UNDERGROUND WASTE LANDFILLS PERMANENT SOURCES OF POLLUTION

DEPOZITELE SUBTERANE DE DEȘEURI SURSE PERMANENTE DE POLUARE

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Abstract*. In Romania there are industrial landfills with an underground position, a situation that involves an uncontrolled pollution phenomenon. A significant example is the landfills left over from the exploitation of salt deposits in the „Ocnele Mari” area, Vâlcea County. It consists of a cavern in which a sodium chloride solution remains. The pollution phenomenon is manifested inside by the propagation of the solution in the rock massif with an effect on the stability of the slope. The implosion of the cave causes the rock roof to collapse and the sodium chloride solution to be expelled to the surrounding area. The pollution phenomenon has a disaster character, having a special impact on the natural and social-human environment.*

Key words: caves, ecological disaster, implosion, brine

Rezumat. *În România există depozite de deșeuri industriale cu poziție subterană, situație ce implică un fenomen de poluare necontrolat. Un exemplu semnificativ sunt depozitele de deșeuri rămase în urma exploatării zăcămintelor de sare din zona Ocnele Mari, județul Vâlcea. Acesta este format dintr-o cavernă în care a rămas o soluție clorură de sodiu. Fenomenul de poluare se manifestă la interior prin propagarea soluției în masivul de rocă cu efect în stabilitatea versantului. Implozia cavernei provoacă prăbușirea acoperișul de rocă și expulzarea soluției de clorură de sodiu în zona înconjurătoare. Fenomenul de poluare are un caracteri de dezastru, având un impact deosebit asupra mediului natural și social – uman.*

Cuvinte cheie: caverne, dezastru ecologic, implozie, saramură

INTRODUCTION

The irrational exploitation of natural resources and the absence of adequate protection measures can cause particularly complex and high intensity negative phenomena. In certain situations, these negative phenomena turn into ecological disasters (Law 137, 1995). Industrial landfills with semi-buried or underground sites have a particularly complex negative impact on the natural and human environment. Landfills or landfills are mainly made by the extractive industry.

The corroboration of natural factors (landslides and landslides, floods, earthquakes) with anthropogenic ones (absence of maintenance and rehabilitation works) determines the initiation and maintenance of phenomena with negative impact on the environment (Avram *et al.*, 2018; Luca *et al.*, 2008; Luca and Bălan, 2008).

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In many cases, ecological disasters have been registered through the degradation of industrial waste landfills, where pollutants have had a local and regional dispersion (Stematiu *et al.*, 2001; Șerban *et al.*, 2002).

A negative impact on the environment is presented by semi-buried tailings dumps resulting from the exploitation of non-ferrous metals (Bartha, 2007; Hobjilă and Luca, 2004). Oil exploitation and transport is a permanent source of soil and water pollution through extraction points, transmission pipelines and intermediate hydrocarbon deposits (Avram *et al.*, 2018; Bica and Dimache, 2002). Ponds and water treatment plants from ore preparation plants are a permanent source of pollution through uncontrolled discharges (Stematiu *et al.*, 2001). Many of them have not been adequately preserved, thus becoming a continuous source of pollution (Bica, 2000), ecological (Luca *et al.*, 2008; Șerban *et al.*, 2002).

The paper aims to analyze a pollution phenomenon produced repeatedly in the last 20 years at the salt exploitation in the area of Ocnele Mari locality, Vâlcea County. About 15-20 years after the accident, the consequences of the ecological disaster caused by natural factors, but especially anthropogenic ones, are still present.

STUDY AREA AND RESEARCH METHOD

The research was carried out in Vâlcea County in the area of Ocnele Mari (fig. 1), where a number of underground deposits / caverns filled with brine are located. The deposits are located in the perimeter of salt extraction for the chemical industry. The mining operation belonged to the National Salt Company and to the Râmnicu Vâlcea Mining Exploitation. The salt extracted as a saturated solution from the underground was delivered through pipelines to two beneficiaries, S.C. OLTCHIM and S.C. U.S. Govora.

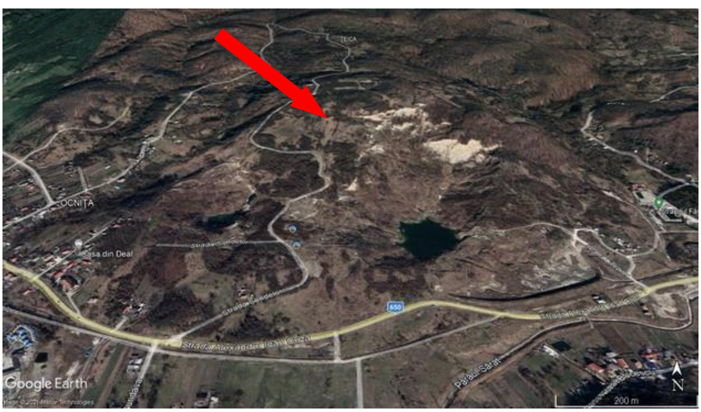


Fig. 1 Location of the research area in the Ocnele Mari area (Google earth image, 2021)

The rock salt deposit from Ocnele Mari is located within several villages belonging to the town of Ocnele Mari. It has the shape of an elongated lens in the E-V direction, measuring in this sense about 7.5 km, and towards the N-S about 3.5 km, presenting an axial elevation in the Ocnita area, with inclinations to the north (Univ. Bucharest, 2003; MINESA- ICPM, 2003; Luca and Tigaret, 2007a).

Theoretical and experimental research was performed on the following fields:

- Studies and research on the evolution over time of brine caves in the exploitation and conservation phase in the absence of maintenance works.
- Research on the phenomenon of cave implosion.
- Studies and research on the polluting impact of brine waves on the natural environment (air, surface and groundwater, soil and subsoil) and anthropogenic.

For the analysis of the situation in the field, a documentary study and an experimental research were carried out on the location of the collapsed caves in the Ocnele Mari area. The research analyzed the destroyed caves, the polluted area, the forms of pollution, the formation of brine waves and the routes followed to Sărat Creek, the condition of the land after the action of brine, etc. The collection of data from the field was done through measurements, taking material samples, photo surveys and filming of the phenomenon of cave development, etc.

The primary data collected were processed using statistical calculation programs, hydrogeological, hydraulic, stability, etc., applicable to the case study (Charberneau, 2000; Weber *et al.*, 1999).

RESULTS AND DISCUSSIONS

Romania has a series of particularly hazardous landfills (tab. 1) that generate rainwater, water and soil, as well as the human environment. Their number is variable, depending on their condition, respectively exploitation or conservation. Bălan (2010) mentioned that in 2009 there were about 83 industrial landfills for hazardous waste. These were in 30 counties and occupied about 450 ha. At the same time, about 29 landfills were underground. The main industrial wastes produced in Romania are the following (Environmental Report, 2018): mining tailings, ash and slag, metallurgical wastes, chemical wastes, ferrous wastes, residual sludges, etc.

Table 1.

Hazardous waste generated by economic activities, year 2014–2018 (thousand tons) (Source: ANPM, 2018)

Economic activity / year	2014	2015	2016	2017	2018
Extractive industry	206.83	343.37	241.99	277.22	244.91
Manufacturing industry	181.44	205.6	226.32	213.16	234.60
Production, transport and distribution of electricity and heat, gas and water	1.37	2.51	1.06	4.08	1.95
Water capture, treatment and distribution	4.26	8.75	5.42	2.88	5.65

Underground landfills have special characteristics due to their formation, operation and conservation. Brine caves are considered among the most dangerous landfills.

The documentary study showed that the salt deposit is encamped in formations belonging to the Getic Depression - the outermost unit of the Southern

Carpathians. Saliferous formations in the Ocnele Mari area were formed in the Pliocene. The tectonic movements arranged the direction of the saliferous layers currently known through the Ocnele Mari-Govora - Slătioarele anticline. The salt massif has a stratiform - lenticular shape and is located on the northern flank of the Ocnele Mari-Govora anticline.

The base of the salt deposit is relatively uniform, compared to the top which is irregular. It has a series of elevations (dome-shaped) and depressions with elongated and irregular shapes. The thickness of the salt deposit is variable, and by measurement values of about 440 m were also found. The deposit slopes to the north, so that the roof in the southern area is at a depth of about 20-50 m, and in the area of north at a depth of 540-800 m (fig. 2). The structure of the salt is macrocrystalline and encompasses anhydrite nests along the entire thickness of the deposit. Sodium chloride content varies between 95-98% (Univ. Bucharest, 2003).

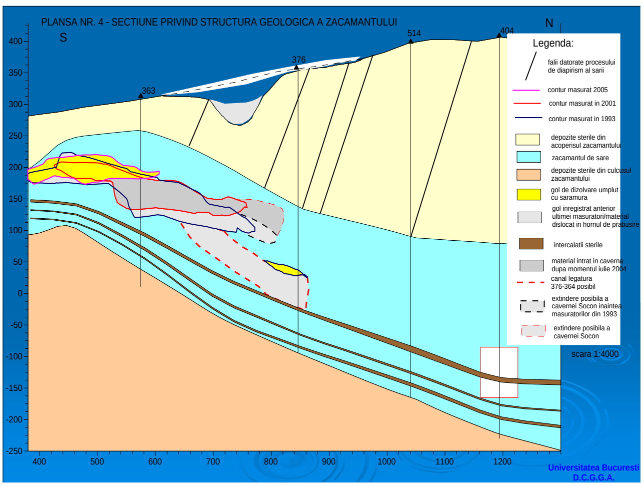


Fig. 2 Geological structure of the salt deposit (source: Univ. București, DCGGA)

In 1960, the exploitation of salt in the form of brine began. The construction in 1985 of the Govora Chemical Plant (later OLTCHIM) increased the production of brine from 300,000 t/year to 850,000 t/year and then to 2,450,000 t/year. The increase in production required an increase in the number of operating perimeters and wells used. The technological process of extraction by wells consists in the controlled dissolution of the salt starting from the base of the deposit to the surface. Sealing the ceiling of the dissolution gap is done with an insulating fluid (diesel). A cave with a three-dimensional evolution over time is formed in the salt and rock massif.

The technological process of salt exploitation by saturated solution with the help of probes requires careful monitoring and rapid interventions to remedy the damage. During the exploitation of the salt deposit, large underground caverns were formed, due to the union of the extraction wells. The decrease of the management in the exploitation of the wells after 1990 determined the appearance of damages. The partial application or absence of maintenance and rehabilitation works of the installations serving the wells led to the implosion of some caverns.

In the perimeter with Ocnele Mari - Ţeica salt extraction wells, a cave implosion phenomenon occurred in September 2001 in the area of well 317 (Luca and Tigaret, 2007). The rock ceiling of the cave collapsed due to the loss of stability and determined the evacuation of the brine with a variable flow in a very short time. By the collapse of the roof and the banks of the cavern, a cone of collapse was formed. In it a natural lake with salt water was formed in the area of Field II of wells (fig. 3).

a b

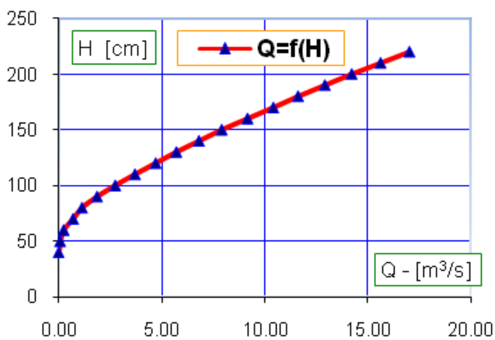
Fig. 3 The implosion of the brine caves at Ocnele Mari: a - the cave from 2001; b - the cave from 2004 (Luca and Tigaret 2008).

The brine formed a wave that moved on the slope to Pârâul Sărat by forming a torrential bed (fig. 4). The flow on Părâul Sărat, with an average monthly value of 0.100 m^3/s, reached a maximum of 12.4 m^3/s in a few hours due to the brine wave (fig. 5). The flow was taken over by the Olt River, it influenced the water quality from the Govora accumulation, as well as from the other accumulations downstream. The chloride concentration in Pârâul Sărat was about 205.61 g/l. The brine wave was also identified at the mouth of the Olt River in the Danube River.

In order to prevent the discharge of the brine wave in Parâul Sărat, a protection dam and a storage basin for the volumes discharged from the caves (fig. 6) were accidentally built at the base of the slope.

a b

Fig. 4 Land pollution by moving the brine wave: a - riverbed at the exit of the cave; b - the riverbed towards the base of the slope (photo Luca 2008).



a b

Fig. 5 Parameters of the brine wave: a - limnimetric key on Pârâul Sărat for wave transport, year 2001; b - the state of water loaded with sodium chloride (Luca and Tigaret 2008).

The amount of brine arriving in Lake Govora in September 2001 varied daily from a maximum of 12,642 t to about 376 t after eight days (tab. 2) (Luca and Tigaret, 2007b).

Table 2

The amount of brine in Lake Govora in September 2001 (Luca and Tigaret, 2007b)

Date	13.09	14.09	15.09	16.09	17.09	18.09	19.09	21.09
W (t)	12,642	22,809	17,518	7,137	2,767	1,088	480	376

The ecological disaster was accentuated in July 2004, following torrential rains that changed the stability of the slope. The change in the stability of a well has resulted in the release of a significant volume of brine on the slope. Starting with 12.07.2004, there was a movement of the material from the collapse cone formed in

2001. On 13.07.2004, the brine was discharged from the storage cavern. This phenomenon determined the local collapse of the cave banks (fig. 3b).

a b

Fig. 6 The basin for taking over the brine waves: a - general view; b - structural degradation of the dam under the action of sodium chloride (Luca and Tigaret 2008).

The influx of brine filled the storage basin at maximum operating levels (fig. 5b). This situation generated a phenomenon of exfiltration through dams and determined the discharge of dams in the SE part. Some areas of the protective dam have reduced their local stability, which has required a controlled breakage of the dam to discharge a volume of brine.

Collapses on the slope with extraction wells also took place in 2005 between September 7 and December 14. These generated the appearance of new craters due to the loss of the stability of the roof to the caverns, but also to the collapse of the interior walls (fig. 7) (Luca *et al.*, 2008).

a b

Fig. 7 The condition of the slope affected by the implosion of the caves in 2005: a - implosion cone and subsidence with brine lake (photo Luca, 2008); b - the development of caves by the collapse of the banks.

The surface area was affected by the occurrence of concentric fractures with the dissolution blocks. On December 12, a crater with a diameter of 30 m and a depth of 22 m was formed at the southern limit of the dissolution area, respectively in the high area of the roof of the cave. The level of immersion was 4-5 m and about 150,000 m^3 of tailings easily entered the cave. The crater expanded rapidly to the north. On December 23, 2005, another collapse occurred that caused about 350,000 m^3 of tailings in the cave, and an equivalent amount of brine was dumped (MINESA - I.C.P.M, 2006; Luca *et al.*, 2008).

The causes that generated this ecological disaster are multiple, being of an objective nature but also subjective. These include:

- The process of exploitation of the salt deposit by the method of dilution and extraction with wells carried out in excess and without a correct forecast of the evolution of the caves in the rock massif was a first factor to trigger the disaster.

- The decrease of the maintenance works and of the rehabilitation works of the extraction/feeding installations of the caverns in order to maintain the hydraulic balance of the brine volume and the stability of the land contributed to the triggering of the implosions.

- The production of disturbances at the brine caverns also took place during the exploitation of the salt deposit, a situation that would have required the increase of monitoring actions, but also of limiting the extraction at some caverns.

- A subjective factor was the return of the land from the extraction area to the former owners. This factor was aggravated by the construction of houses and annexes on the perimeter of the salt deposit. Even after the ecological disaster occurred in 2001, repeatedly in 2004 and 2005, housing construction continued.

The main forms of impact and risk determined by industrial landfills with underground position, in the order in which they are perceived by the population are the following: air pollution, surface and groundwater pollution, changes in soil fertility until salting, changes in the composition of biocenoses on lands adjacent to degraded caverns, changes in relief, landscape, flora and fauna, visual discomfort, etc. The brine waves severely affected the land by removing it from the natural and economic circuit. The recovery process is long and expensive.

The ecological disaster has severely affected the natural and anthropogenic environment. The area affected by the pollution phenomenon reached about 50 ha. An area of at least 10 ha was completely destroyed by the collapse of the slope, by runoff of brine and diesel and salting of the soil (fig. 8). The land can never be used again in agriculture or for planting shrubs and trees. Following the collapse of September 2001, a number of 113 households were affected.

Greening measures taken after the disaster (demolition of houses and affected areas, levelling of the groundwater) cannot restore the natural environment polluted with sodium chloride over a relatively large area. The climate regime through torrential rainfall, specific to current climate change, can cause landslides and the generation of actions that cause cave instability.

Fig. 8 The way of degradation of the natural environment in the exploitation perimeter in 2005: a - general view towards the upper part; b - implosion cone and collapse with brine lake (photo Luca, 2008).

The evolution in time of the process of infiltration of the brine in the rock layers, as well as of the one of dissolving the binder between the rock particles determines the loss of the cave instability and its implosion. The phenomenon is difficult to monitor and requires complex equipment and qualified personnel.

The construction of industrial waste landfills without respecting the minimum principles of protection of the natural and anthropic environment can lead to disaster phenomena with a long-term impact (Technical Regulation, 2004). Such a case is represented by the brine caves from Ocnele Mari.

CONCLUSIONS

1. Underground industrial waste dumps are permanent sources of pollution of the natural and anthropogenic environment during the period of operation and conservation, especially in the absence of maintenance and conservation works.

2. Inadequate conservation of underground landfills coupled with the limitation of protection measures can lead to highly complex and high-intensity pollutants on the subsoil and groundwater that can turn into ecological disasters.

3. The limitation of safety measures in the conservation of salt extraction caverns has triggered an ecological disaster that is difficult to control and repair for a large area where the soil has been turned into salt.

4. The absence of an efficient monitoring of the parameters that characterize the evolution in time of the underground and surface environment in the brine extraction area has triggered an ecological disaster on a large and lasting surface.

5. The absence of complex works for environmental protection and carried out in a unitary way can determine the appearance and development of ecological disasters in the case of underground industrial waste sites such as the one registered at Ocnele Mari.

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