CONSIDERATIONS REGARDING THE CROSS-BORDER POLLUTION PHENOMENON

CONSIDERAȚII PRIVIND FENOMENUL DE POLUARE TRANSFRONTALIERĂ

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Abstract.
The interference between natural and anthropogenic risk factors can trigger pollution phenomena, which can be transformed into local and regional ecological disasters. In the case of a fast transport vector (water and wind), pollution can also be cross-border. The ecological disaster produced in the area of sodium chloride extraction from Ocnele Mari, Valcea County caused such pollution. The implosion of some underground caverns with sodium chloride generated a wave of brine that was successively taken over by the Paraul Sarat River, the Olt River and the Danube River. The brine wave generated a local pollution phenomenon, later transformed into a regional and cross-border one. The initial flow of salt water was 3.0 – 4.0 m^3/s, and the brine concentration was 30.000 mg/l – 250.000 mg/l. The discharged brine flow decreased over time to 0.15 - 0.20 m^3/s, and the brine concentration to 225.0 - 250.0 g/l. The brine wave polluted the Olt River, the downstream reservoirs (mainly Govora) and finally the Danube River.

Key words: *brine surge, concentration, ecological disaster, river*

Rezumat.
Interferența dintre factorii de risc natural și antropici poate declanşa fenomene de poluare, care pot fi transformate în dezastre ecologice locale și regionale. În cazul unui vector rapid de transport (apa și vântul), poluarea poate fi și transfrontalieră. Dezastrul ecologic produs în zona de extragere a clorurii de sodiu de la Ocnele Mari, județul Vâlcea a determinat o astfel de poluare. Implozia unor caverne subterane cu clorură de sodiu a generat o undă de saramură care fost preluată succesiv de Paraul Sarat, Râul Olt și Râul Dunărea. Unda de saramură a generat un fenomen de poluare local, transformat ulterior în regional și transfrontalier. Debitul inițial de apă sărată au fost de 3,0 – 4,0 m^3/s, iar concentrația saramurii de 30.000 mg/l - 250.000 mg/l. Debitul de saramură evacuat s-au redus în timp la 0,15 - 0,20 m^3/s, iar concentrația saramurii la 225,0 - 250,0 g/l. Unda de saramură a poluat râul Olt, acumulările din aval (în principal Govora) şi în final fluviul Dunărea.
Cuvinte cheie: *concentrație, dezastru ecologic, râu, undă de saramură*

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INTRODUCTION

The phenomenon of pollution can be initiated and developed in the three characteristic environments: air, water, soil and subsoil. The pollution phenomenon can be natural or anthropogenic. The pollutant can be transported from the source to the emissary by convection, diffusion, dispersion and reactive processes [Hancu S., 2008]. Monitoring the pollution phenomenon generally requires knowing the transport distance, the deposition area and the concentration of its pollutants in various significant points or areas. The main transport vector is the velocity of the medium in which the pollutant is incorporated. The pollution phenomenon can be local, on a small area, or regional in the case of affecting large areas of land. When state borders are crossed, the phenomenon of pollution becomes transboundary.

Cross-border type pollution phenomena are generally carried out by a fast transport vector such as air speed and water speed. A classic example of cross-border type natural pollution is that produced by volcanoes. Anthropogenic cross-border pollution is that produced by the noxes emitted by the thermo-energy industry in the atmosphere [Luca M. et al., 1996]. Also, the noxes emitted into the atmosphere by the steel industry can create cross-border pollution.

Watercourses can generate cross-border pollution phenomena through the transport vector represented by the speed of the liquid current. Water courses take in a wide range of pollutants which they process through diffusion and dispersion, a situation in which the concentration of pollutants decreases. The transport of pollutants in water courses in Romania created local and regional pollution with a particular impact on the natural and human environment [Stematiu D. et al., 2001, Manescu A. et al., 2014, Hobjila V. and Luca M., 2004].

The pollution phenomena produced in the underground environment due to the extraction of minerals have a local extension and in certain situations are of a regional type [Hobjila V and Luca M., 2004]. The pollution produced by industrial waste deposits has negatively modified the quality of groundwater at the local level [Luca M. and Balan R., 2008]. The geographical areas where mining operations are located permanently present natural and anthropogenic risk factors on the environment. The combination of natural and anthropogenic risk factors can generate and maintain a series of negative actions on the natural and social environment. Natural risk factors include earthquakes, landslides, collapses, floods and others. Among the anthropogenic risk factors, the absence of conservation works of mines and tailings deposits, the lack of annual repair and maintenance works, negligence in the operation process and others are highlighted [Hobjila V and Luca M., 2004]. In certain situations, pollution phenomena occurred, which turned into local or regional ecological disasters [Luca M. and Tigaret G., 2007].

In this situation is the mining of non-ferrous metals through waste dumps located in mountainous areas [Hobjila V and Luca M., 2004]. Oil exploitations, through the locations of extraction points and intermediate hydrocarbon deposits, present the danger of triggering ecological disasters [Avram M. et al., 2018]. The discharges from the settling and water treatment ponds located next to the ore preparation plants are negative phenomena that can turn into ecological disasters under certain conditions [Stematiu D. et al., 2001].

Such a situation is exemplified by the phenomena produced in recent years at the Ocnele Mari salt mine [Luca M. and Tigaret G., 2007, Luca M. et al., 2021]. The accumulation of some deficiencies in exploitation, but also the cooperation of some negative factors initiated and triggered an ecological disaster. Due to the speed of transport of the pollutant, the ecological disaster has expanded its scope at the regional and cross-border level.

MATERIAL AND METHOD

The research was carried out on the propagation path of the salt water wave produced in the mining operation in the Ocnele Mari city area, Valcea county. In the mining of sodium chloride used in the chemical industry, a number of underground deposits (caverns) filled with brine were in the conservation phase.

The serial implosion of a number of caverns at different time intervals generated pollution phenomena on the surface of the land, underground and in water courses. The theoretical and experimental research was carried out in the following fields of study:

- Studies and research on the natural and anthropogenic risk factors that intervene in the evolution over time of brine caverns in the exploitation and conservation phases.
- Researching the phenomenon of cave implosion and the formation of brine waves.
- Research on the polluting impact of brine waves on the environment at local, regional and cross-border levels.

The research used data from various studies and research carried out on the phenomenon of pollution produced in the Ocnele Mari area (S. C. MINESA and I.C.P.M. S. A. Cluj-Napoca 2006, Serban P. *et al*., 2002, ANM, 2018). Also, an own experimental research was carried out on the site of the collapsed caverns in the Ocnele Mari area [Luca M. and Tigaret G., 2007]. The research carried out in the field analyzed the state of the caverns destroyed by implosion, the formation of brine waves and the routes followed on the ground and in the water courses (Sarat Stream, Olt River, reservoirs and others). Data collection from the field was carried out through measurements, taking material samples, photo surveys and filming of the phenomenon of the development of caverns, etc. The primary data collected were processed by using calculation programs specific to the transport of pollutants [Hâncu S., 2008, Drever J.I., 1997].

RESULTS AND DISCUSSIONS

The pollution phenomenon was generated by the degradation of the caverns that contain the waste resulting from the extraction of sodium chloride in the area of Ocnele Mari, Valcea County. The mining operation belonged to the National Salt Society and the Ramnicu Valcea Mining Company. Sodium chloride was extracted from the underground layers of salt in the form of a saturated aqueous solution. The concentrated solution in sodium chloride was transported through pipelines to beneficiaries in the chemical industry [Luca et al., 2008, Serban et al., 2002].

Extraction of sodium chloride is done with probes through a controlled dissolution with water. The dissolution starts from the base of the deposit towards the surface, and a hole in the form of a cavern results in the rock. The cavern was filled with an aqueous salt solution, and the ceiling was sealed with an insulating fluid (diesel). Thus, over time, a three-dimensional cavern is formed in the massif of salt and rock, which evolves in size over time. Some caverns have increased in size by joining extraction wells. This situation requires monitoring during the conservation period and resupplying the caves with water.

The partial application or absence of maintenance and rehabilitation works of the installations serving the wells led to the implosion of some caverns at various time intervals. A series of failures occurred in September 2001 in the Ocnele Mari - Teica extraction area, a situation that caused the implosion of the cavern at well 317 [Luca and Tigaret 2007, Serban P. et al, 2002]. The rock ceiling of the cavern collapsed due to loss of stability. The amount of rock that entered the cavern expelled part of the brine volume in the form of a fluid wave with a time-varying flow rate. The cavern immediately turned into a brine-filled surprise cone. The collapse of the cavern banks under the effect of gravity (fig. 1.a), but also of the chemical action of the brine, continued the evacuation of some amounts of solution saturated in salt on the surrounding land [Luca and Tigaret 2007, Luca et al., 2008].

a b

Fig. 1. The evolution of the local pollution phenomenon in the Ocnele Mari extraction area: a – view of the cavern after the implosion (year 2001); b – local pollution of the land through the discharge of brine (year 2004) [Luca and Tigaret 2008].

The phenomenon of the degradation of the caverns was repeated in July 2004, being determined by the torrential rainfall that affected the stability of the slope with the location of the salt extraction wells. The action of the pollutant wave in the basement, on the land surface and in waters (rivers, lakes) highlighted the spatial distribution of the pollution phenomenon (local, regional and cross-border). The implosion of a cavern caused an initial local type of pollution, which was manifested by the expulsion of the brine solution in the area of the extraction wells. The land occupied by vegetation was chemically degraded, thus being excluded for agricultural use (fig. 1.b).

The movement of the brine wave in the well extraction area caused a "*local pollution*". This affected a limited area of land in the area where the caves are located (fig. 2.a). The location of the wells being on a slope allowed the quick evacuation of the brine wave and increased the polluted surface. The degradation of the spaces between the caves, the exploitation roads, the cave conservation facilities, as well as some constructions was accelerated in a very short time (fig. 2.a, fig. 3).

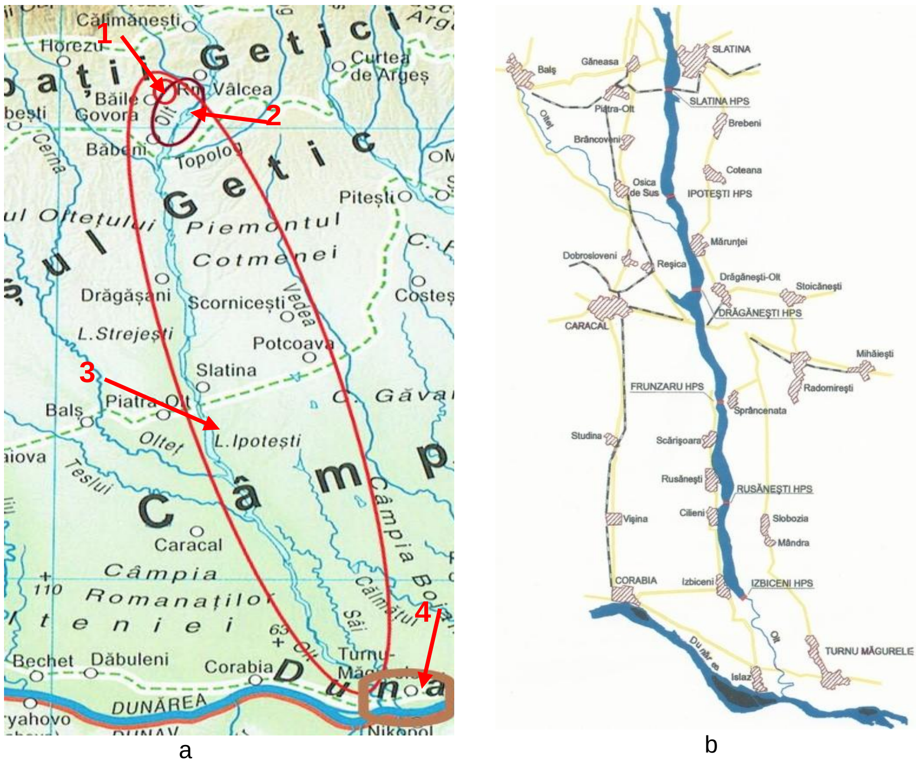

Fig. 2. Pollution areas of the brine wave: a – types of pollution in the Olt River area, 1 – local pollution, 2 – extensive local pollution, 3 – regional pollution, 4 – cross-border pollution; b – regional pollution of reservoirs on the Olt River.

The brine wave produced by the implosion of the cave travelled a route formed by the slope of the extraction area, Sarat Stream and discharged into the Olt River, respectively into the lakes in the area of the city Rm. Valcea. Thus, local pollution became "*extensive local pollution*". The 2001 brine wave increased the flow on Sarat Stream from the monthly average value of 0.100 m^3/s to a maximum of 12.4 m^3/s in a few hours. The concentration of sodium chloride in Sarat Stream was about 205.61 g/l. The brine wave significantly influenced the quality of the water in the Govora reservoir on the Olt River. In September 2001, an initial amount of maximum brine of 12.642 t entered Govora Lake, which after eight days decreased to 376 t [Luca *et al.*, 2008].

Fig. 3. Transport routes of the brine wave: a – in the location of the caverns; b – wave on the Salt River [Luca and Tigaret 2008].

In July 2004, following the collapse of the cavern walls, a total volume of brine of about 400,000 m^3 was expelled. A large part of this volume was retained in an accumulation basin made at the base of the slope. In this situation, the initial flow on Sărat Stream had maximum values of 3.05...3.80 m^3/s (fig. 4), and the initial concentration of chlorides was a maximum of 225.0 - 250.0 g/ l (fig. 5).

The pollution caused by the brine is complemented by that induced by the diesel fuel used to stabilize and waterproof the walls and ceiling of the extraction caverns. Diesel fuel began to be driven and moved underground, as well as on the surface in the water course.

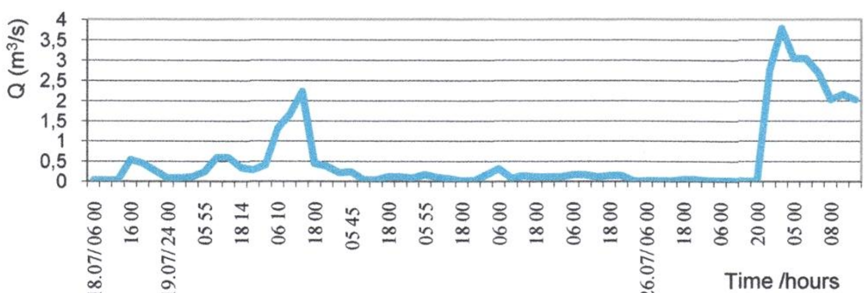

Fig. 4. The variation of brine flows on Sarat Stream in July 2004 [Luca *et al*., 2008].

The in situ research carried out by the authors in 2007 revealed a continuous degradation of the geotechnical structure of the caverns affected by the implosions. Their walls showed continuous collapses, which led to the expulsion of salt water (fig. 1.a). At the current stage, a salt water lake has formed in the extraction area, as a result of the union of the imploded caverns.

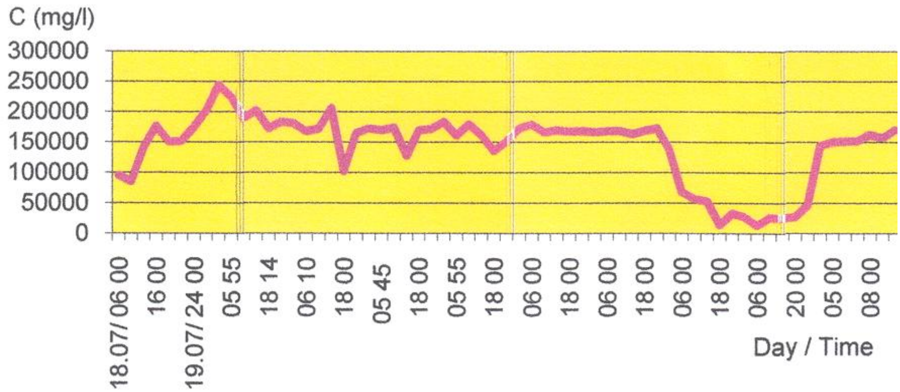

Fig. 5. Chloride concentration variation in Sarat Stream in July 2004 [Luca *et al*., 2008].

The wave of brine spilled into the Olt River affected the water quality from the existing downstream reservoirs (fig. 2.b), and especially the Govora Reservoir (a concentration of 2900 mg/l). The water from the Govora Reservoir was used in industrial technological processes. The movement of the brine wave on the Olt River turned "local pollution" into "regional pollution". The movement of the brine wave was favoured by its higher density, which placed it towards the bottom of the reservoirs. Ensuring the servitude flows from the lakes is achieved by emptying the bottom of the dams. This process of exploitation of the reservoirs allowed the transmission downstream of an important amount of salt water.

Downstream from the Rm. Valcea town and up to the town of Islaz, there are 15 reservoirs along an approximate length of 210 km, namely Râureni, Govora, Băbeni, Ionești, Zăvideni, Drăgășani, Strejești, Arcești, Slatina, Ipotești, Drăgănești, Frunzaru, Rusanesti, Izbiceni and Islaz. Their accumulation volume is between 142,167 million m^3 (Strejesti) and 14.10 million m^3. The brine wave moved with average speeds of 0.90 - 1.50 m/s along the Olt River to the Danube River, a situation in which the concentration of sodium chloride decreased through a dilution process in the volume of water existing in the lakes of accumulation.

Concentrated sodium chlorides were monitored along the path of the flood wave and mainly in the reservoirs. Water from the reservoirs on the Olt River downstream from the Rm. Valcea city is used to supply the population and industrial facilities, water for irrigation and fish farming, leisure and others. The monitored sodium chloride values in the reservoirs are shown for the brine flood of July and August 2004 are shown in (fig. 6, fig. 7). The maximum and minimum values highlight the evolution of the concentration along the path of the brine wave, respectively the intensity of the dilution phenomenon over time.

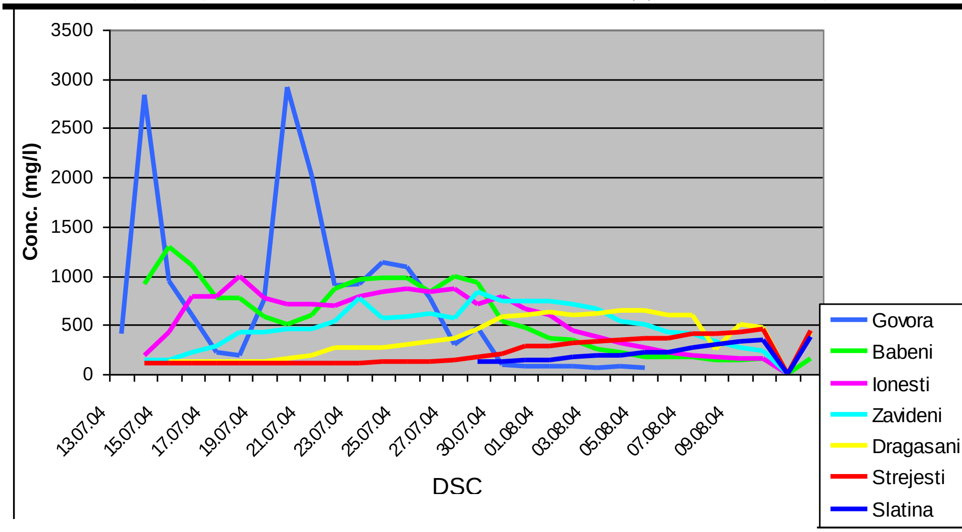

Fig. 6. The variation of the concentration of sodium chloride in the reservoirs between July and August 2004: Conc. – concentration of the solution; DSC – sample collection date.

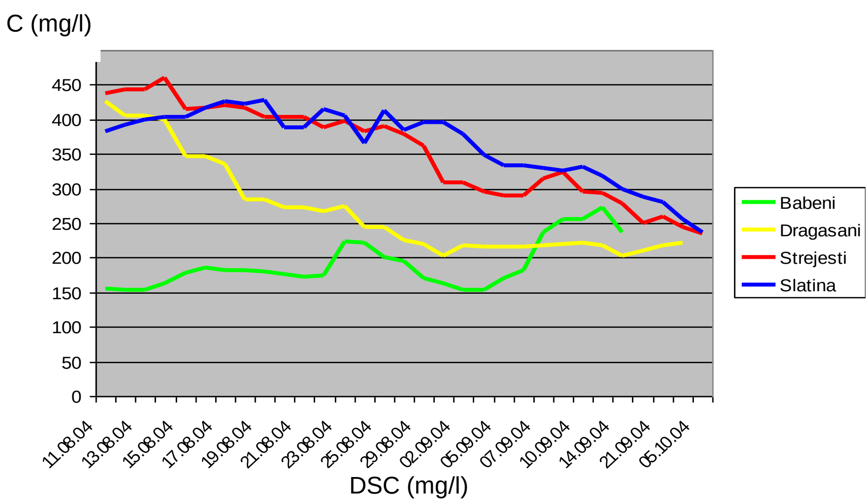

Fig. 7 The variation of the concentration of sodium chloride in the reservoirs on the Olt River in the period August - October 2004: C. – concentration of the solution; DSC – sample collection date.

The maximum concentrations at the confluence of the Sarat Stream in the Olt River, respectively in the Govora Lake, show the influence of the random expulsion of salty water during the cave degradation process. The maximum value of the brine concentration at the entrance to Lake Govora was 280-290 g/l. The value of the brine concentration varied in each lake depending on the distance from the source, the volume of accumulation, the operating conditions of the lake and others.

For example, Lake Babeni with an accumulation volume of 52 million m^3 presented high values of the initial brine concentration (C_{max} = 130 g/l). Lakes with accumulation volumes of 45 – 25 - 52 $mil.m^3$ (Ionești Zavideni, Drăgășani) presented much lower values of brine concentration (fig. 6). The Strejesti reservoir, which has the largest accumulated volume (142,167 $mil.m^3$), presented low brine concentration values at the initial moment. The low speed of pollutant movement in this lake allowed the concentration of sodium chloride to increase over time (fig. 6).

The polluting wave from the Olt River also reached the Danube River after a period of time. The phenomenon of sodium chloride pollution was highlighted by river residents in 2001 and 2004. In this context, the regional pollution process turned into a "cross-border pollution process". The Danube River being an international watercourse, or a border for Romania, requires compliance with water quality parameters. The presence of cascading accumulations on the Olt River allowed a satisfactory dilution of the brine, so transboundary pollution was reduced in value. The absence of accumulations would have determined an important pollution of the Olt and Danube rivers.

The natural process of surging of the cave walls and sliding of some areas of the slope, on which the mining operation is located, has a random character. These situations influenced the variation and parameter values of the pollutant wave formed by brine with a certain concentration of chlorides. The local pollution of the land in the extraction area was caused by a mixture of chlorides and hydrocarbons (diesel oil used to waterproof the cavern). In the dam lakes built along the Olt River, the presence of a clogging process was found as a result of the large amounts of alluvium transported from the catchment area and from the bed of the Sarat Stream. The prevention of this type of disaster necessarily requires a process of permanent monitoring of the pollution phenomenon. Following the 2001 disaster, a series of measures were taken by the Olt Water Basin Administration to limit the volume of the flood wave and monitor the water quality along the path of the brine wave (Univ. Buc. 2003, Luca M. and Tigaret G., 2007).

CONCLUSIONS

1. Pollution sources located underground or on the surface, in the case of caverns with residues from the exploitation of sodium chloride, can emit noxes at a local, regional and even cross-border level depending on the characteristics of the transport vector and the level of concentration existing in the initial stage.

2. The main pollutant transport vector is speed, represented by the speed of air, water and solid mass. The second vector is given by the concentration of the pollutant and its evolution along the transport length and in time.

3. Air speed manages to transport gaseous pollutants, mixtures of gases and liquids, and dusts to very large distances, of the order of thousands of kilometres, a situation in which classic cross-border pollution is achieved.

4. The speed of the water in the rivers makes it possible for the pollutants incorporated in the liquid stream in the form of dissolved gases, liquids and solid

particles to be transported to medium and long distances of the order of tens and hundreds of kilometres, a situation in which cross-border pollution can occur.

5. The absence of an effective monitoring of the parameters that characterize the evolution over time of the brine caves under conservation can trigger an ecological disaster at the local, regional and even cross-border level.

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