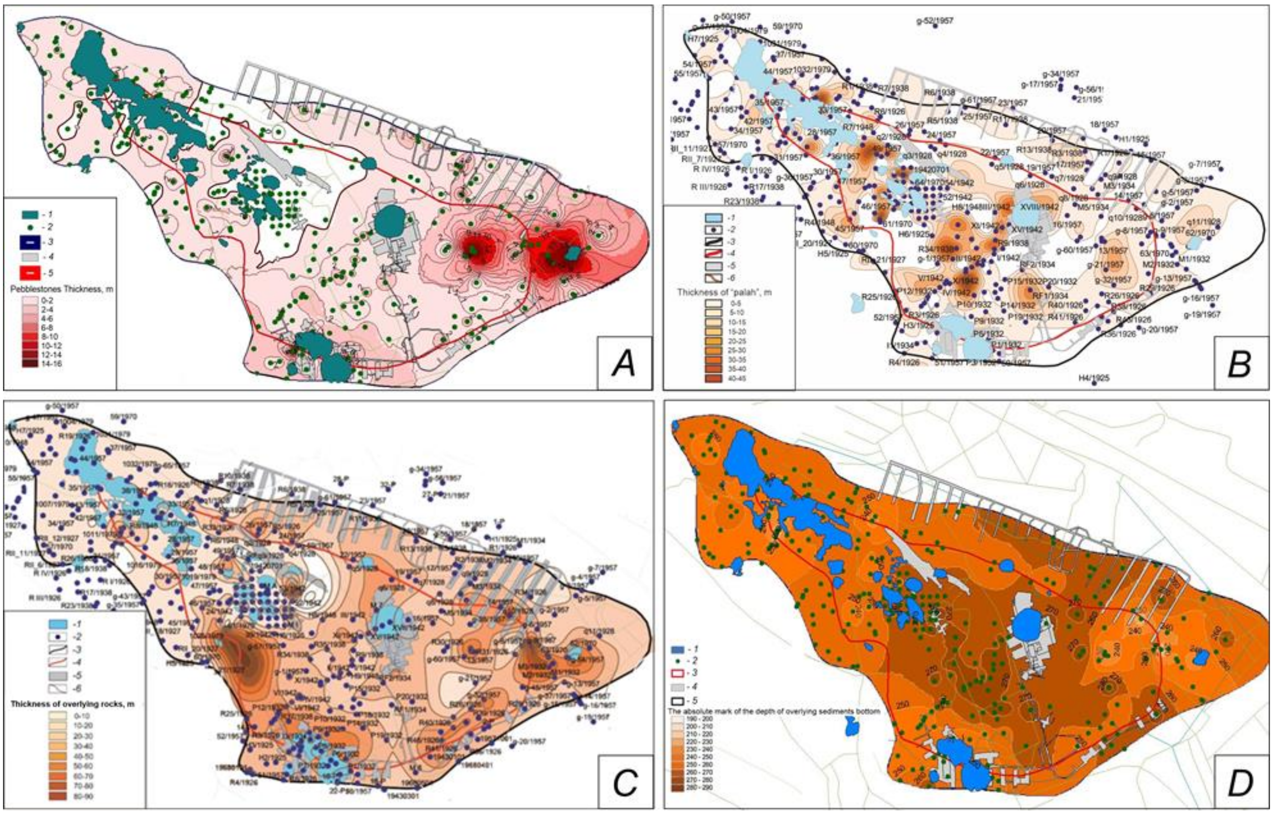


Figure 50. Models of the boundaries and thickness of the sedimentary formation overlying the salt dome structure: A – model of gravel-pebble rocks thickness; B – model of the thickness of "palah"; C – model of the total thickness of overlying rocks above the Solotvyno salt dome structure; D – model of the Quaternary sediments (palah & gravel) bottom surface. Legend: 1 – water bodies; 2 – wells; 3 – salt dome contour on the surface; 4 – salt dome contour at the absolute mark of 0 m; 5 – roads; 6 – mines *(Shekhunova, S.B., Siumar, N.P., Aleksieienkova, M.V., Stadnichenko, S.M. (2021) Lithological model of the suprasalt complex of the Solotvyno Salt Dome structure. Collection of Scientific Works of the Institute of geological Sciences NAS of Ukraine, 14 (2). DOI: https://doi.org/10.30836/igs.2522-9753.2021.245822)*

Consideration in the integration geological model of these tectonic elements and thicknesses of overlying deposits, their lithological composition is necessary to develop a refinement of the hydrodynamic model, karst prediction and correctly locate monitoring observation boreholes.

3.6.2.2. A modernised hydrodynamic model of the Solotvyno rock salt deposit and adjacent territories

A modernised and improved hydrodynamic model of the Solotvyno rock salt deposit and adjacent territories was created based on the refined filtration parameters of the suprasaline deposits of the Solotvyno salt dome structure and an updated database, which made it possible to predict the direction and the speed of groundwater flow over time.

The hydrogeological model of the object under study was improved based on the received new materials regarding the peculiarities of the geological structure and hydrogeological conditions of the research area, as well as the initial data on groundwater monitoring (June 2020 - May 2022) provided by the UM. Its functional compliance with natural and anthropogenic conditions has been proven. The database for further research has been significantly expanded. The direction of movement of groundwater and its speed in time have been determined.

The main source of initial data for the schematization of natural conditions within studied area was the report on previously conducted research and the initial data of the created preliminary model (Shestopalov et al., 2008) and the database of the integrated geological model of the Solotvyn structure (Shekhunova et al., 2015, 2021). Based on a detailed analysis of the preliminary hydrodynamic model of the Solotvyno rock salt deposit and adjacent territories (Stetsenko et al., 2021), its elements that require clarification and refinement were determined.

The MODFLOW software complex with the ModelMuse graphic envelope was used to create a geofiltration model of the territory of the Slotvyn deposit, which is a system for modeling the filtration and migration of groundwater.

First, based on the analysis of the original geological data and the integrated geological model of the Solotvyn structure (Shekhunova et al, 2015), a conceptual model of the studied area was built. Results on natural conditions schematization within the studied area the following aquifers and geological formations were considered):

- aquifer of Quaternary sediments of the Tisza floodplain and supraflood terraces, represented by various boulder-pebble deposits with different zones of values of filtration coefficients.
- the separating layer between the Quaternary deposits and the areas of the salt dome structure, represented by dark gray clay "palah";

- aquifer in the karst fields of the salt dome structure under alluvial deposits (rock salt is covered by a "palag" with hydraulic "windows");
- Tortonian aquifer in layers of fractured argillites, sandstones, tuffs (Solotvyno Suite);
- predominantly waterproof lithological unit — salt dome (light gray and gray rock salt, Tereblyanska Suite).

To justify the contours and boundary conditions of the model, watershed lines were constructed using a digital terrain model. The boundaries of the model were mainly chosen along the watersheds of the mountain Magura ridge and the contour of the Tisza river. This is a difference from the previous model of the Solotvyno deposit, which covered a larger area of the Tisza-Apshitsa interfluve area with a mountain range. The calculation grid was created within the selected contour. The area of the model region is 24.6 km^2. The size of the calculation blocks varies from 50 m around the model to 25 m for the approximation of rivers and the territory adjacent to the salt diapir, which require a more detailed study.

To consider, the possible spread of salt brines and their impact on the quality of groundwater in the area adjacent to the salt shaft, calculations were made of the flow lines of the inert pollutant with and without considering tectonic disturbances of various ranks.

The software graphic interface allows to visualize velocity vectors, isolines of groundwater pressures, flow lines for any estimated time, save images in the form of maps for further use (Figure 51, 53). With the aim considering tectonic disturbances in the model which were set on model by increasing the hydraulic conductivity in the fractured aquifer to 1 m/day in narrow zones corresponding to tectonic faults. Calculations have shown that the presence of such zones on the model has a significant impact on the calculated hydraulic heads distribution, even in the upper aquifer of the Quaternary sediments. The deformation of the model groundwater flow lines indicates an increase in water exchange in the fracture zones areas (Figure 52, 54). This can accelerate and intensify the spread of saline water in aquifers.

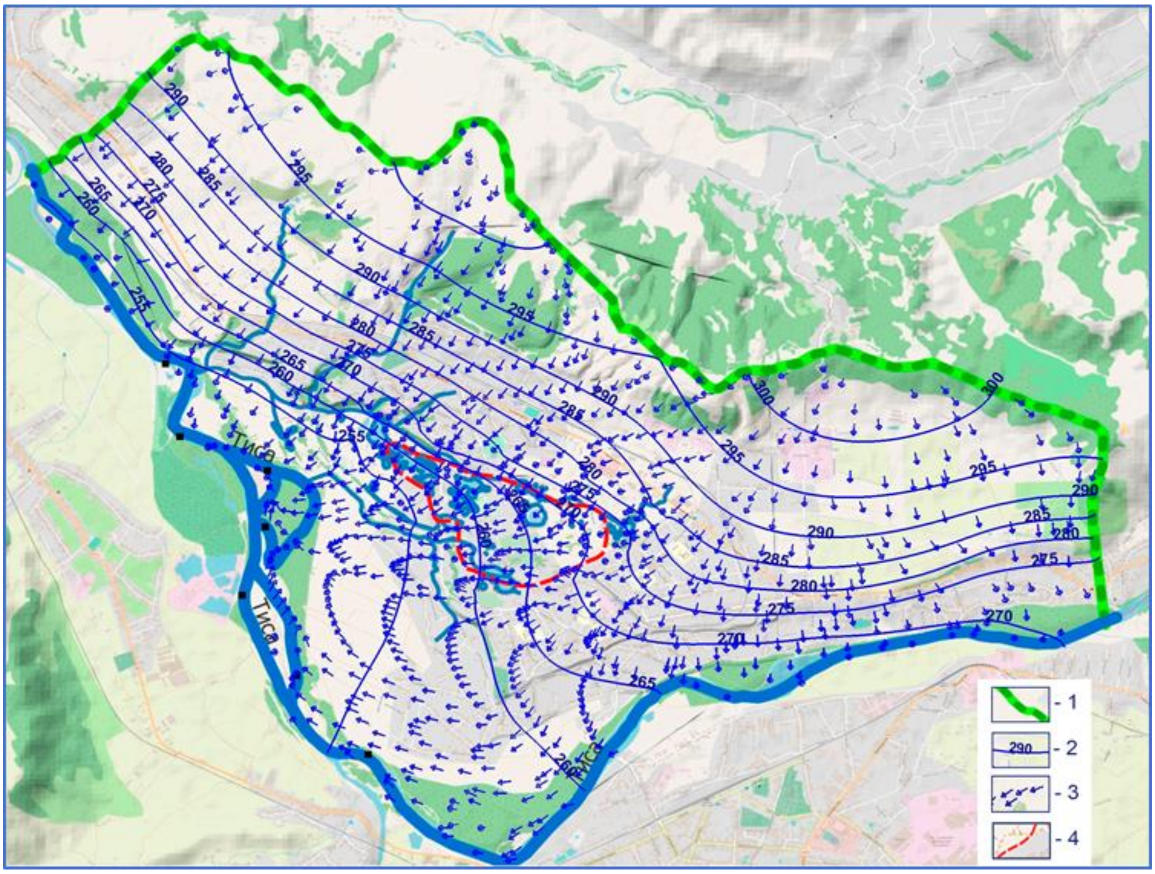


Figure 51. The groundwater level isolines and actual flow velocity vectors of the Quaternary groundwater aquifer visualisation according to the modelling results (without considering tectonic disturbances), Legend: 1 – watershed; 2 – groundwater level isolines; 3 – actual flow rate vectors; 4 – salt dome structure contour on the surface of alluvial sediments.

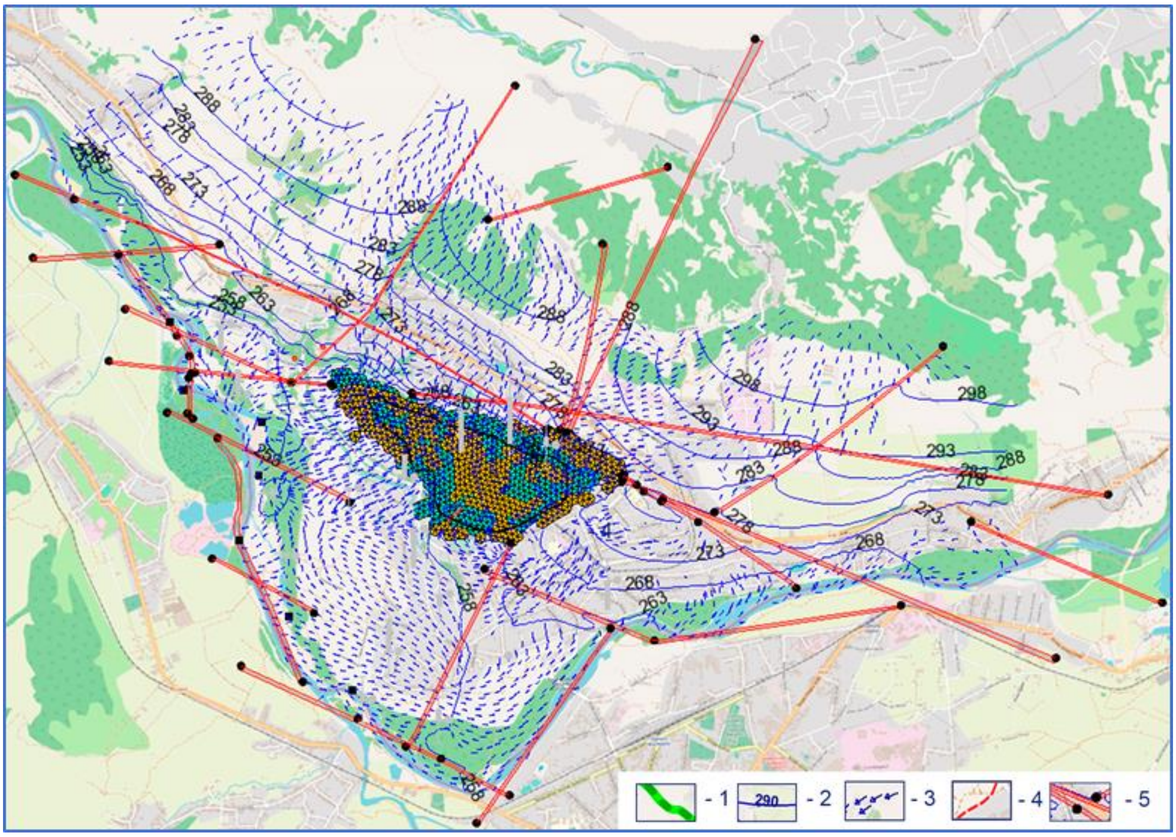


Figure 52. The groundwater level isolines and actual flow velocity vectors of the Quaternary groundwater aquifer visualisation according to the modelling results (considering tectonic disturbances of various ranks). Legend: 1 – watershed; 2 – groundwater level isolines; 3 – actual flow rate vectors; 4 – salt dome structure contour on the surface of alluvial sediments; 5 – tectonic disturbances (faults)

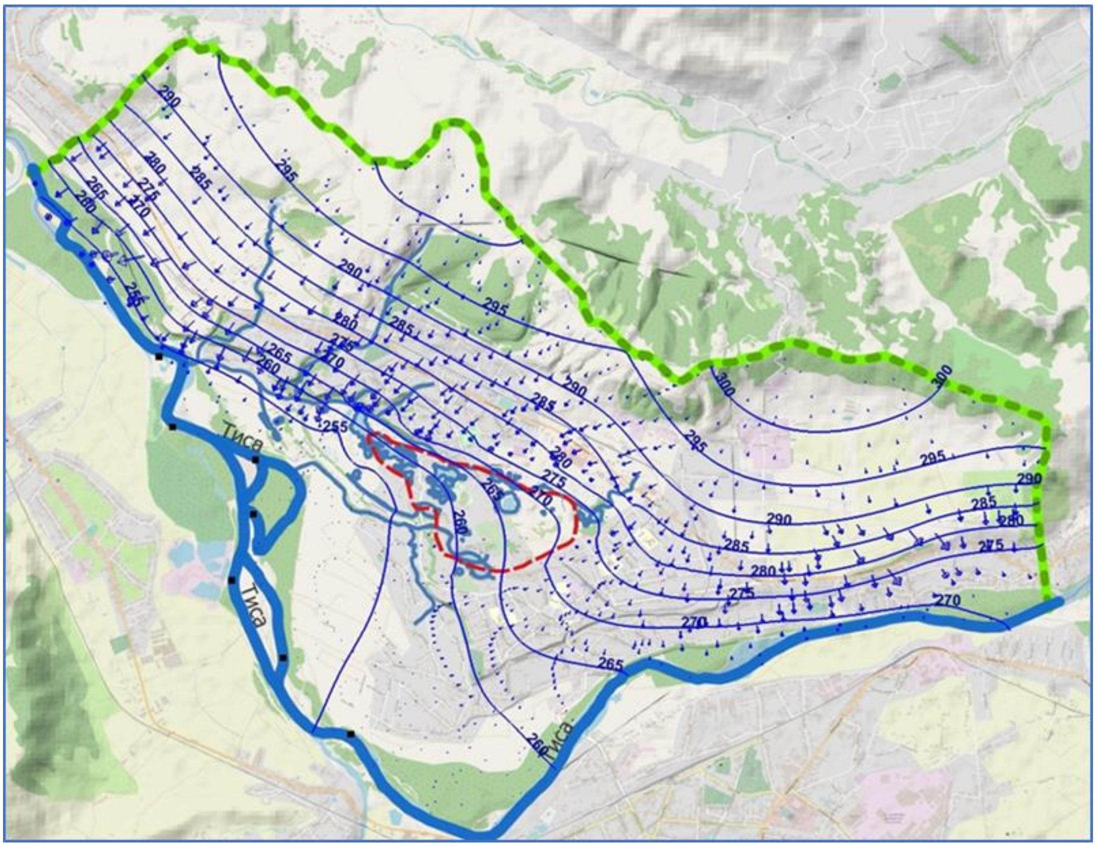


Figure 53. The groundwater level isolines and actual flow rate vectors of the Tortonian aquifer visualisation according to the modelling results (without considering tectonic disturbances of various ranks)

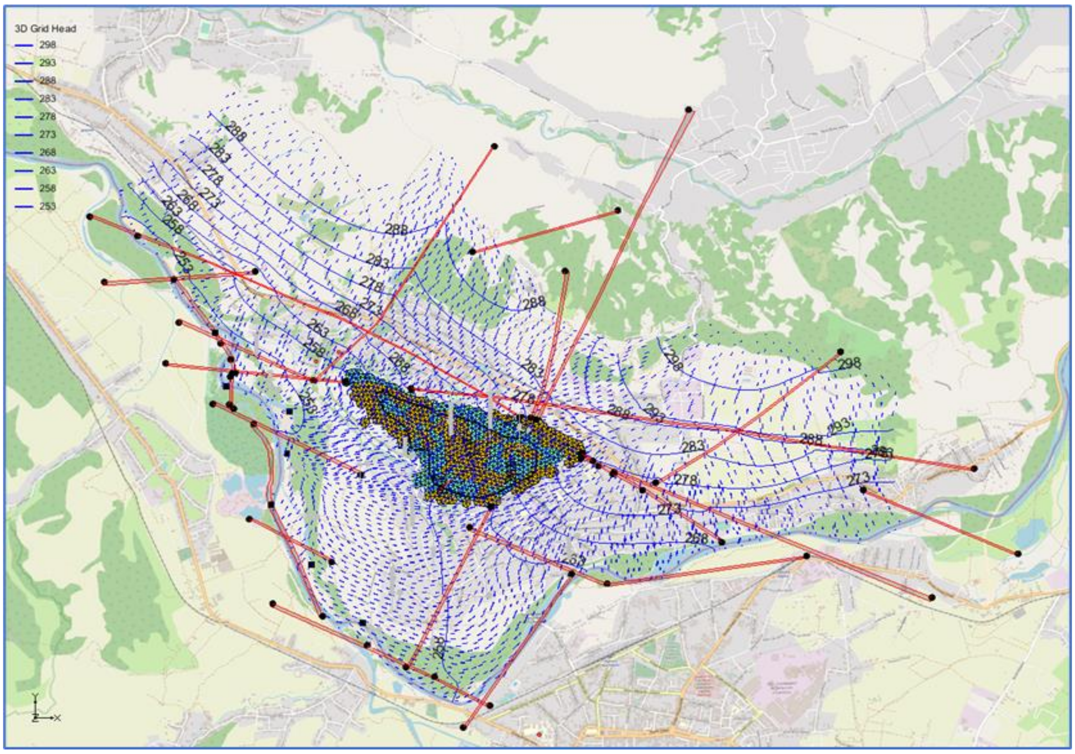


Figure 54. The groundwater level isolines and actual flow rate vectors of the Tortonian aquifer visualisation according to the modeling results (considering tectonic disturbances of various ranks)

Schematic three-dimensional visualization of the hydrodynamic model – the spatial relationship of the salt dome structure and the two aquifers (Quaternary and Tortonian) in the form of actual velocity vectors of the groundwater flow and with the reflection of tectonic disturbances within the studied area (Figure 55).

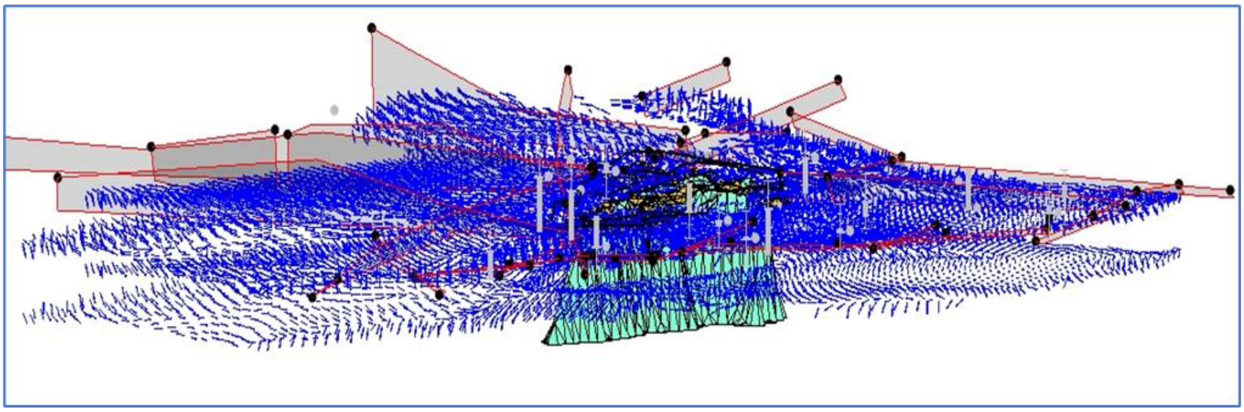


Figure 55. Fragment of the three-dimensional hydrodynamic model of the actual velocity vectors of the groundwater flow of the Quaternary and Tortonian aquifers with a salt dome structure and tectonic disturbances

Conclusions

- **A modernized hydrodynamic model of the Solotvyno rock salt deposit and adjacent territories was developed, which includes information on the three aquifers based on the updated geological database (detailed geological structure of the salt dome surface and suprasalt deposits lithology) considering tectonic disturbances (faults).**
- **Modelling calculations aimed at considering tectonic disturbances (faults) in the model showed the deformation of the model groundwater flow lines, that indicates an increase in water exchange in the fracture zones areas. This can accelerate and intensify the spread of saline water in aquifers.**
- **To check the compliance of the created mathematical model with the natural hydrogeological conditions of the research object, several inverse problems were solved. As a result, it has been established that the hydrodynamic situation reproduced on the model reflects the natural conditions with sufficient probability thus the obtained model can be used to solve practical problems.**
- **The main feature of the model is the use of the Layer-Property Flow (LPF) calculation unit, thanks to which the filtering problem is solved in a truly three-dimensional setting, and not in a quasi-three-dimensional one, as it was implemented in previous studies. This determined the most accurate, as far as the available initial data allowed, the display of the geometry of the calculated layers (absolute marks of the roof and bottom of aquifers and separate waterproof layers). The created model allows with a sufficient degree of probability to predict the direction of movement and the actual speed of groundwater in time.**
- **The created modernized hydrodynamic model can be used as a basis for building subsequent migration models of mass transfer in groundwater for a more detailed study of the problem of salinization of aquifers and their interaction with salt rock of the Solotvyno rock salt deposit.**
- **The created hydrodynamic model containing information on five layes (geological units – formations) with maps of the velocity vectors, isolines of groundwater level, flow lines provided for two aquifers (Quaternary and Tortonian) with and without taking into account tectonic disturbances of various ranks, that made it possible to determine the network of monitoring hydrological and hydrogeological observation**

points optimally required for informative and reliable monitoring (in detailed presented in Subchapter 3.9).

- **Monitoring changes in water quality within a post-mining area is very important for the protection of water resources. A comprehensive water quality monitoring system is essential for the environmental management of the post-mining area operation. It enables water quality performance to be assessed. Undesirable impacts can thus be detected at an early stage and remedied.**
- **The permanent hydrodynamic model as an integrated element of the recommended complex monitoring system should become a tool for managing the use of natural resources in the Solotvyno settlement – brines and rock salt.**

Recommendations

- **To Apply the developed hydrodynamic model as the basis of a continuously updated hydrodynamic model as an element of the complex monitoring system of the Solotvyno rock salt deposit and surroundings for the purpose of sustainable management & use of natural resources.**
- **The hydrodynamic model became the basis for determining the number and spatial location of the network of monitoring hydrological observation points and hydrogeological wells in accordance with the developed plan of the monitoring system and observation regime (see Subchapter 3.9.3., Figure 70).**

3.7 Contaminant transport modelling

To build the salt transport model, we have used the previous conceptual and detailed hydrodynamic models presented in the previous sections but have rebuilt it with transport modelling considerations in mind.

The system has been built using the WGS84 Universal Transverse Mercator (UTM) 34N projection system based on previous experience, partly to ensure compatibility with previous models and partly to make the use of previous spatial information as simple as possible.

Five layers have been included in the model in a way that best fits the reality. The following set of layers was used in the model:

- Layer 1. Sandy gravel Pleistocene aquifer and the upper layer of the Miocene formations of the Magura Mountains on the NE side
- Layer 2. Clayey aquifer level "pallag" and the middle level of the Miocene formations of the Magura Mountains on the NE side
- Layer 3. Upper level of the salt dome with shallow salt mine cavities and surrounding Miocene formations, including the sediments of the Magura Mountain to the NE
- Layer 4. Middle level of the salt dome, with deep salt mine cavities (mines #8 to #10) and surrounding Miocene deposits, including sediments of the Magura Mountains to the NE
- Layer 5. The intact deep level of the salt dome and the surrounding compacted high depth Miocene formations, including sediments of the Magura Mountains to the NE

In this way, the model was able to capture the shape of the soda atom down to -200 mBf. Considering that the hydrodynamic capacity of the layers decreases with depth, we did not consider lateral and upstream inflows and fluxes at great depths and assumed the bottom of the model to be impermeable, which is a negligible error in terms of the water balance of the system.

The boundary surfaces of the formations fitted to the model are shown in **Figure 56.**

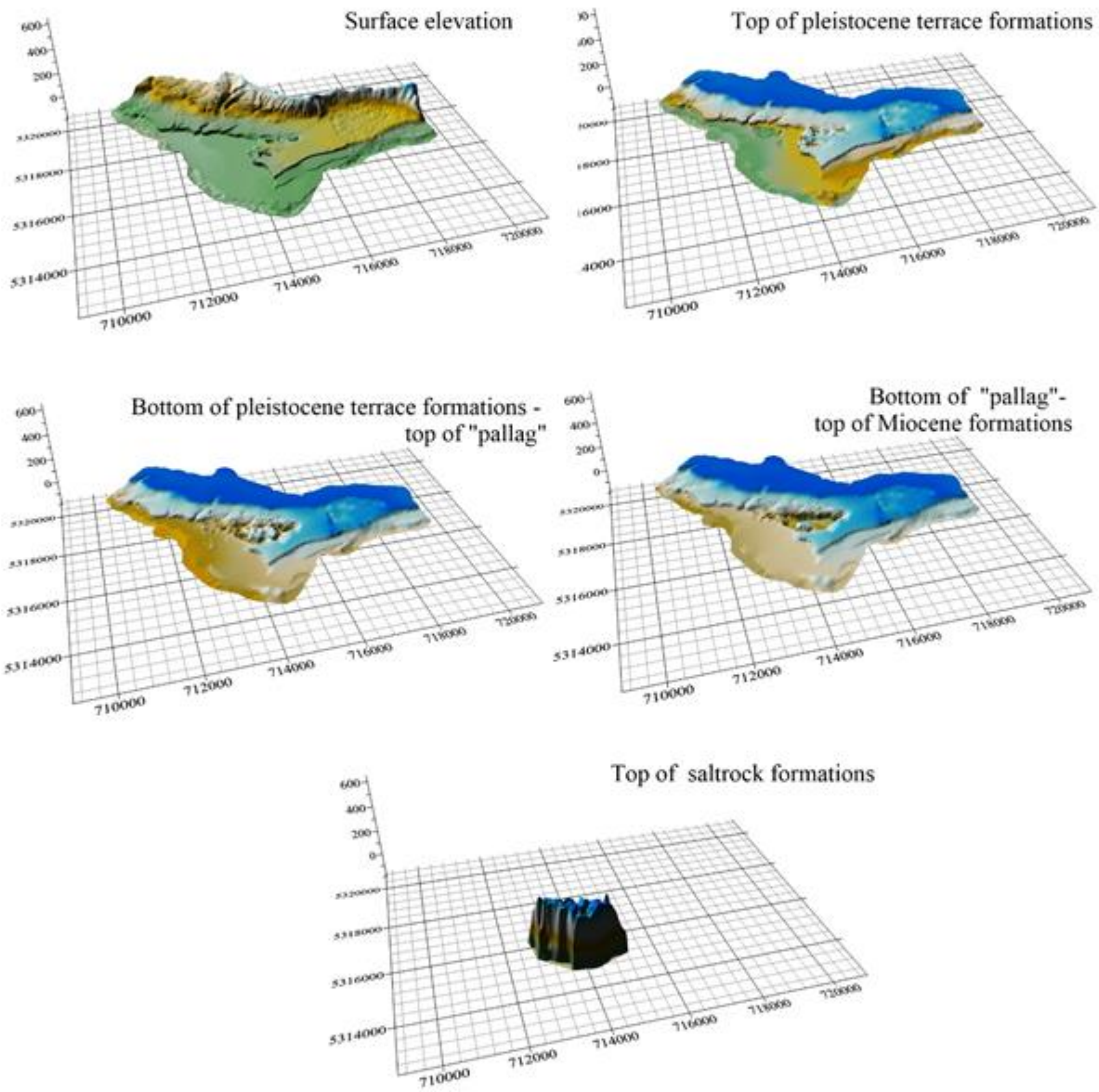


Figure 56.: Geometry of soil bodies adapted into the transport model

To ensure the stability of the transport model calculations, an equidistant grid of 25x25 m was applied over the entire area. The modelled area was the 8500 x 7000 m area between the coordinate lines X = 710180 - 718680 and Y= 5312350 - 5319350 of the aforementioned WGS854 UTM 34N projection. Thus, the model consisted of 340x280 elements per layer (**Figure 57**).

In the model, the hydraulic parameters are given in a different regime for each layer. The properties of the terrace layer were approximated by a continuously varying parameter field, and the Magura Mountains formations were described with constant properties per level, but with decreasing hydraulic conductivity with depth. The properties of the "pallag" aquiclude clay layer are determined by several processes. Its formation is best known above the salt rocks in the center of the dome, but it is also likely to be found away from the salt dome. It is also known that in the shallow mines (mines 1-7), some land subsidence (**Figure 58**) due to collapse of underground mine chambers has occurred, resulting in the formation of salt mine lakes.

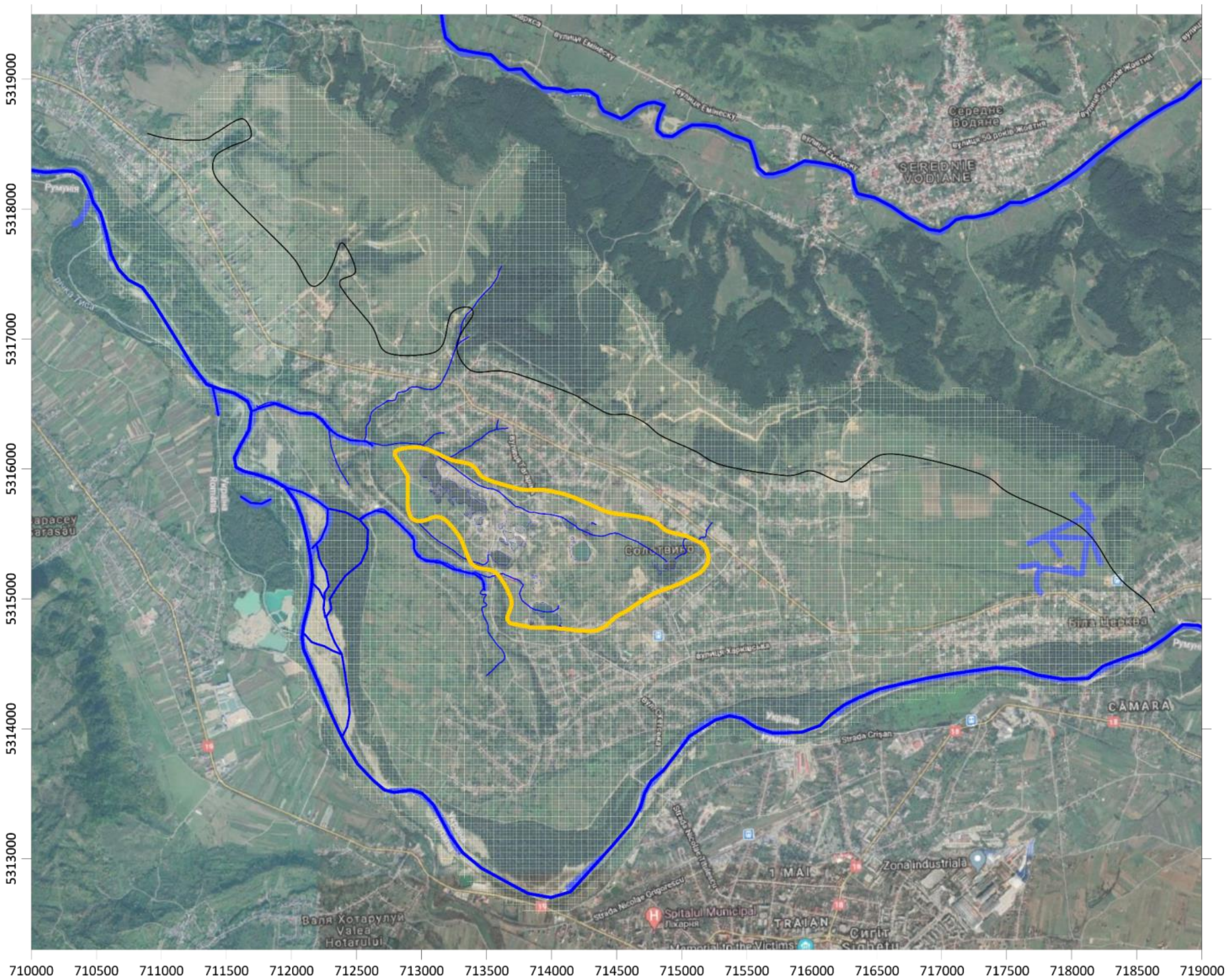


Figure 57.: The grid of the transport model

In the salt mine collapse originated in the lake region, therefore, the continuity of the “pallag” is disrupted and a weakened but existing connection between the groundwater incorporated in salt rocks and in overlying gravel formations was assumed, which was simulated by reducing the hydraulic conductivity of the "pallag" layer. Data on the extent of subsidence were also considered.

Based on subsidence maps published by Trofymchuk et al 2020, we also varied the hydraulic conductivity of the "pallag" in the salt domes region (**Figure 58**), assuming that where salinity dissolution is higher at depth, subsidence is faster and the connection between the shallow aquifer and the groundwater stored in the salt domes is faster and easier to establish. In addition, it must be taken into account that salt water seeping vertically through the "pallag" may result in a flocculated, more permeable structure of the clay. In this way, the conductivity of the "pallag" was increased both at the salt lakes formed above the mine cavities and by following the areas of maximum land subsidence velocities of more than 10 mm/year, the hydraulic conductivity of the clay was gradually increased towards the center of the movement. In these places, the possibility of a hydraulic connection between the water stored in the salt lakes and the water of the gravel complex is clear.

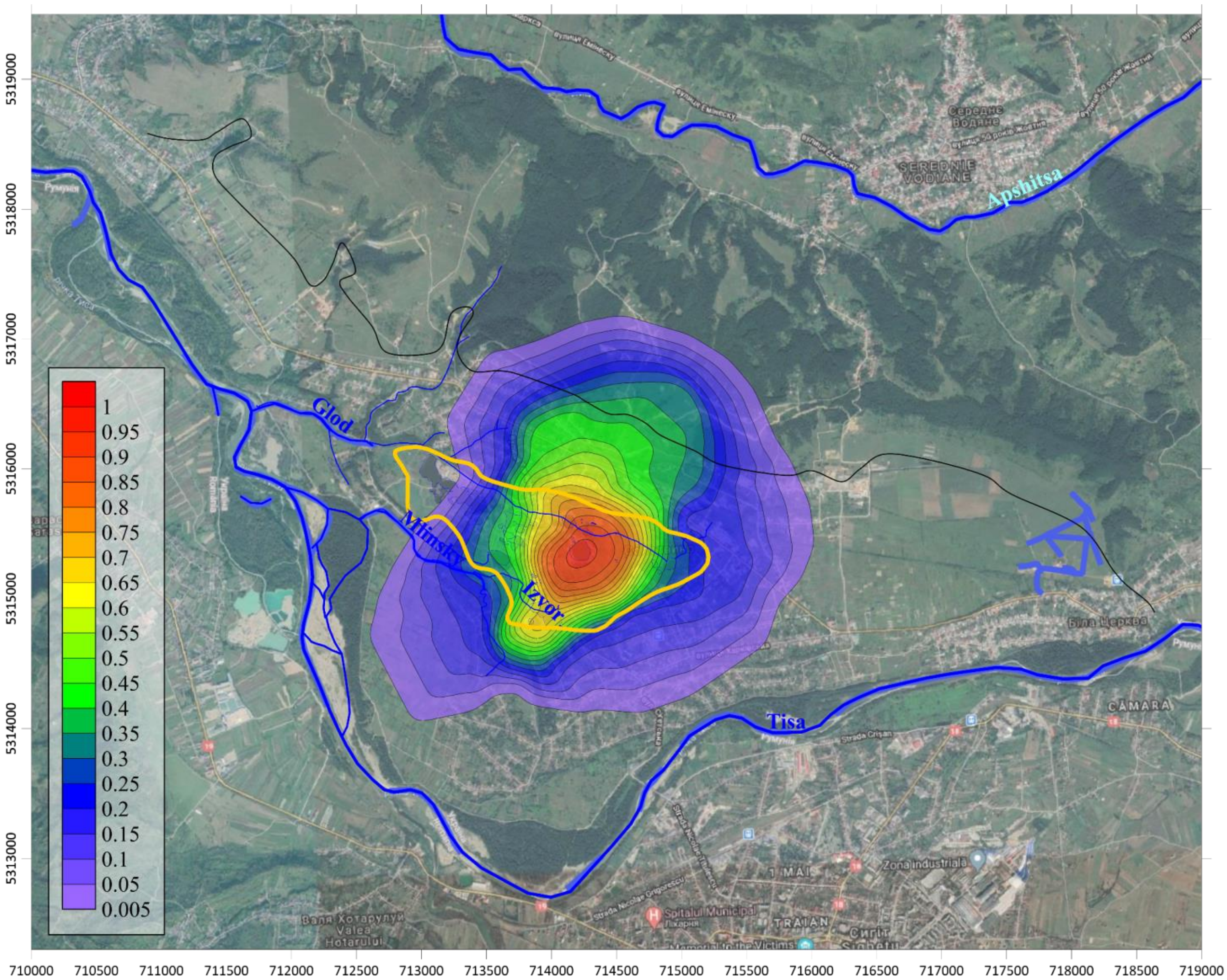


Figure 58. Land subsidence rates nearby Solotvyno considered as a hydraulic contact strengthening factor (after Trofymchuk et al 2020)

Most of the Miocene formations are high dipping strata, consisting of clays and Aleurites, but also tuffs and sandy levels. Seepage within the Miocene formations is impeded by the poorer water conductivity of the salt rocks, but around the salt dome there is unimpeded seepage in all directions within each formation. The usual anisotropy does not apply to these formations due to the high slope, and in the model these formations were considered as blocks with low anisotropy.

The Miocene strata, deposited in a SW direction from the salt dome, are fed by saline waters, depending on the quality of the clay cover, which may then move towards the surface through open tectonic zones. It is partly due to these Miocene strata that some of the saline water can move towards depth and only break up to the surface in areas away from the salt rock body. The Miocene formations therefore play a complex role in the system, especially the aquifers between aquitards and aquicludes.

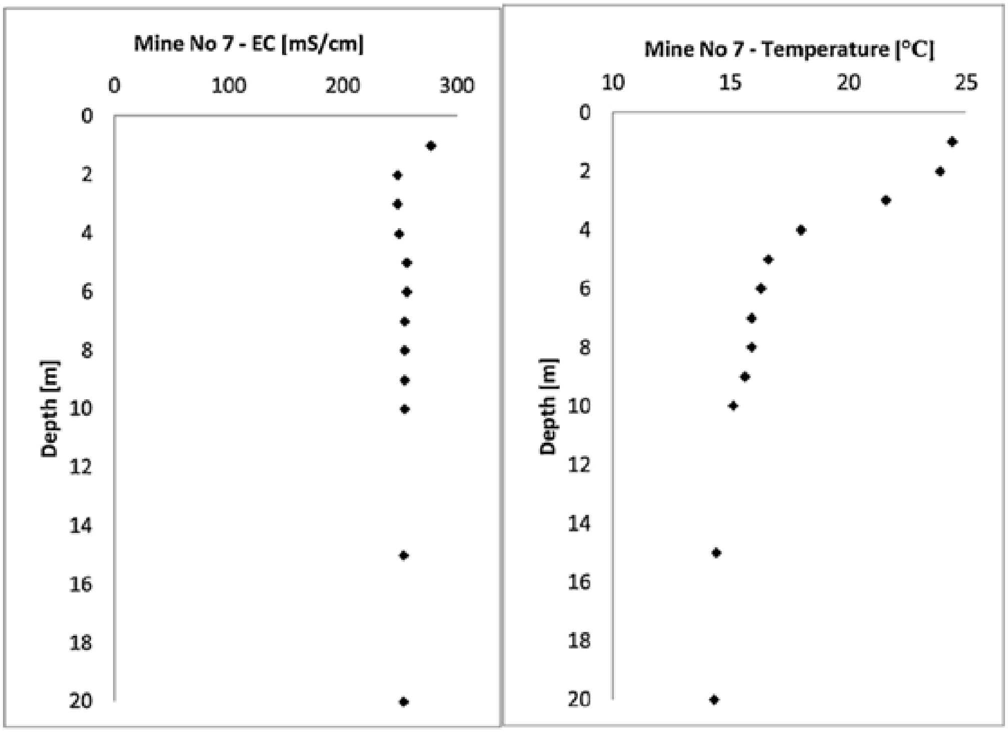
The intact salt rocks are the least permeable in the system, but it is known that both the deep and shallow mines have been filled with water, so that the salt is dissolved by the fresh water inflow. Dissolution starts near the preformed discontinuities and the hydraulic conductivity of the discontinuities gradually increases due to the continuous solution of salt bodies nearby. In this way, this dissolution process of salts appears to be unstoppable if the system is replenished with freshwater.

In the model, the hydraulic conductivity of the intact salt rocks is the same regardless of settlement depth, but around and immediately adjacent to the chambers of the deep #8-#10 mines, the conductivity is orders of magnitude higher than in the intact rock itself. The average "porosity" around the chambers is also increased, up to 0.7-0.8, depending on the element size. The hydraulic conductivity change is even larger in the shallow mine areas where the solution has caused the cavities to collapse and to open up, the movement of water is almost unimpeded, while in other mines where this has not happened (e.g., mines #5 and #6), the hydraulic conductivity is also increased.

Flow conditions are difficult to estimate from water levels, as the density of saltwater is higher than freshwater, so the saltwater levels in the mines are slightly lower than in the surrounding freshwater, but this indicates the same hydraulic potential.

The salt concentration of about 7.5% at Dolphin Lake (measured by Geogold Kárpátia Ltd.) represents a density of 1.052 g/cm^3, i.e., a 5-6% lower saltwater column can balance the freshwater column. EC measurements in the mine shafts indicate a value of 250 mS/cm, which could indicate a salt concentration of up to 300-350 g/l, consistent with the solubility of salt in water (359 g/dm^3 @25 °C), i.e. salt in the mine shaft area is fully saturated or near saturated.

Moreover, if we examine the EC-depth and EC-temperature profiles for each mine, we see that the EC profile for mine #7 shows a constant value of 250 mS/cm (**Figure 59**, top charts), which means that as the lake breaks up from the mine area, there is a continuous upward flow of saturated brine, which is then moved or may be moved further laterally down gradient by lateral seepage. The higher EC near the surface is a temperature effect.



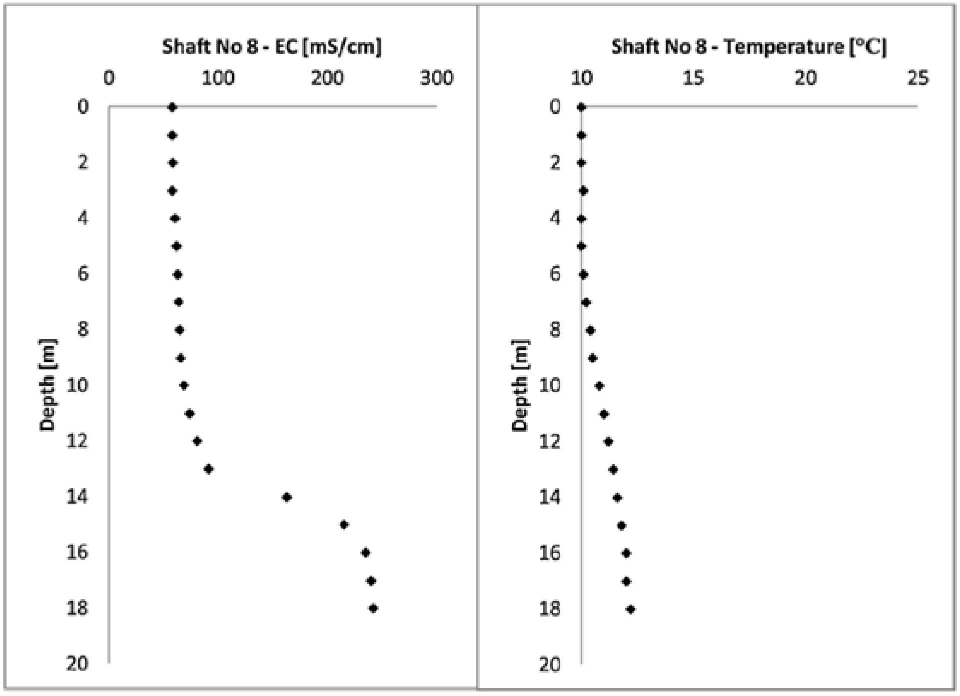


Figure 59.: EC and temperature profiles in mine shafts #7 and #8 (Stoeckl et al., 2020)

If we compare this with the EC profile of mine #8 (**Figure 59**, bottom charts), we can see that the EC level is lower in the surface zone, which rises abruptly with depth. This indicates that there is currently no saltwater discharge through the shaft from Mine #8, the mine openings are saturated to the appropriate temperature, which is then diluted by lateral groundwater seepage near the surface. In this region, therefore, the shallow groundwater flow does not receive any significant saline load.

EC measurements therefore provide a clear indication of whether the protective layer of the "pallag" is functioning and whether a given formation or mine area is hydrodynamically connected to the shallow aquifer. All these insights were adapted to the model by varying the hydraulic conductivities.

Infiltration was adapted into the model using zones (**Figure 60**). In the steeper slopes of the Magura Mountains, higher surface run-off and therefore lower infiltration was assumed. Infiltration is inhibited by the medium-low conductivity of the formations but enhanced by the high precipitation of 1000-1200 mm/year typical of the region. Final residual infiltration values were determined during calibration.

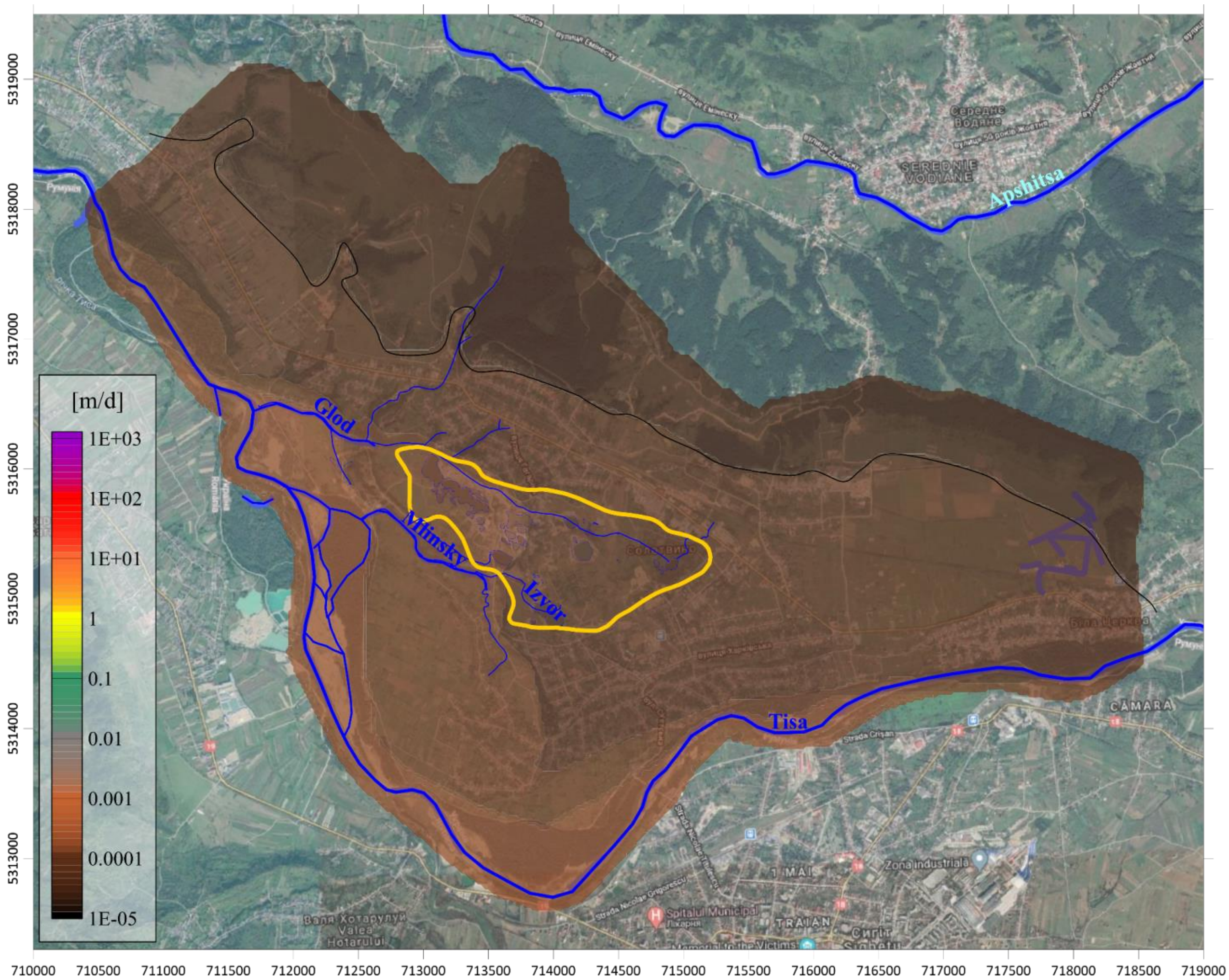


Figure 60. Recharge rates into groundwater

The largest river in the region, the Tisza, was adapted to the model with a river package, with an average width of 45-50 m and water levels of 280 m asl at the inlet and 249 m asl at the outlet. The average water column height in the river is 2 m. The river data were taken from the data of the staff of IGS NASU.

Smaller watercourses and streams were simulated with drains, like previous models. In the study area, streams run in shallowly incised bedrock, thus discharging into the high groundwater. When the groundwater is low, the streams become diving streams, so all small streams, not just Glod and Mlinsky streams, have been adapted to the system.

The distribution of groundwater levels in the area was based on water level measurements from Geogold Kárpátia Ltd. (**Figure 61**) and previous IGS NASU models.

We have identified 4 production wells in the area screened for the Pleistocene aquifer. All wells have a yield of 375 m^3/d. For the wells, NASU IGS data on location and production rates were used.

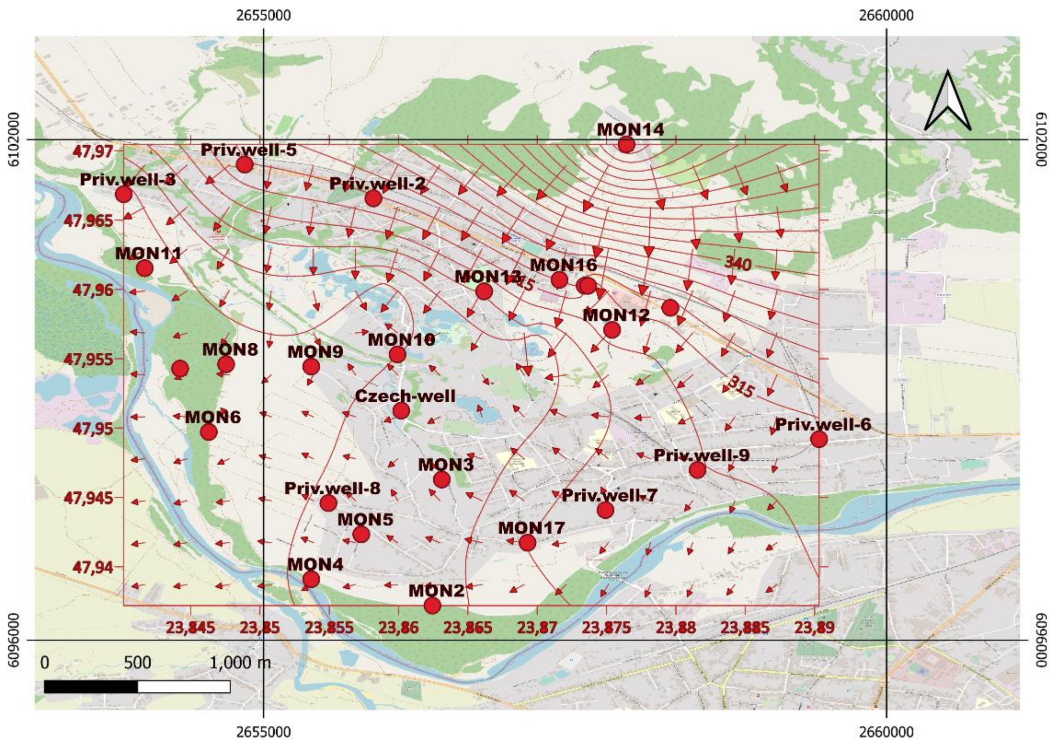


Figure 61. Groundwater flow potential map based on measurements during the July 2020 – October 2021 period (Geogold Kárpátia Ltd, 2021)

The brine transport model was built using the SEAWAT code developed by the USGS. The code was used to investigate chloride ion transport taking into consideration that only little information is available about the distribution of concentrations of different components, the transport parameters of individual rock formations, and many of the factors that influence transport processes. As such, the brine transport model produced needs to be further developed, checked with later available data, calibrated and validated in the future. The brine transport model as it stands is a first approximation, the results of which should be accepted with due caution.

The initial concentrations in the system are given by the concentration of saturated brine in the mine tailings, while the concentration distribution in the shallow aquifer is taken from the concentrations measured in monitoring wells and lakes. The initial concentration distribution is based on certain assumptions and hypotheses. To draw an accurate map more and uniformly distributed monitoring points for larger areas are required (**Figure 62**).

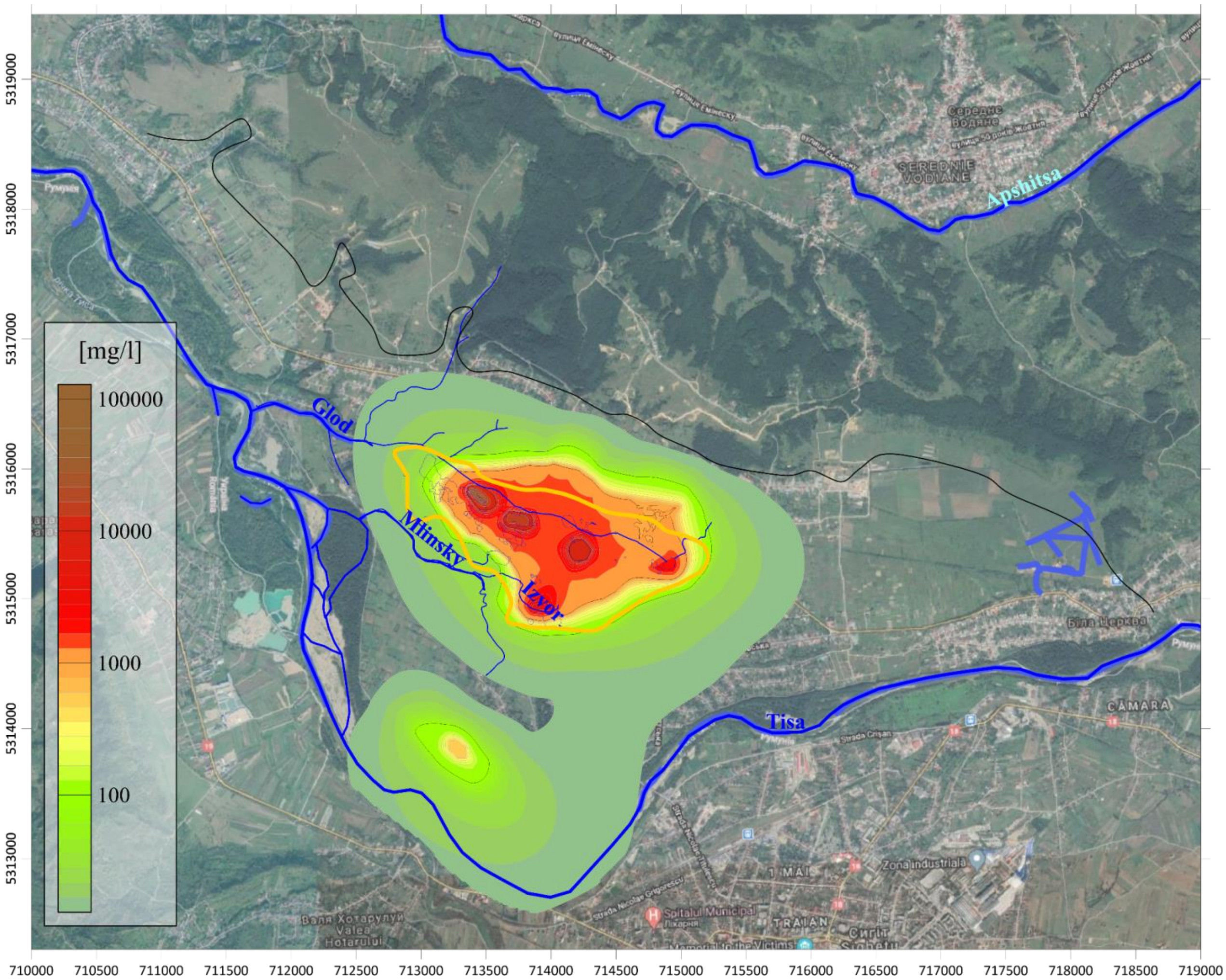


Figure 62. Hypothetical recent shallow groundwater chloride concentration distribution based on concentration and EC measurement data in the lakes, shafts and monitoring wells

With this solution, it was assumed that the saltwater lakes are connected to the terrace layer water due to infiltration, while for the freshwater lakes a balance between surface and groundwater was assumed. The distribution of points reflects local conditions and is obviously not a full representation of the actual concentration distributions, so in some places, assumptions were made in the map construction to reflect this concept.

Low chloride concentrations were assumed in the Magura Mountains and in the deeper

Miocene strata. In the calculations, only advective and dispersive transport was considered, since chloride ion is not an adsorbing and non-degradable component, so that, by definition, sorption and degradation processes in the system are negligible or not occurring.

The advective transport of the pollutant was calculated using the hybrid streamline method (Hybrid Method of Characteristics, HMOC). The method is characterized by the fact that where there are significant concentration variations, it uses the conventional MOC solution with many particles, while in places with less variable concentrations it uses the modified method of characteristics (MMOC), thus combining the advantages of both methods.

The numerical solution of the system of equations generated by the HMOC method was performed using a hybrid first-order Euler and fourth-order Runge-Kutta algorithm as a function of local concentration gradients. The Courant number was defined to be 0.75, which prevents the contaminant particle from travelling more than one cell during a time step, i.e., from skipping elements in the model.

The arrival of fictitious pollutant fluxes at the model boundary due to numerical errors resulting from the fulfilment of the mass retention can cause instability, which is stabilized by using fixed concentration elements (constant zero concentration) at the boundaries in the discharge situation (e.g. Tisza River region) (the solution does not prevent the movement of the pollutant towards the boundary, but rather, in principle, accelerates the transport processes due to a possible increase in concentration gradients).

The use of a hybrid method of characteristics based on linearization of the transport equation to reduce the numerical errors in the resulting system, and the use of fixed (constant) concentration elements, has reduced the absolute value of the numerical errors, providing a double protection.

To reduce the numerical errors, we have already used the uniform grid mesh (cell side dimensions 25x25m) in the hydrodynamic modelling to work with optimal transport time steps, both to reduce the numerical errors due to the reduction of the number of iterations and to reduce the computation times.

The dispersion of the pollutants under study is essentially determined by the phenomenon of dispersion, the effect of diffusion being of much less importance. The parameter characterizing diffusion is the effective molecular diffusion constant. The characteristic describing the hydrodynamic dispersion is the dispersivity [m], which multiplied by the cellular leakage rate [m/d] gives the hydrodynamic dispersion constant [m^2/d].

In determining the dispersion properties, we have considered the measurements of Altair Inc., who investigated the transport properties of "pallag" samples (**Figure 63**).

Since the diffusion transport fluxes are subordinate, the effect of the exact effective diffusion constant on the result is irrelevant, so an effective diffusion constant of $5 \cdot 10^{-6}$ m^2/d was calculated for the whole system. For the dispersity, a dispersity of 0.35 m was given for the coarser Pleistocene formations, 1 m for the fine-grained clay ("pallag") formations and 0.5 m for the Miocene formations. The horizontal transverse dispersivity was set to one tenth of the longitudinal dispersity and the vertical transverse dispersity to one twentieth of the longitudinal dispersity. The continuously changing river stages of Tisza River were adapted into the model by elevated dispersity values on the riverbank. Since the direction and velocity of flow in each cell is constant in time (permanent flow), but naturally varies from cell to cell in the permanent calculations we used, we used a constant in time but spatially varying dispersion parameter field in each element of the model.

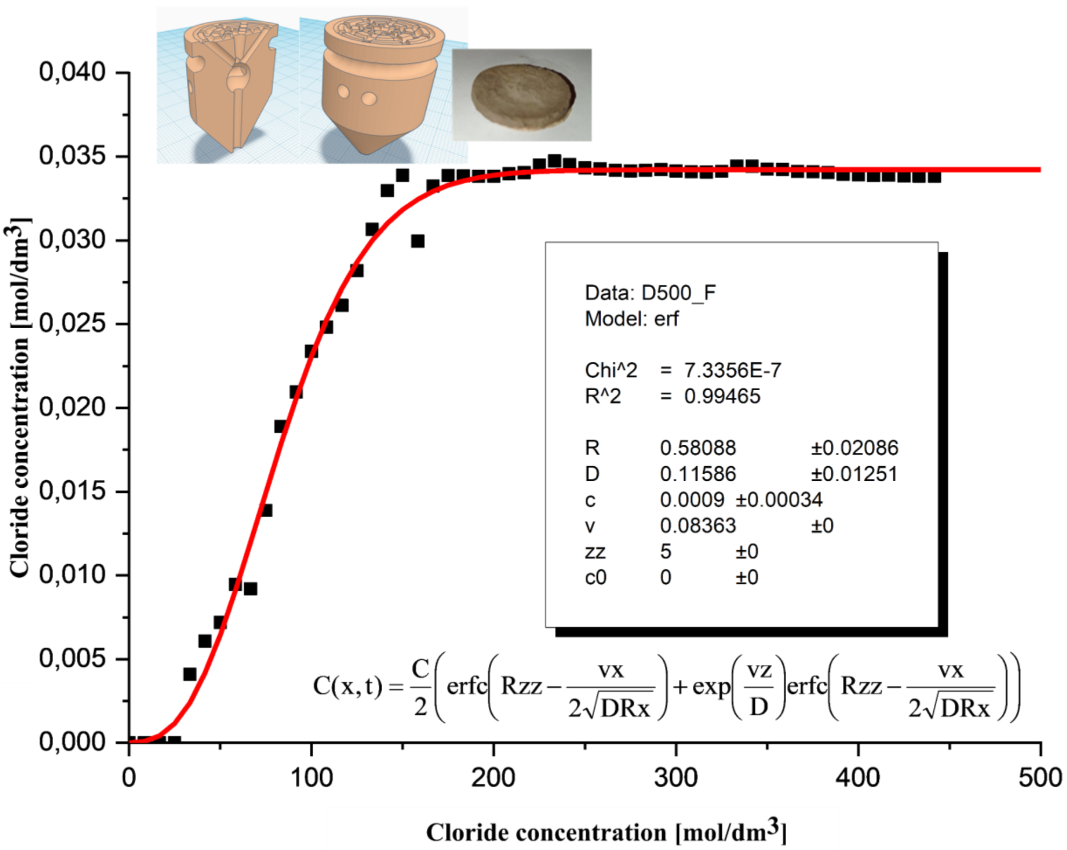


Figure 63. Determination of transport parameters (after Altair Inc., 2021)

We used the model to calculate both the hydraulic and chemical potential values (i.e., hydraulic heads (**Figure 64-65**.) and concentrations (**Figure 67-68**.) in the permanent leakage velocity space.

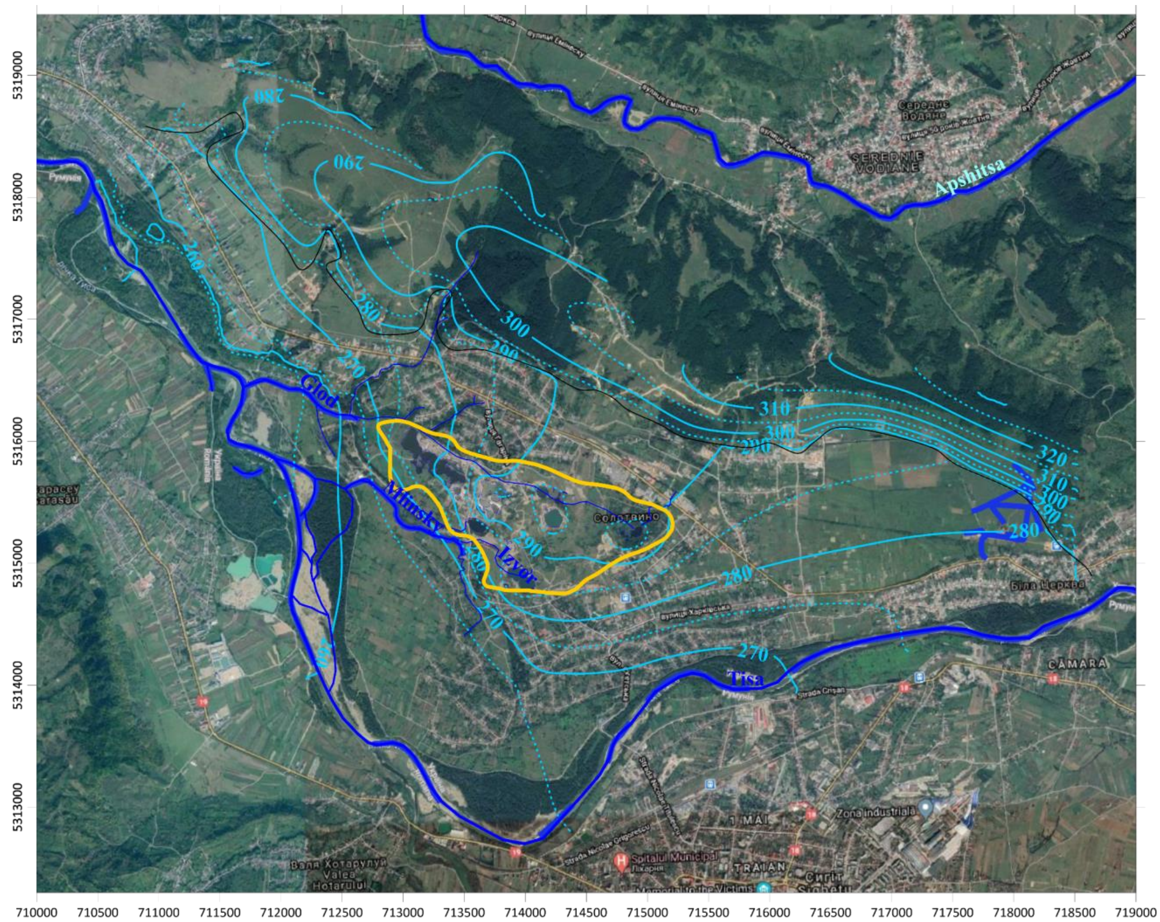


Figure 64.: Calculated hydraulic heads in the 1st model layer (mainly pleistocene)

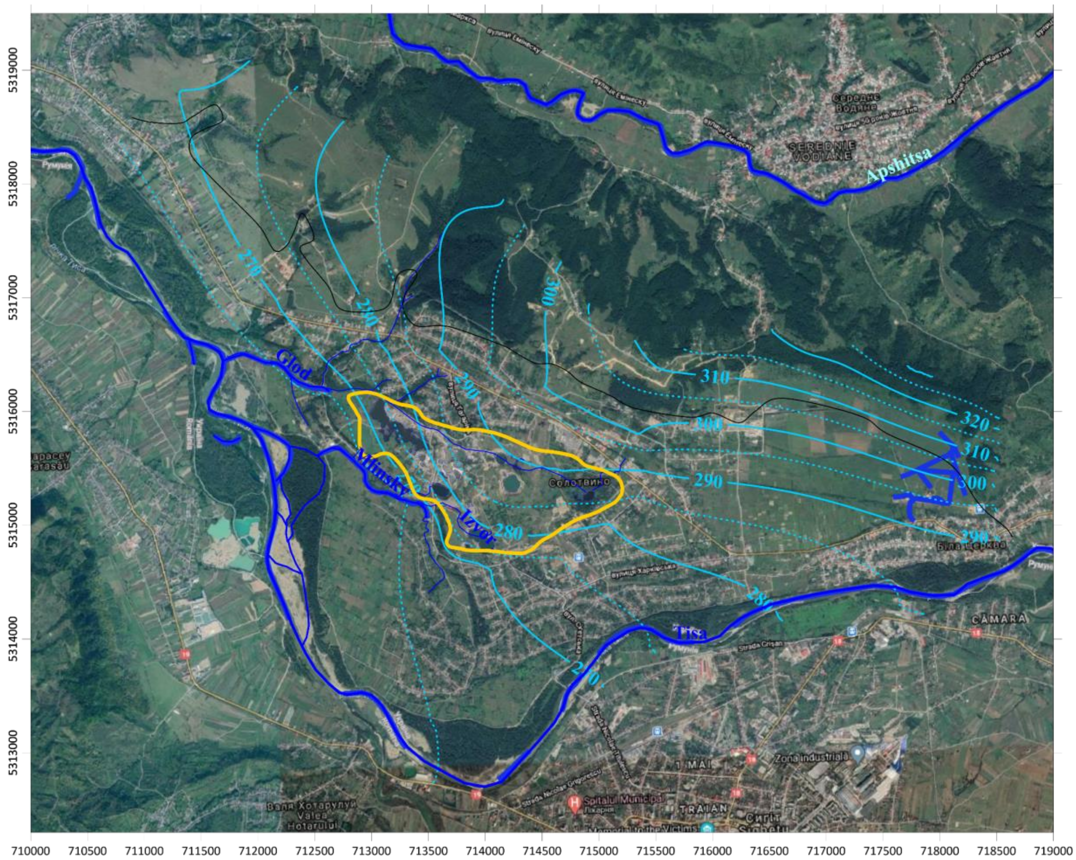


Figure 65.: Calculated hydraulic heads in the 5th model layer (Miocene and bottom part of the salt rocks)

The potential distributions are shown in Figure 64-65. From the figures the Tisza spatial potential levels are determined by the average water level of the river and that the Tisza is discharging the alluvial basin formations in the whole study-area. Groundwater seepage from the Magura Mountains continues to seep into the Tisza valley alluvium, with strongly decreasing hydraulic gradients, until it is discharged by the gravelly substrate of the Tisza. In this way, the Tisza River clearly takes up the salt load that is transported to the terrace layer through the terrace layer relicts above the Solotvyno (Aknaszlatina) salt dome.

The four production wells filtered onto the Pleistocene riverbank aquifer do not significantly affect the groundwater motion in the layer, but only create drawdown in the narrower vicinity of the wells. The recharge area of the wells lies around the Solotvyno (Aknaszlatina) salt ponds (**Figure 66**). The purpose of the operation of the wells is unknown to us, but in any case, it is calculated that they will not unload either the Tisza or the river bank layers from brine load on the downstream side of the salt lake but merely increase the fluxes of brine water above the salt lake and the volume of brine water leaving the ponds through the mining areas by 1500 m^3/d, and as such their effect will be more detrimental to the system than beneficial. The effect of the well series is only to reduce the salt load in the small area downstream of the wells, towards the Tisza.

According to water balance calculations to be refined in the future, 13-15 m^3/d of saturated brine is received directly from the salt mines, while about 15-16000 m^3/d of groundwater seeps through the surface area of the salt dome when the four wells are in operation.

Without the drawdown of the wells, the yield from the salt dome is 10-12 m^3/d, while the yield of water seeping in the Pleistocene aquifer in the salt dome area is 14000-14500 m^3/d.

The current brine load on the riverbank layers therefore comes from two sources, the 13-15 m^3 of saturated brine seeping up from the mines and the water seeping through the ponds in the former collapsed mine cavities.

Considering that the saturated concentration of salt is 360 g/l = 360 kg/m^3, the approximate salt load from the salt mines is 4.7 metric tons per day. If this mass is divided by the 15 000 m^3 of groundwater daily flux leaking through the salt lake area, a salt concentration of 310 mg/l (= 190 mg/l chloride concentration) is obtained, to which is added the salt yield from the water leaking through the salt ponds.

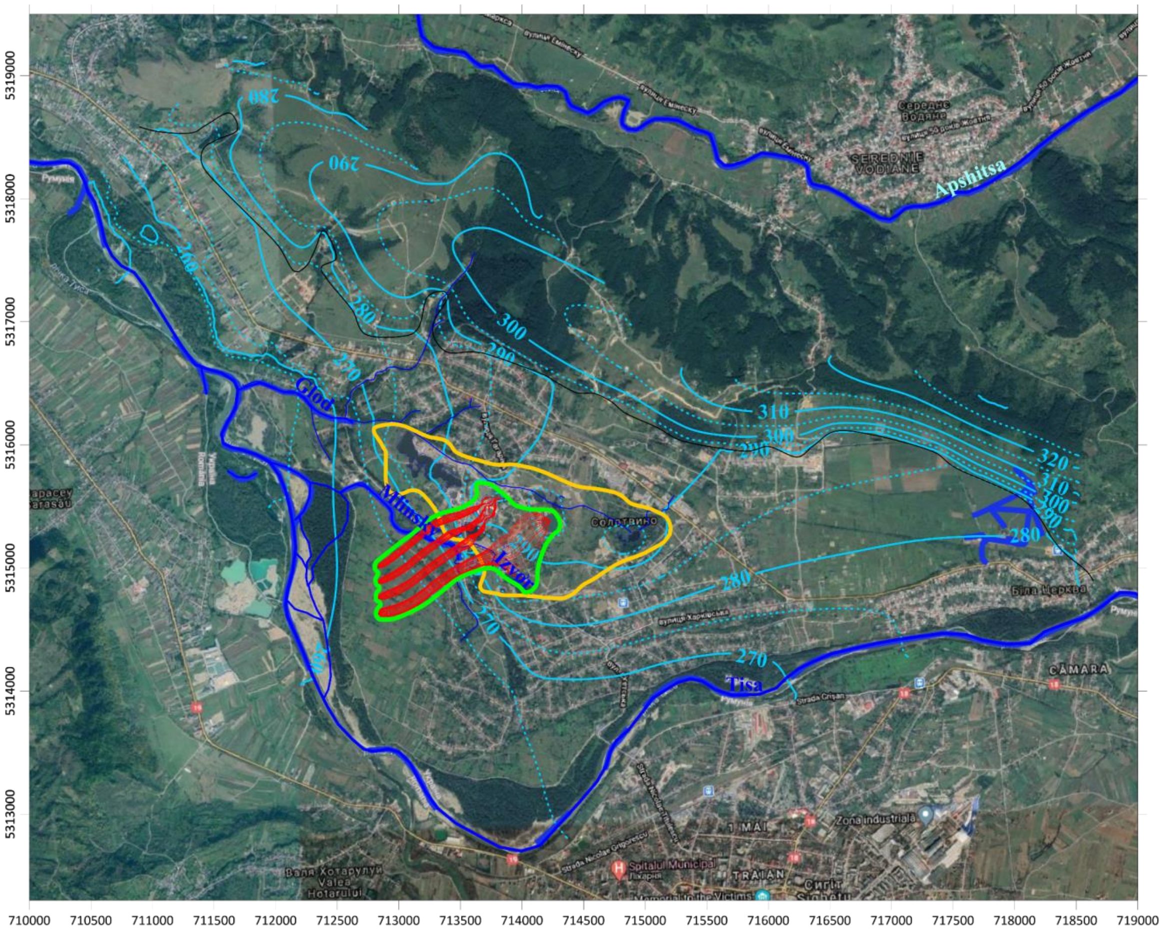


Figure 66. The pathlines from the production wells and the zone of influence related to production wells

For the latter, the water balance calculations give the following data: For the Dolphin Lake the water exchange between the Pleistocene aquifer and the lake is about 600 m^3/d, for the Ferenc Mine 600 m^3/d, for the #8 Mine 300 m^3/d, for Kunigunda Lake 450 m^3/d, which is about 2000 m^3/d in total. If we assume that, although the concentrations in the monitoring wells vary radically, the chloride concentrations in the wells closest to the lakes are no higher than 2000 mg/l, then the 2000 m^3/d of water exchange between the salt ponds and the groundwater would add roughly 4 metric tons of chloride per day to the Pleistocene layer, which could cause an additional 270 mg/l increase in chloride concentrations.

In total, a distributed chloride load of about 460 mg/l from the two sources and, assuming a Na/Cl=23g/35.5g mass ratio, a maximum sodium load of about 300 mg/l can be assumed.

The estimate is a rough and robust approximation and, in many respects, a worst case. This theoretical calculation does not take into account the effect of density-dependent transport of salt, which means that saturated brine is only released from the mine in the case of relatively strong upward seepage, and that in the case of low seepage the denser saturated brine is rather in the mine and is merely diffused into the ponds, so that the salt load of 4.6 t/d is in any case exaggerated. The calculation for the loading of the lakes is also overestimated in any case, given that the concentrations in the terrace layer fluctuate strongly and are practically based on the observed maximum. The concentrations in the lakes were not considered because of the unobstructed seepage between surface and groundwater due to the colmation of the lake bottom, and the concentrations in the lakes in any case assume an elevated concentration due to evaporation losses. It is therefore unlikely that the concentrations observed in the pond will be directly discharged into the Pleistocene aquifer.

In this way, it can be said that in the current state, a maximum of 4600 kg/d of NaCl is released from mines and 6600 kg/d from saltwater lakes, i.e. a total of 11 200 kg of rock salt is loaded into the Tisza River. Assuming a rock salt density of 2100 kg/m^3, this would result in a daily leaching of 5-5.5 m^3 of rock salt per day, which would mean a maximum of nearly 2000 m^3 of cavitation below the surface per year.

If we accelerate the flow of water from the mine areas, this yield can be increased regrettably easily, but by reducing the leakage, the environmental impact can be substantially reduced. The aim of regional water management from an environmental point of view is therefore to prevent further cavity collapses, to reduce mine water flows and to reduce the salt yields from the mine to the surface.

The figures obtained can be roughly estimated, since the 11.2 metric tons of rock salt per day entering a 15000 m^3/d water flow gives a total concentration of 750 mg/l of brines, which again, calculated using mass ratios, gives a chloride concentration of 455 mg/l and a sodium concentration of 295 mg/l. If we look at the observed concentrations, we see that they gradually decrease from 1500 to 2000 mg/l in the salt dome region away from the salt body, resulting in overall average concentrations of around 300 to 500 mg/l, which is in order of magnitude of the modelling and rough estimation.

Of course, the transport model was also used to calculate the evolving concentrations, which allowed us to obtain the expected extent of the plume and the evolving concentrations (**Figure 67-68**). The extent of the soda ash plume is an area of about 1 km^2 (98 ha), which covers practically the entire catchment of the Glod and Mlinsky creeks up to the Tisza.

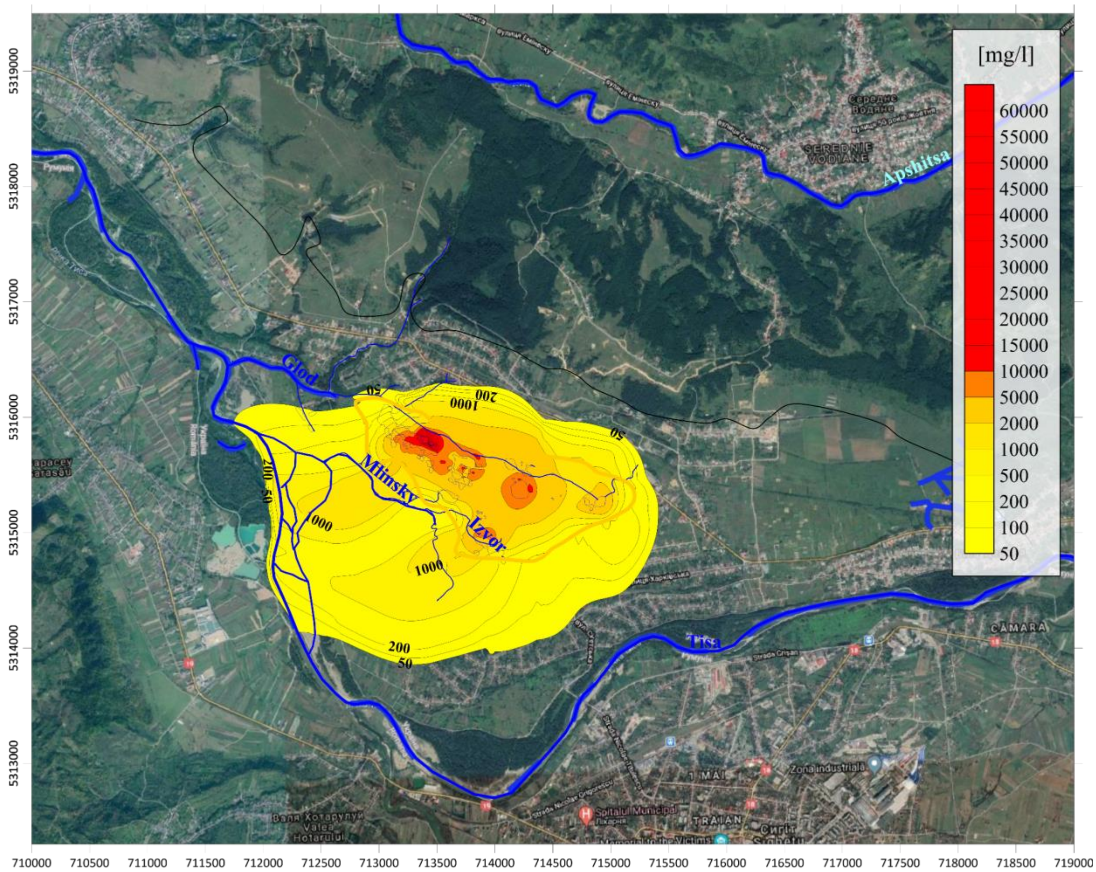


Figure 67. Estimated short term chloride concentrations (in 10-20 years)

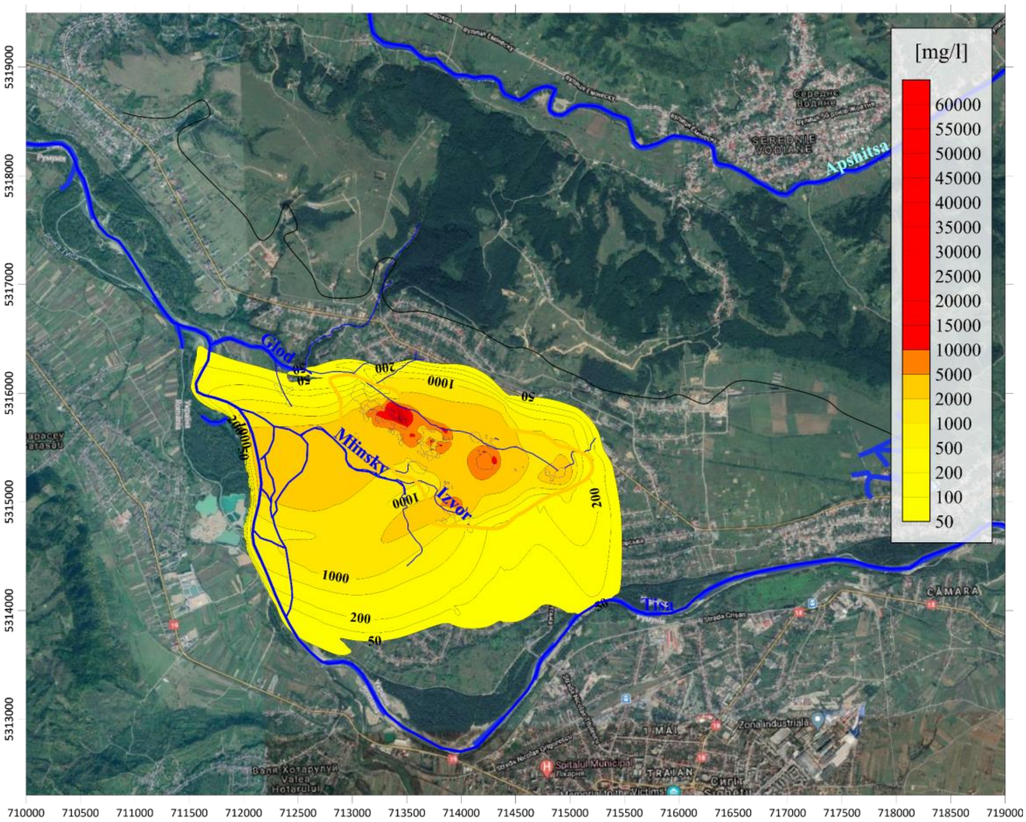


Figure 68. Estimated long term chloride concentrations

The area of influence cannot be reduced by wells, except by artificially reducing the flow of water through the bottom of the lakes formed by the collapse of the existing salt pits and continuously forming, by narrowing or blocking the exits of the pits and shafts even below the groundwater bodies, so that the salt water in the flooded mine pits is brought into full equilibrium by saturation, and in this way further desalination is induced only by fresh water infiltrating along the tectonic lines. This would not impede the use of salt ponds for tourism at all but would merely reduce the salinity load on the Pleistocene riverbank layer and the Glod and Mlinsky streams that discharges it. In this way, the salt concentration in the crater lakes (above collapsed mine chambers) would be reduced slightly, but the groundwater would be reduced substantially. Well water production should be eliminated or banned in the current area of influence of the salt dome.

Salt dissolution in deep layers must be curtailed, otherwise it will cause a steadily accelerating phenomenon, with increasing amounts of salt being dissolved along increasingly large, dissolved surfaces, causing ever larger underground cavities and accelerating

subsidence. The process can only be stopped by a radical reduction in deep groundwater flow, which is possible because of the geological and hydrogeological conditions. Reasonable solutions can slow the process down, and significant artificial interventions can reduce it completely, but this should be started as soon as possible, while it is still possible to reduce the process and the environmental damage does not destroy the living conditions of the population in the area.

3.9 Local Complex Monitoring Plan

3.9.1. Environmental State Monitoring for Solotvyno: Objectives, Regulations, Functions

Worldwide, former mining activities affect many regions; some of them taking place centuries ago. In many cases, the extraction and processing of raw materials carry an inherent risk to humans and the environment, first for geological subsoil as main „depo” of technogenic aftermaths.

An important aspect of post-mining research is the continuous monitoring of the mining area to get a full process understanding. With this process understanding, important (post-mining) aspects and effects can be derived.

In this research area, the researchers develop technical systems for the monitoring of post-mining activities with the aim of combining remote-sensing methods, geophysical survey, geogetic measurements, modelling and/or simulating the risks and bringing them together to form integrated risk management systems. Thus, in the future, all essential processes in post-mining can be monitored efficiently, and preventive measures can be initiated. The application of satellite data allows the detection of ground motion and thus the potential prognosis of the occurrence of subsidence and sinkholes. By integrating the results from remote sensing with the underground analysis the overburden, significantly improved interpretations and forecasts can be achieved, which are also important for risk forecast, assessment, and management.

Monitoring of the geological environment - a system of observation, collection, processing, transmission, storage, and analysis of information about the state of the geological environment, forecasting its changes, development of scientifically based recommendations for making relevant decisions.

Monitoring of the state of the geological environment is carried out in relation to: exogenous and endogenous geodynamic processes (including determination of their spatial characteristics, activity of manifestations); groundwater (including assessment of resources, their hydrogeological and hydrochemical indicators and properties); geochemical indicators; geophysical parameters etc.

And, a sufficient element of geological natural environment state analysis of Solotvyno is the monitoring of natural and anthropogenic hazardous geological processes development that are potentially dangerous for the population: karst & suffosion (subsidence, sinkholes, collapses), seasonal floods and flash floods, flooding, slope mass movement (erosion, landslides).

The legal principles of environmental monitoring are regulated by the Law of Ukraine "On the Protection of the Natural Environment" (*https://zakon.rada.gov.ua/laws/show/1264-12)*, the main principles of the operation of the SSME are defined in the Resolution of the Cabinet of Ministers of Ukraine dated 30.03.1998 No. 391 "On Approval of the Regulation on the State System of Environmental Monitoring" (*https://zakon.rada.gov.ua/laws/show/391-98-%D0%BF/conv*).

The legal definition and support of the organization and implementation of the State Environmental Monitoring System in the part of State water monitoring is determined by the following legal acts:

- Water Code of Ukraine *(https://zakon.rada.gov.ua/laws/show/213/95-%D0%B2%D1%80#Text*);

- Law of Ukraine "On the approval of the State-wide target program for the development of water management and ecological improvement of the Dnipro river basin for the period until 2021" (*https://zakon.rada.gov.ua/laws/show/4836-17#Text*);

- Resolution of the Cabinet of Ministers of Ukraine dated September 19, 2018 No. 758 "On approval of the Procedure for State Water Monitoring" (*https://zakon.rada.gov.ua/laws/show/758-2018-%D0%BF#Text*).

The Law of Ukraine "On the State Geological Service of Ukraine" contains the concepts of "monitoring of the geological environment" and "monitoring of the mineral and raw material base" and, among other main tasks, assigns the State Geological Service of Ukraine the task of monitoring the mineral and raw material base, geological environment and groundwater (*https://zakon.rada.gov.ua/laws/show/1216-14#Text*).

An important aspect of national legislation is the provision of Article 22 of the Law of Ukraine "On Environmental Protection" (*https://zakon.rada.gov.ua/laws/show/1264-12#n351*), which provides for monitoring the state of the environment and the level of its pollution by enterprises, institutions and organizations whose activities lead or may lead to the deterioration of the environment. In addition, it is stipulated that the mentioned enterprises, institutions and organizations are obliged to transfer the analytical materials of their observations to the relevant state bodies free of charge.

Chapter 6 of the Water Code of Ukraine provides for the maintenance of State water records and the State Water Cadastre (*https://zakon.rada.gov.ua/laws/show/213/95-%D0%B2%D1%80*). The task of State water accounting is to establish information on the quantity and quality of water, as well as data on water use, on the basis of which water is distributed among water users and measures are developed for the rational use and protection of water and the reproduction of water resources. In accordance with the Procedure for keeping state records of water use, the organization of State records of water use is carried out by the State Water Agency and entrusted to the State Water Agency and the State Emergency Service (in the part of surface water) and the State Geonadra (in the part of underground water).

The Law of Ukraine On Environmental Impact Assessment dated May 23, 2017 No. 2059-VIII establishes the legal and organizational principles of environmental impact assessment aimed at preventing environmental damage, ensuring environmental safety, environmental protection, rational use and reproduction of natural resources, in the process of making decisions on the implementation of economic activities that may have a significant impact on the environment, taking into account state, public and private interests. *(https://kodeksy.com.ua/pro_otsinku_vplivu_na_dovkillya.htm).*

To the list of EU standards:

- Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive);
- Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage;
- Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration;
- Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on

the management of waste from extractive industries and amending Directive 2004/35/EC – Statement by the European Parliament, the Council and the Commission;

- Commission Directive 2009/90/EC of 31 July 2009 laying down, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, technical specifications for chemical analysis and monitoring of water status (Text with EEA relevance);
- Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (Text with EEA relevance);
- Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context (2008);
- ISO. 2009. ISO 31000: Risk Management – Principles and Guidelines on Implementation. International Organization for Standardization. 26 p.;

Analysis of the actual policies and directives related to the environmental problem in post-mining areas in EU are the following (DEMINE-project);

- Several administrations and sectorial departments have competence over wastewater from abandoned mines. In many cases, the administration that must deal with the treatment of mine effluents is not clearly identified. Regulations should clearly identify the administration responsible for treating the wastewater.
- The criteria used by member States for the declaration of the “National inventory of dangerous extractive industries to health or the environment” are not clear. Administrations responsible for water management should perform a periodic sampling on those mining effluents from abandoned mines considered to be of greatest risk, followed by a risk analysis with regard to the river that received these effluents.
- The European legislation does not establish thresholds for most metal pollutants despite its recognized toxicity for the environment. Each Member State defines their own limits. This creates a great disparity in thresholds limits across Europe that should be unified.
- In the European legislation, salinization of freshwaters is not considered an important problem and no legally prescribed environmental quality standards exist for salt. Salinity standards for specific ions and ion mixtures, not just for total salinity, should be developed to protect freshwaters.

Geological control over the study and use of subsoil regulated *i*n accordance with the Regulation on the State Service of Geology and Subsoil of Ukraine, approved by the Cabinet of Ministers of Ukraine Resolution No. 1174 dated 12.30.2015 (as amended), the State Geosoil Service implements the state policy in the field of geological study and rational use of subsoil.

Regarding the territory of Solotvyno, the main functions of the monitoring system include monitoring of:

- the condition of buildings and natural objects in the zone of influence of the mine field;
- the state of the subsoil in the zone of influence of mining operations;
- the state of hydraulic facilities in organizations under the control of state mining supervision bodies;
- flow rates, level and composition of surface and underground waters;
- pollution caused by the use of subsoil, surface water and geological environment, including underground water;
- compliance with the established regime in zones and districts of sanitary and mining-sanitary protection of underground water deposits, as well as minerals classified as balneological;
- development of mineral deposit areas;
- landslide susceptibility areas;
- accounting for the movement of mineral reserves (in case of legalization of the use of brines, they will be considered as minerals);
- expert assessments and forecasting of the harmful impact of mining operations on the environment, the level of rational and integrated use of mineral reserves and the provision of subsoil protection.

On the territory of Solotvyno, the formation of an unbalanced complex natural and man-made geosystem of the zone of technogenic impact of salt mines is taking place, which relates to the formation of ecological threats to the safety of life in the territory of the Solotvyno settlement.

Now, a modern monitoring system of the above-mentioned natural and man-made geosystem is extremely necessary, which would provide an opportunity for timely detection and assessment of dangerous changes in the state of the geological environment and factors of threats to the safety of life at the local and cross-border level.

To assess the risks and forecast the development of the above-mentioned hazardous processes, it is necessary to monitor the development of karst, subsidence (earth surface deformations), quantity & quality of surface and underground waters (levels and chemical composition).

Groundwater quality monitoring is one of the most important aspects of protecting groundwater resources. This is best achieved by constructing a network of wells. Undesirable environmental impacts can thus be detected at an early stage and remedied effectively. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Wells required upstream and downstream, in the direction of groundwater flow to monitor changes in water level and quality across a site and to monitor the performance and stability of parameters. Also wells must be located within geological features that are most likely to transmit groundwater, such as along fault lines or in alluvial sediments.

3.9.2. Vision on monitoring of Solotvyno waters

Water quality and quantity monitoring in surface and groundwaters

The evaluation of water issues and the implementation of management solutions require hydrogeological data. The purpose of water quality monitoring is to observe spatial and temporal changes in salinity, to explore the causes of changes in state, to classify waters, to classify the state of water quality, to compare it with water quality limit values, and to estimate annual and seasonal averages and critical concentrations. The quantity monitoring is needed to detect potential changes in groundwater flow and to follow the depth variation in hydraulic head.

The period of observation was between June 2020 and May 2022. During this time, a monitoring network consisting of a total of 49 monitoring points was designated and examined. **Of these, 13 locations apply to the monitoring of changes in the quality and quantity of surface water (6 points in the Tisza, 6 mining lakes, 1 freshwater lake), and 36 locations using existing wells and monitoring wells deepened during the project.**

In the case of the 36 locations, 7 piezometer wells (with an average depth of 10 m, enabling the recording of the water level/flow pattern of the waters moving in the alluvium and the water chemistry tests as well) were installed in the immediate vicinity of the Tisza River, parallel and perpendicular to the flow direction, 8 in the background area, in the interior of the settlement.

The 1-year monitoring comprised the collection, analysis, and storage of a range of data on a regular basis according to specific circumstances and objectives.

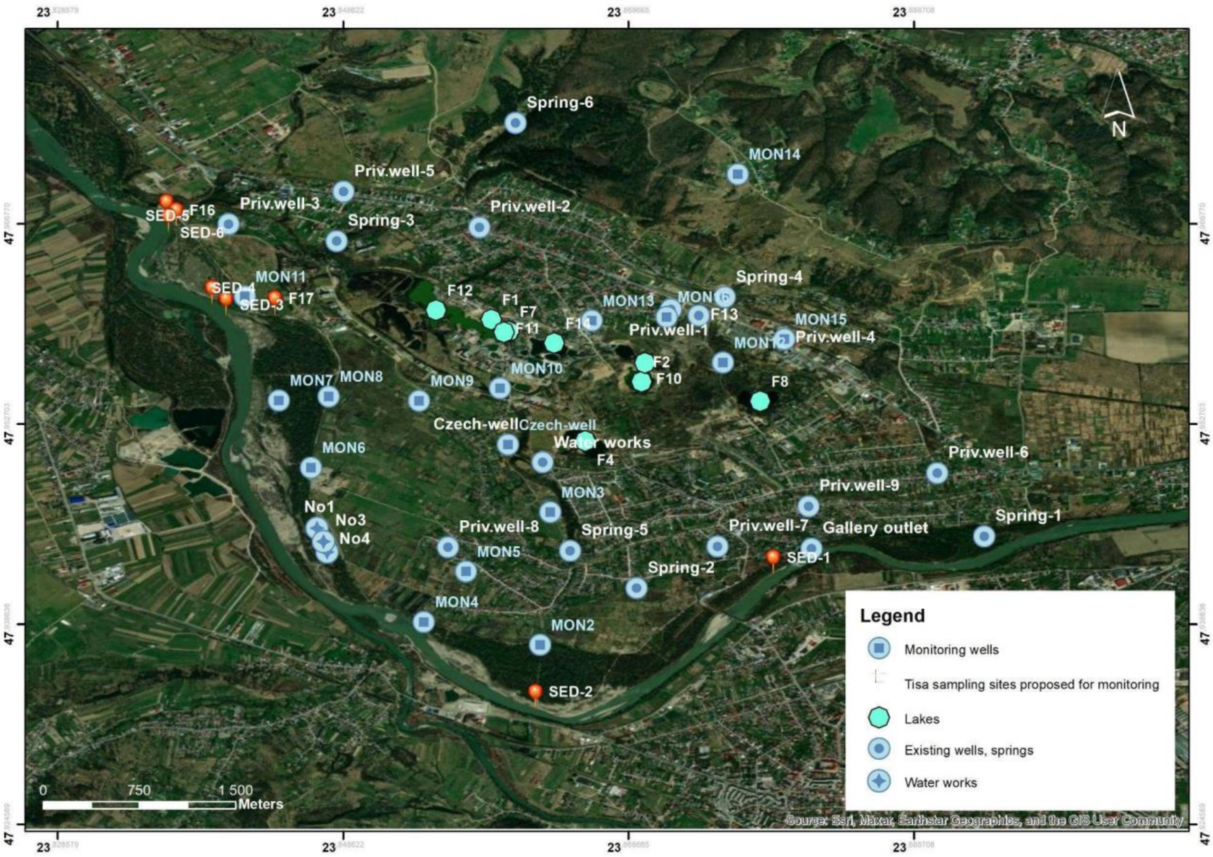


Figure 69. The residential and water supply wells, springs, outfalls, lake sampling sites, etc. that form the basis of the planned monitoring network, partly made of during the project, as MON piezometers, and partly included the others in the one-year measurement. *(Geogold Ltd)*

3.9.3. Complex Monitoring System Plan for Solotvyno salt mine area and its surroundings

Based on obtained studies results (field observations, remote sensing satellite radar monitoring data analysis, geological and hydrodynamic modelling) the complex monitoring system plan, which fits into the wider regional framework for tracking the surface and near subsurface water qualitative and quantitative changes and the ground surface deformations in Solotvyno area have been developed (Figure 70, Table 3).

Planned Complex Monitoring System includes:

I. ***Remote sensing*** (satellite radar monitoring of ground surface deformations using DInSAR with corner reflectors).

Assessment of displacements and deformations of the ground surface using interferometric processing of satellite radar monitoring data with PS & SBAS techniques.

II. Hydrological and hydrogeological monitoring

Water Quantity (levels & flow rate for hydrological observation points (river, springs) & Quality (temperature, pH, conductivity, TDS (total dissolved solids), alkalinity, acidity, hardness, macro components - sodium, chlorine, sulphates; micro components - Br, I etc.).

Proposed hydrological and hydrogeological monitoring network contains: **9** hydrological observation points (4 – Tisza River; 3 – lakes, 2 – flooded mines #7, 8 collapses); **24** hydrogeological observation points / wells (including 5 combined points, which consist of two wells: for the Quaternary unconfined and Tortonian fractured aquifers).

Monitoring wells design of conditional areas with combined lithological sections have been provided for the hydrogeological observation points for the Quaternary unconfined and Tortonian fractured aquifers (Figure 71). Description of the conditional area with a combined lithological section (hydrogeological observation points for the Quaternary unconfined aquifer) (Table 4).

III. Geophysical survey

Containing microgravity, geoelectric and seismic methods within the revised risk area. Assessment of geological environment state (stability). Estimation of geophysical anomalies. Microgravity – new data on surface structure changes of the salt dome and overlying rocks.

IV. Geodetic survey

Verification of remote studies of the ground surface deformations (interferometric processing of satellite radar monitoring data).

The geospatial development of ground surface deformations outside the mining area requires the organization of systematic geodetic monitoring of critical infrastructure objects sites; large housing complexes areas (permanent residence); within sites adjacent to the mines collapses and mining facilities (water drainage galleries, water drainage systems, etc.; as well as an abandoned military facility (fuels storage);

V. On-site inspection

Examination and evaluation of the current environmental state of the area; data collection and analysis on karst development (sinkholes: geometric dimensions and frequency of occurrence, ground subsidence etc.) for critical infrastructure objects sites and large housing complexes areas (permanent residence); within sites adjacent to the mines collapses and mining facilities (water drainage galleries, water drainage systems, etc.; as well as an abandoned military facility (fuels storage);

VI. Modelling

Improvement of hydrodynamic model, up-to-date actualization according to hydrological and hydrogeological monitoring data obtaining;

VII. Risk assessment

Analysis of hazardous geological processes development; Reassessment of high-risk zone of technogenic impact of salt mines and development of the hazardous exogenous geological processes (up to date/yearly).

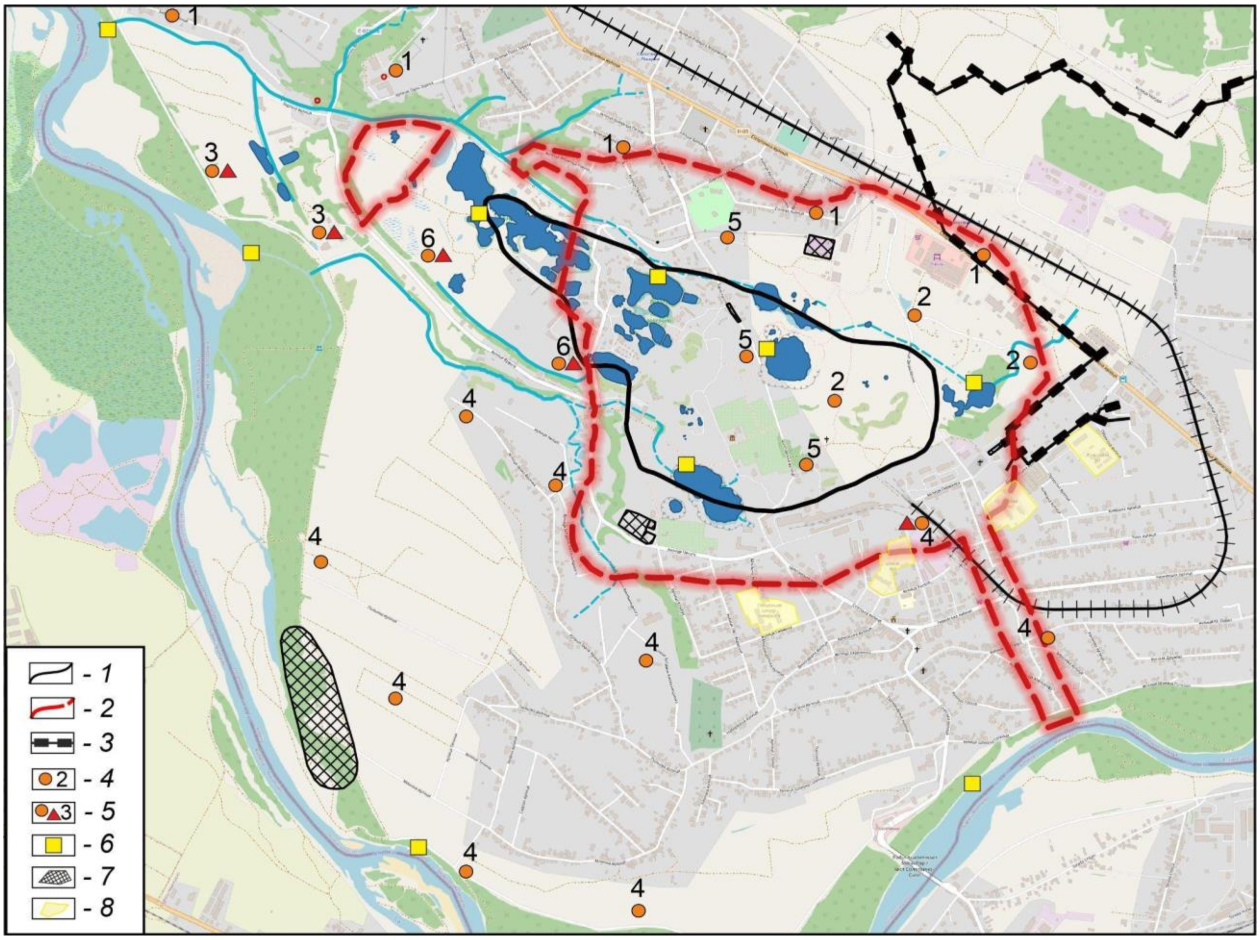


Figure 70. Complex Monitoring System Plan of the Solotvyno salt mine area and its surroundings: 1 – contour of the salt dome structure on the surface of alluvial sediments; 2 – zone of technogenic impact of salt mines and development of the hazardous exogenous geological processes; 3 – gas pipeline; 4 – project monitoring hydrogeological observation point (well) and the number of the consolidated geological section type according to lithological data; 5 – project monitoring hydrogeological observation point (combined point, which consists of two wells: for the Quaternary unconfined and Tortonian fractured aquifers) and type number of the consolidated geological section according to lithological data; 6 – project monitoring hydrological observation point; 7 – critical infrastructure objects; 8 – preschool and school educational institutions

Table 3. Planned Complex Monitoring System

#	Methods of geomonitoring	Purpose (information gained)	Details	Frequency
I	Remote sensing (satellite radar monitoring of ground surface deformations using DInSAR with corner reflectors)	Assessment of displacements and deformations of the ground surface using interferometric processing of satellite radar monitoring data	The corner reflectors' location scheme within DInSAR studied area (PS & SBAS techniques)	Twice a year April & November
II	Hydrological and hydrogeological monitoring	Quantity (water levels & flow rate for hydrological observation points (river, springs) Quality & chemical composition (temperature, pH, conductivity, TDS (total dissolved solids), alkalinity, acidity, hardness, sodium, chlorine, sulphates, macro-, microcomponents - Br, I)	Contains: - **9** hydrological observation points (4 – Tisza River; 3 – lakes, 2 – flooded mines #7, 8 collapses); - **24** hydrogeological observation points / wells (including 5 combined points which consist of two wells: for the Quaternary unconfined and Tortonian fractured aquifers)	Monthly (quantity) Monthly (quality - automatically measured parameters) Quarterly (sampling for laboratory analysis)
III	Geophysical survey within the revised risk area	Assessment of geological environment state (stability) Estimation of geophysical anomalies Microgravity – new data on surface structure changes of the salt dome and overlying rocks	Containing microgravity, geoelectric and seismic methods	Annually (during groundwater low period)
IV	Geodetic survey	Verification of remote studies of the ground surface deformations (interferometric processing of satellite radar monitoring data)	Sites of critical infrastructure objects and large housing complexes areas (permanent residence); within sites adjacent to the mine collapses and mining facilities (water drainage galleries, water drainage systems, etc.; as well as an abandoned military facility (fuels storage)	Annually (during groundwater low period)

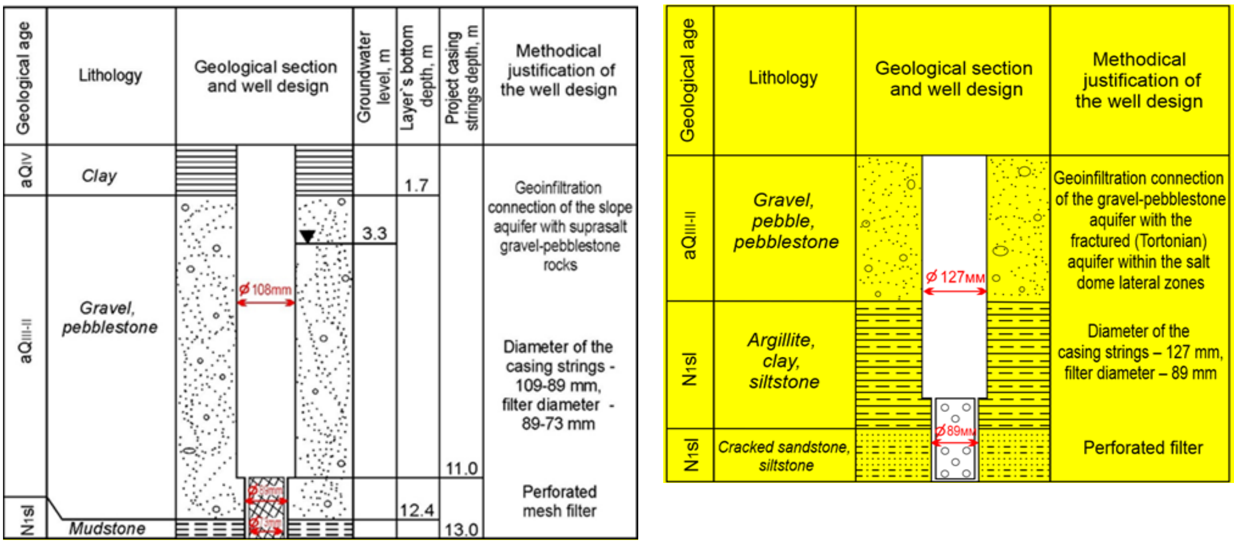
V	On-site inspection (field visual monitoring observations) of hazardous geological processes development	to examine and evaluate the current environmental state of the area data collection and analysis on karst development (sinkholes: geometric dimensions and frequency of occurrence, ground subsidence etc.)	Field visual monitoring observations of hazardous geological processes development for critical infrastructure objects sites and large housing complexes areas (permanent residence); within sites adjacent to the mine collapses and mining facilities (water drainage galleries, water drainage systems, etc.; as well as an abandoned military facility (fuels storage)	Twice a year
VI	Modeling	Improvement of hydrodynamic model based on hydrological and hydrogeological monitoring data		Up-to-date actualization according to hydrological and hydrogeological monitoring data obtaining
VII	Risk assessment	**Analysis of** hazardous geological processes development; Reassessment of high risk zone of technogenic impact of salt mines and development of the hazardous exogenous geological processes		Up-to-date/yearly

Table 4. Description of the conditional area with a combined lithological section (observation point)

№ of a conditional area with a combined lithological section (observation point)	№ of wells included in the conditional area	Top, m	Bottom, m	Water level, m	Lithology
1	MON-16, g-40/1957, g-17/1957	0,0 1,7 12,4	1,7 12,4 20,5	3,3	Clay Gravel, pebblestone Mudstone
2	MON-12, 14/1957, 15/1957	0,0 26,2 106,8 127,9	26,2 106,8 127,9 433,0	12,0	Pebblestone Siltstone and mudstone interlayering Mudstone Rock salt

3	MON-8, MON-9, g-42/1957, g-48/1957	0,0 4,4	4,4 9,2	3,2	Pebblestone Mudstone
4	MON-4, MON-5	0,0 8,1	7,2 12,0	5,4	Pebblestone Clay, mudstone
5	MON-13, 25/1957, g-61/1957	0,0 13,7 46,1 70,7	13,7 46,1 70,2 184,5	10,2	Pebblestone Mudstone, clay Sandstone and siltstone interlayering Rock salt
6	MON-10, 60/1970	0,0 4,0 8,0 216,7	4,0 8,0 216,7 543,0	3,4	Pebblestone Clay Mudstone and sandstone interlayering Rock salt (well 60/1970)

Monitoring wells design of conditional areas with combined lithological sections (hydrogeological observation points for the Quaternary unconfined and Tortonian fractured aquifers as examples) are shown in the Figure 71.



a *b*

Figure 71. Consolidated well design of monitoring hydrogeological observation point: a – for the Quaternary unconfined aquifer (conditional area No. 1); b – well design of observation point on the fractured (Tortonian) aquifer

Conclusions

- **Operation of the monitoring system are required for the sustainable use of natural resources (brines and rock salt) and protection against transboundary spread of surface and underground water pollution.**
- **Based on obtained studies results (field observations, remote sensing satellite radar monitoring data analysis, geological and hydrodynamic modelling) the complex monitoring system plan, which fits into the wider regional framework for tracking the surface and near subsurface water qualitative and quantitative changes and the ground surface deformations in Solotvyno area have been developed.**
- **Planned Complex Monitoring System includes monitoring of ground surface deformations using DInSAR; hydrological and hydrogeological monitoring (water quantity & quality); geophysical survey (microgravity, geoelectric and seismic methods); geodetic survey; on-site inspection of hazardous geological processes development; modeling (up-to-date improvement of hydrodynamic model); risk assessment, preliminary substantiations of protective measurements.**

Recommendations

- **The implementation of a monitoring system with an integrated permanent hydrodynamic model should become a tool for managing the use of natural resources in the Solotvyno settlement – brines and rock salt – as the main factor for its sustainable economic and social development.**

4. Summary of achievements and conclusions

4.1 Suitable and sustainable salt-water management

The investigations and previous analysis of collected data (geological, hydrogeological water quality and quantity) of Solotvyno salt mine area revealed that the groundwater in the area has deteriorated. The model results revealed that the flow direction is going toward the Tisza River carrying salt-water from the mining area to the river. For sustainable salt-water management in the area sustainable solutions should be provided to protect the area and Tisza River from contamination based on hydrological model results. As suggested from previous studies, re-open the salt mining in this area with new constraints could help in solving the problem, but if it is not possible other options can be provided and assessed through modelling and investigations. The solutions depend on different parameters including, the flow direction, amount of water, types of salts and concentrations and different activities in the area.

For salt-water management in the study area, we suggest three different techniques based on the available data and investigations:

1. Design and construction of a dewatering system surrounding the cultivated mining area for protecting the area and Tisza River from contamination. The wells system abstracts the contaminated water and pumps it to a small treatment plant. The dewatering could help in lowering the groundwater level in the study area and prevent the flow of contaminated water to the Tisza River. The abstracted water can be treated in a treatment plant according to the type of contaminants and concentrations then used for different purposes such as agriculture, irrigation of farm trees and green areas, etc.
2. Design and construction of vertical barriers from impermeable materials surrounding the cultivated mining area that prevent the movement of groundwater flow towards the Tisza River. This could intersect the flow direction and direct it to other directions based on the topography and land use.
3. Design and construction of French trench surrounding the cultivated mining area that consists of vertical trench filled with permeable material that direct the flow into a pipe with holes laid at the base of the trench with a slope that direct the water to sumps then the collected water can be collected, treated, and used for different purposes such as agriculture, irrigation of farm trees and green areas etc.

The above three techniques can prevent the movement of contaminated water into the study area and towards the Tisza River. The techniques should be modelled using hydrological model and select the best alternative then design the selected one based on the hydrological model results as following:

1. The first technique requires selection of well locations that intersect the flow direction towards the river, determine the number of wells, diameter, depth, spacing between wells and abstraction rates. The design of the treatment plants should be provided based on the capacity of the plant and the uses of water can be selected based on the activities in this area.

2. The second technique requires selection of barrier locations that intersect the flow direction towards the area and the river, determine the width and depth of the barrier and then select the material that will be used.
3. The third technique requires selection of trench locations that intersect the flow direction towards the river, determine the width and depth of the trench and then design the pipe and the sump that will be used to collect the water. The collected water can be used for different purposes after treatment.

All the above systems need the establishment of a monitoring system consisting of piezometer wells to monitor the changes in groundwater levels and take samples for water quality assessment.

Also, the flooding due to heavy rain should be assessed and the direction of flood can be diverted or controlled using some structures such as dams to prevent the flow loaded by salts that go to the Tisza River and cause contamination.

Finally, the first stage of the project has been done with aims of monitoring and investigation of the problem and detecting its causes and spread of the contaminants in the area.

We suggest a second stage of the project that could assess different techniques for management of salt-water in the study area and Tisza River. Then select and design the best technique that can be implemented to protect the area from contamination based on social, economic, and environmental aspects.

4.2 Ground movements and assets protection (buildings, infrastructures)

It is of great importance to reconsider land use and urban planning according to hazardous areas as the situation is still quite uncertain especially regarding the underground and groundwater movements and land movement in deeper layers.

The socioeconomic damages and the negative economic impacts would be much higher in case the subsidence and landslide affect a public institution or a public utility as relatively low numbers of households are in imminent threat. In Solotvyno both are possible. The incidental damage of the gas pipeline, the drinking water or the electric power system would generate enormous losses for the settlement, not to mention the transport system, because the main road and the railway ensure the transport of the local products and resources in the potentially affected zone. Without these connections the local factories and businesses would be out of operation. Moreover, a school, a kindergarten and two municipal institutions are in the danger zone too, where the affected social groups are outstandingly vulnerable.

Recommendations

- Rethink the land use planning and urban development policy by strict zoning and strict construction permits that push new developments to focus on areas with low hazards.
- Support mobile structures and buildings of high-quality materials that can be more resilient to landslides, cracks and other movements.
- Adapt a monitoring system and survey from time to time the condition of buildings.
- Relocation and any new developments of larger scale should consider the wider socio-economic relations, the urban fabric and community ties within the settlement, and territorially integrated approach should be supported that stretches beyond the sole demolition and construction of individual buildings.

4.3 Protection of environment

4.3.1 Solid waste management

One of the most crucial areas to reinforce protection of the environment is to support a comprehensive waste management system. The proportion of recycling is very low. Depositing of the waste in landfills is the accepted and common way of waste management; the proportion of this method in Tiachiv Raion was 97.9% (5 894.8 tons) in 2020. The official landfill is located next to the hole of mine 7, which has a negative effect on the local waters and soil. Since there is no other place to bring waste, this is the only landfill around.

The reform and development of strict waste management is crucial because the landfill-usage and the unregulated disposal of solid waste are a great risk to health and the environment, since it does not just impair the quality of the salt resource, the drinking water and the fresh water of the Tisza, but it deprives the region of its potential developmental opportunities (tourism etc.).

Recommendations:

- It is recommended to cooperate in creating, maintaining, and developing waste management systems by building knowledge exchange opportunities as well as technology transfer, know-how exchange with the Hungarian organisations responsible for waterworks and sewage treatment.
- Encourage circular economy approaches, first by improving waste processing that can also provide additional jobs and income.
- Eliminate illegal ad hoc landfills and filled sinkholes along the floodplain of the Tisza in and around Solotvyno. Try to reuse or recycle the removed materials and waste.
- Establish a new modern landfill facility of EU standards further away from the river and the salt mines, and protect the surface and ground waters from pollution and transmission.

4.3.2 Protection of the Tisza River

Salt loading of the Tisza is a long-term process, probably lasting several decades, but it was mostly hidden due to the lack of control, monitoring stations, and larger and more spectacular mine disasters.

From around the end of 2006, spectacular sinkholes and craters were created, which are still visible today and they enlarge over time. Due to these phenomena, extremely high values of electrical conductivity (EC) and chloride content exceeding the limit were measured in the Hungarian section of the Tisza and in the Tisza section of the Hungarian-Ukrainian border section, already in 2008. (Figure 72)

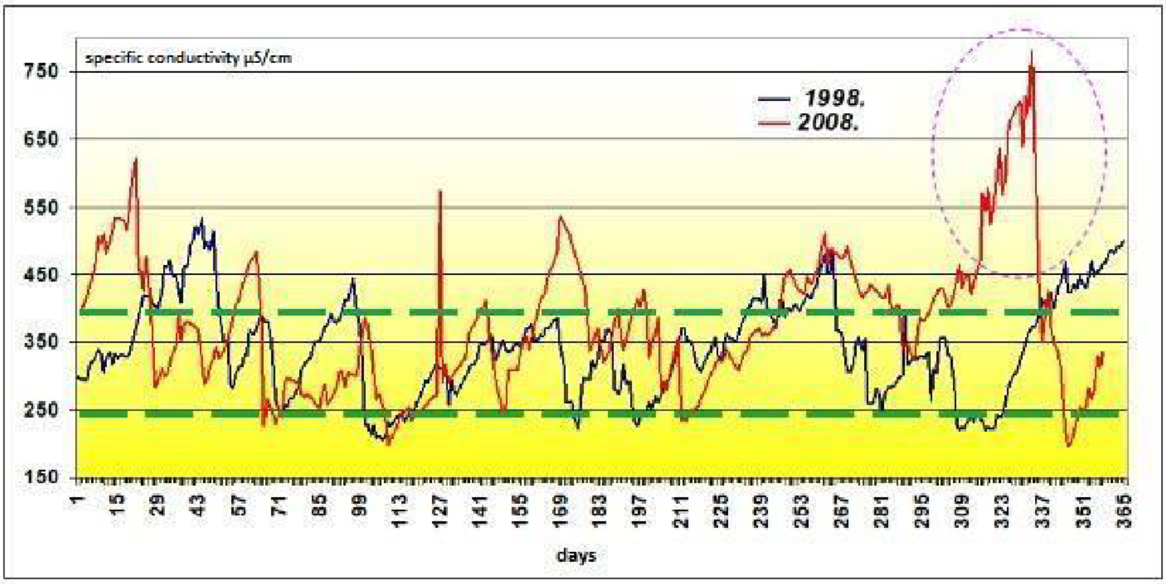


Figure 72 Specific conductivity values measured in 1998 (as an average year) and 2008 above Szolnok in the Central Tisza, Hungary (µS/cm) *(Middle-Tisza Regional Water Directorate, Hungary, 2008)*

To protect the Tisza and preserve aquatic life, it is extremely important from a biological point of view to know the inorganic chemical elements (Halobiotic elements/components), such as organic ion composition, total salt concentration, pH, conductivity, etc.

Accordingly, - within the framework of the project – in the downstream direction tests were carried out at sampling points examining the Tisza River and its sediments. The locations and the results summarizing them are shown below (Figure 73).

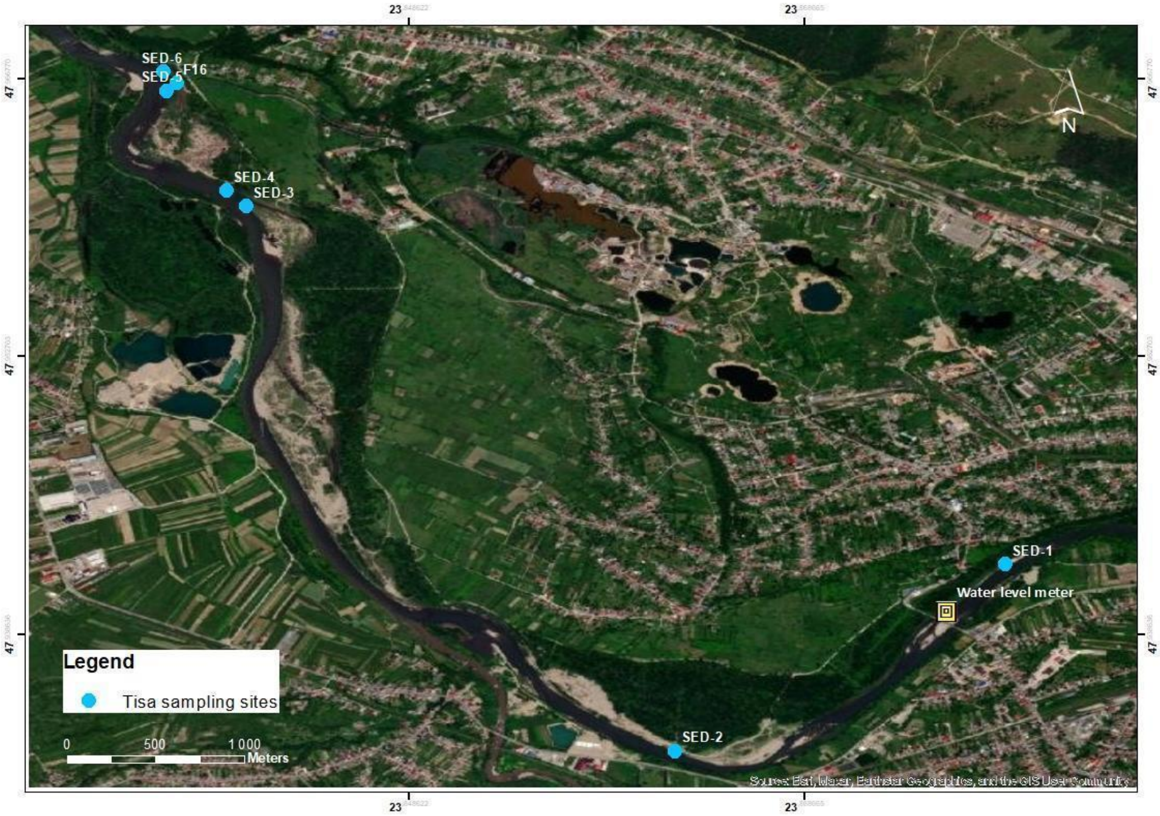


Figure 73 Locations of water chemistry and sediment sampling sites along the Tisza River *(Geogold Ltd))*

Based on the data of the water chemistry tests, **the EC values of the Tisza water measured downstream at Solotvyno increase monotonically from EC= 231 µS/cm to EC=1740 µS/cm.**

Measuring point F 16, - at the mouthing of the Glod – watercourse -, represents a direct salt load on the Tisza River from the Glod.

In the measurement period lasting up to 07.2020 and 09.2021 was proven that the Glod – watercourse collected the salty waters pumped out by the previously functioned North dewatering gallery system and the mine. Currently is charged by the waters of the salty lakes, and salty pools of Solotvyno.

The natural source of the salt load is therefore the leaking water coming from the direction of the Solotvyno salt dome, as well as the drainage of anthropogenic water withdrawals (used water of open-air baths) into the Tisza River.

Figure 74 The Glod – watercourse (measuring point F 16), which today collects the water of the salt lakes used for bathing and leads it into the Tisza (in the background) *(Googol Ltd))*

It is recommended to install a permanent water quality measuring station below the SED 6 measuring point downstream from the confluence of the Glod – watercourse (Figure 27). Following, establish a reference station measuring the water quality of the Tisza upstream from the SED 1 measuring point, and a measuring station (so, altogether three stations) measuring the effect of the still partially working Southern branch of the Tisza dewatering gallery. This should be located at the section of the Ukrainian-Romanian road border bridge, or a little further downstream from it.

The195oneed three Tisza measuring stations can thus 195onected to the water quality measuring station previously established at Técső (Tjachiv), which is 35 river kilometers downstream from Solotvyno, as part of the Transnational Tisza Monitoring System.

6. Vision and proposals for revitalization of Solotvyno – further actions for the revitalization process

6.1 Sinkhole/crater management & land use revision connecting to the risk mapping (projections for the future, possible re-utilization of the craters for anything)

- Some of the former mining facilities and premises could be targets of innovative sports and recreational developments such as extreme sports, urban games, escape rooms, theatre etc. as well as interactive open-air and underground exhibitions. Risk assessment is a must here, however, before any decisions are made.

6.2 Salt water and lakes management (water management, health & public tourism

Recommendations

Tourism is a relatively new, growing field of the local economy that can serve employment and additional income for the region**.** The use of salt (and salt lakes) for tourist purposes as developing resources in Solotvyno began in the 1970s, but it was enhanced mostly just in the 2000s, when mining could not employ as many people as before. Incomers bathe in the lakes formed in the former mining area, furthermore more and more fresh and saltwater pools have been established. Tourism has become a major sector that shapes the status of the whole hromada, and there is a shift towards recreational and medical tourism. Medical tourism has widened with spa tourism**.**

It is important to highlight that the mere existence of salt is not sufficient for sustainable economic and social development, there should be good quality of services, accommodations, leisure activities, medical treatment and decent infrastructures and equipment, which can ensure the basis of qualitative tourism.

Despite the majority of houses in Solotvyno being connected to a sewer, the sewage treatment facility built in the 1970s does not work properly and the wastewater flows almost directly into the Tisza river. In the last decades updating the sewer system enjoyed lower priority than improving drinking water supply. In addition, from other parts of the settlement the wastewater flows directly into the sinkholes without any filtration, which further enhances the occurrences of landslide and subsidence. Moreover, due to subsidence many sewage water pipelines were possibly broken and remained hidden contaminating groundwater.

After the closure of the salt mines, the tourism industry – currently the main sector that provides workplaces for the locals – was able to survive the local economic recession. It is mainly the pollution of saline water which deteriorates the tourism potential of Solotvyno. It is important thus to limit water and soil pollution by limiting the leaking, the transmission of polluted materials and groundwater, increasing the level of treatment.

The growth of the tourism sector cannot be achieved without preventing the spread of water pollution. The local salt resource is the most important value of the area, and currently it gives the brand of Solotvyno. However, if this geological resource is polluted further, Solotvyno will not be able to utilise this special endowment anymore.

- Support local people to be part of the sector by encouraging quality improvements for them to be involved in the accommodation sector as well in the selling of local products and souvenirs.
- Initiate contacts with spa towns of European expertise.
- Those kinds of investments should be supported which are further away from the risk zones, and which encourage the shift to quality tourism and the introduction of complex new health services and medical treatments.

6.3 Spatial planning and development plan for renewing the recreational freshwater lakes

The growing number of guests triggered the development of tourism infrastructure, namely accommodation and catering, and the hospitality sector. Solotvyno became a true recreational centre with hotels, bars, and other accommodation facilities. The infrastructure was built up spontaneously and it focused mainly on the Salt Lake Kunigunda which was divided by small dams to ensure the decent water level for the bathers (Stoeckl et al., 2020). Speaking of the accommodation facilities, during the summer main season sometimes even more than 2000 tourists are accommodated locally (interview with Mr Kocserha, 2022). As a relatively new phenomenon bigger and higher quality hotels are being built. A total number of more than 60 accommodation units operate; some of them host few dozens of tourists, while others are larger facilities. In addition, many other private accommodation units (family houses, flats) offer additional beds to the larger accommodations. However, despite this positive process of tourism growth, there is a growing need for spatial and land use planning that serve both the further development of the tourism sector and the sustainable development principles to better protect and utilise the territories around the freshwater lakes.

There is a constant danger of landslide and subsidence deterring the new investors and companies, as they do not want to invest in a risk zone. In addition, there are some smaller scale land movements around the recreational area of Solotvyno too. Local businesses try to mitigate and react to these processes, however according to local sources no major steps forward took place recently.

- The sources of pollution and the spread of it should be localised to avoid contamination, making tourism impossible or at least less attractive.
- Sustainability in tourism should be increased to find a balance between further development of the sector and the quality of the environment.
- Only those new developments should be authorised which keep in mind the environmental hazards and risk (e.g. the contamination of water bodies, or collapse of buildings).

6.4 Opportunities for a new mine opening

Considering recent changes and circumstances, there is a potential to restart mining at a larger scale (according to Deputy Mayor osf Solotvyno). With the war-related problems in the largest salt mine of Ukraine, at Soledar Salt Mine of Donetsk Oblast, which offered salt for many Eastern European regions, the role of the resources in Solotvyno have gained higher importance. Salt became a demanded product in the rest of Ukraine. The reopening of mines would create impetus for the development of the new industrial park as well, where a processing plant could be set up. Still, past and present recommendations should be taken into account in case the mining activity is planned to be increased.

Salt mining has a long tradition in Solotvyno given that the development of modern-day Solotvyno was based on mining in the first place. This also means that the situation of salt mining shapes the present and future of the local economy, and it is not secondary to what will happen to the sector.

Recommendations

- It is a topic of further investigation to find out if it is environmentally and economically feasible to support the redevelopment of the salt mining sector. Strict and improved monitoring should be deployed in case of positive answers.
- Salt processing and products based on salt mining should be supported more compared to previous times meaning salt can be considered more than just a raw material to mine in large amounts.

6.5 Health Center/Hospital possible re-opening

Two hospitals can be found in Solotvyno which are important socio-economic assets of the settlement. The hospital, maintained by the oblast of Transcarpathia, treats 100 patients with asthma and respiratory diseases. In the national hospital 350 patients are treated. More than 500 people worked in the two hospitals making it an important sector of the settlement. It would impact the whole hromada if the hospital stopped its operations given that many intellectuals, doctors and other crucial local workforce and human capital can be kept by having these health care institutions. Since the health benefit of the underground chambers is of great importance, underground allergology hospitals were established which received patients not just from Transcarpathia, but from other parts of Ukraine mainland. After the closure and the instability of the mines, the hospitals could not use the chambers anymore. There is still a great demand for hospital treatments connected to salt, which is a huge potential for Solotvyno, if the whole situation is properly managed and controlled.

6.6 Health & Culture Tourism in cooperation with Sighetu Marmatiei

Potentials lie in being in a stronger functional integration with Sighetu Marmației, Romania. Sighetu Marmației was the former centrum of the transboundary Marmarosh Basin, the historical centrum of the wider area, Sighetu Marmației, which concentrates more than 30 000 inhabitants and provides services with regional importance on the Romania's side, but partly also for Romanians living in Ukraine. The ethnic heterogeneity of Solotvyno, which is the centre of people of Romanian origin living in Transcarpathia, supports mutual understanding, peaceful intercultural and cross-border cooperation, furthermore the language knowledge supports easier business, labour and tourism connections, interactions with the Romanian partners. Border crossing infrastructure has been improved (2007: new bridge across the Tisza, 2024: four lane bridge at Bila Tserkva to be built). As the influencing zone of Sighetu Marmației gets less distorted and truncated by the border owing to new transport links, and as Ukraine's European integration gets new impetus, vivid relations could be built in certain fields with the largest city in the vicinity of Solotvyno, Sighetu Marmației.

Recommendations

- Try to better build upon the potential lie in the cross-border influencing zone of Sighetu Marmației by initiating cross-border more institutionalised cooperation forms and governance structures (e.g. urban platform).
- Focus on urban functions, institutions, and services of regional importance (tourism facilities, hospitals etc.) and attraction to maintain and strengthen urban development.
- Better base any sort of international relations including trade, tourism and culture on the multilingual and multicultural environment available in Solotvyno.
- Make Romania and Hungary, the national and local stakeholders in urban and regional planning, minority and cultural policy interested in investing in the joint heritage of the three countries (e.g. by supporting cross-border thematic cultural routes, reconstruction of historical monuments).

6.7 Improve & increase the public awareness.

The residents dispose of their domestic waste into the sinkholes, because the waste transportation system does not meet the needs of the hromada. Illegal littering contaminates the groundwater, the Tisza and the lakes, sinkholes too.

Recommendation

- Support awareness raising activities (e.g., by waste collecting and recycling competitions) among the local communities.

6.8 The former mine conservation as an industrial heritage

Many facilities within the territory of the mining company have collapsed and almost completely disappeared (e.g., carpentry workshop, sawmill, a mining tower). Out of the remaining constructions, e.g. the former directorate building is worth mentioning.

It is also important to preserve the mining heritage, because the equipment and the infrastructure still exist, and they belong to the cultural heritage of the region. Health tourism and tourism connected to the lakes can be supplemented by heritage tourism with unique attractions based on the industrial past.

Recommendation

- Mining and its transport can also be seen as a joint cultural heritage of the settlement and the wider region including the hromada of Solotvyno, which can support international tourism.
- Cooperation with other mining towns in the wider region as well as with other destinations along the international river of Tisza could be improved.
- In order to support Solotvyno becoming an integrated tourist attraction on the market, the hromada needs to build up a unified brand, which facilitates the partnership building among the actors of the local tourism sector. For instance, it is inevitable to develop an integrated destination management and a coherent product and service development, which fosters the establishment of quality tourism in the region. With these measures, Solotvyno will be able to represent itself at international level as well.

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