A New Classification of Open Pits and their Remaining Gaps in Terms of Hydrogeological Conditions

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Abstract

As open-pits occupy the land only temporarily, post-mining planning for sustainable land reuse represents an important stage and it can be done since the pre-exploitation stage.

There are more possibilities to reuse former open pits depending on the nature and location of ore deposits. Coal open-pits are often reused as artificial lakes. Depending on local hydrology and hydrogeology the flooding process of former open-pits may be done naturally or artificially (combined). Reuse of the remaining gaps of open-pits requires a good evaluation of possibilities and limitations specific to the area.

The classification of open pits and their remaining gaps in terms of hydrogeological conditions is necessary for a better post-mining planning of the area. This paper proposes a multicriterial classification of open pits and their remaining gaps taking into account the hydrogeological conditions and the action of some hydrogeological parameters that have an important contribution in establishing the approach to their flooding process. The most important hydrogeological conditions of the region are investigated (the hydrogeological structure, types and number of aquifers, nature of aquifer rocks, hydrodynamic characteristics of the region) and the results are processed for the development of a multicriteria classification. Depending on the results of hydrogeological classification of open pits and their remaining gaps, the possibility of natural and/or artificial flooding can be established or, contrary, the need to consider a different reuse direction, other than flooding.

The proposed classification is useful as in literature no multicriteria classification exist, most of them being focused on single criterion classification. In this paper, more open-pits and their remaining gaps were analyzed from a hydrogeological point of view and classified based on the proposed classification which takes into account more evaluation criteria.

Keywords: *open pits, remaining gaps, hydrogeological conditions, hydrogeological classes, groundwater, inflow*

1. Introduction

Open-pit mining activity temporarily occupies the land, being an efficient method for exploitation of superficial ore deposits, but unfortunately it has negative impacts on environment (Walker and Willing, 1999). After the cessation of the mining activity results degraded land, usually as a result of the depletion of the useful minerals (Cooke and Johnson, 2002) and sometimes as a result of unfavorable technical or economical conditions. Reclamation of the land is needed in order to reintegrate and reuse it in a sustainable way (Laurence, 2011; Shen et al., 2015; McCullough and Lund, 2006).

The operating project includes planning of all stages of mining activity, taking into account the local conditions, offers the possibility to choose the most efficient exploitation and dumping methods and, subsequent, the type of reuse of the degraded land. Early planning allows applying the best practices of exploitation and dumping with regards on the future reuse of the land (Bangian et al., 2012; Miller, 2008; Maczkowiack et al., 2012; Donovan and Perry, 2019; Zhang et al., 2017). The possibility of executing the exploitation - dumping works in open-pits depending on the future land use, in at least acceptable technical and economical conditions, ensuring the necessary stability reserves of slopes, brings benefits such as reducing the costs of remodeling and reintegration into the landscape, reducing the geotechnical risks which may occur under the influence of new factors and faster takeover of the future function.

Classification of open pits and their remaining gaps according to the hydrogeological conditions is very important for establishing the approach to their flooding process after the exploitation activity is stopped.

Remaining gaps resulting from the exploitation of lignite in open pits are sometimes used to form lakes, by natural, artificial or combined flooding processes. These lakes can take on various uses, such as water sources for agriculture, horticulture and viticulture, for social and industrial activities in the surrounding areas or as leisure facilities (Mborah et al., 2016).

Natural flooding of the remaining gaps is specific to lignite deposits with complex hydrogeological structures, on the depths of which there are aquifers that extend over large areas and thicknesses and in the adjacent areas to the exploitation perimeters, with important static and dynamic groundwater resources. Artificial flooding of the remaining gaps is applied

Tab. 1. Multicriteria classification of open pits according to their hydrogeological conditions. * meter width of layer/aquifer horizon
Tab. 1. Wielokryterialna klasyfikacja wyrobisk odkrywkowych ze względu na ich warunki hydrogeologiczne. *metrowa szerokość warstwy/poziomu wodonośnego

	Classification / Specification	Hydrogeological conditions			
		I Simple	II Moderate	III Difficult	IV Complex
1	Hydrogeological structures	Open structures, with natural supplying and drainage conditions	Mixed open and closed structures, located above and below the local erosion base	Closed structures located under the regional erosion base	Complex structures with infinite aquifer horizons and inexhaustible water resources
2	Type of aquifers	Phreatic and captive with free level and limited water resources	Phreatic and captive with free or ascending groundwater level	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	Homogeneous or inhomogeneous multilayer aquifers with very large extension and with or without hydrodynamic connections between them
3	Type of aquifer rocks	Medium and coarse sands or mixtures of sands and gravels	Medium sands (Φ = 0.25÷0.5 mm)	Fine or dusty sands (Φ<0.25 mm) and medium sands	Fine sands, dusty or clayey sands and sometimes medium or coarse sands (Φ≥0.25 mm)
4	Number of aquifers	Two or more aquifers layers with limited extension	Two or more aquifers layers with large extension	Two or more aquifers layers with variable extension	Two or more aquifers layers with very large extension
5	Aquifer thicknesses	Under 15÷20 m	20÷40 m	30÷50 m	Over 40÷50 m
6	Piezometric pressure P [m H_2O]	10÷15	20÷50	40÷60	Over 60
7	Permeability of aquifer rocks, k_f [m/day]	Over 10	2÷10	0.5÷2.0	0.1÷0.5
8	Transmissivity T [m^3/m*·day]	100÷500	100÷250	50÷100	50÷200
9	Water inflow per ton extracted q [m^3/ton]	≤ 3	3÷5	5÷10	Over 10

in cases where groundwater resources are reduced, and involves supplementing the water supply by adductions, in order to reduce the flooding period of the remaining gap and, with it, the risk of landslides. An important role in the process of flooding the remaining gaps is played by the zonal or regional rainfall regime and the amplitude of the characteristic evapotranspiration.

2. Multicriteria classification of open pits

Formation of groundwater inflow towards the remaining gaps of the open pits depends on the presence and nature of aquifer formations, rock's aquiferity and hydrodynamic parameters of groundwater flow and occurs after the dewatering works are stopped.

The size of the inflows is dependent on several factors, including:

- type and size of groundwater resources;
- the hydrogeological characteristics of the rocks;
- the structure of aquifers currents and the hydrodynamics of groundwater;
- the contour of the aquifer supply domain;
- the size of the drained surfaces.

Of the three types of groundwater resources (static, dynamic and elastic), the dynamic resources have a great influence on the flooding process of the remaining gaps (including the stability of their final slopes), as they represent the inflow of groundwater provided by the natural supply of aquifers, which makes them virtually inexhaustible.

The evaluation of dynamic resources takes into account the precipitation modulus, the surface and groundwater flow modulus, the flows of the surface runoff, the groundwater drainage possibilities, the size of the active surfaces and the groundwater flow gradients.

Static resources are exhaustible under the conditions of the existence of natural or artificial drainage areas and can be regenerated only under the influence of the existence of sources and areas of natural supply.

Elastic resources, even if they exist in the lignite deposit conditions, become without influence by the de-stressing of aquifers when creating drainage conditions due to mining excavations that intersect closed type aquifers, with pressurized water.

Among the hydrogeological characteristics of the rocks, essential for the formation and volume of water inflows are:

- rock's permeability defined by the hydraulic conductivity, expressed by the filtration or permeability coefficient;
- rock's storage and release capacity, depending on the particle size composition and the porosity of the rocks.

The aquifer currents that form towards the remaining gaps evolve from unilaterally plane parallel currents on each side of the remaining gap, in non-permanent regime, to symmetrical or asymmetric radial currents with permanent flow regime.

The structure of aquifers currents is dependent on the geological structure of the region, the configuration of the works system, the geomorphological characteristics of the land surface, the existence of surface water sources and the contour of the aquifer supply domain. From this point of view, the contour can be linear when the supply is made in one direction, rectangular when the supply is made in two directions, circular or elliptical, when the supply is made in several directions and of surface when the supply is made by drainage or infiltration of precipitation into groundwater phreatic (surface) formations.

The size of the drained surfaces directly influences the inflow of water into the remaining gaps as the flow (inflow) is

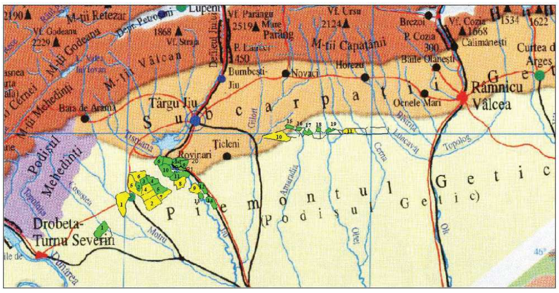

Fig. 1. Oltenia coal basin; Open-pit mining perimeters (green color; 1. Husnicioara; 2. Lupoaia; 3. Roșiuța; 4. North Jilț; 5. South Jilț; 6. Tismana II; 7. Tismana I; 8. Gârla; 9. Rovinari Est; 10. Pinoasa; 11. Roșia de Jiu; 12. North Peșteana; 13. Urdari; 14. South Peșteana; 15. Seciuri; 16. Ruget; 17. Olteț - Alunu; 18. Berbești; 19. Panga; 20. Balta Unchiașului; 21. Beterega; 22. Cicani); Underground mining perimeters (yellow color)

Rys. 1. Zagłębie węglowe Oltenia; Granice kopalni odkrywkowych (kolor zielony; 1. Husnicioara; 2. Lupoaia; 3. Roșiuța; 4. Północne Jilț; 5. Południowe Jilț; 6. Tismana II; 7. Tismana I; 8. Gârla; 9. Rovinari Est; 10. Pinoasa; 11. Roșia de Jiu; 12. North Peșteana; 13. Urdari; 14. South Peșteana; 15. Seciuri; 16. Ruget; 17. Olteh - Alunu; 18. Berbești; 19. Panga; 20. Balta Unchiașului; 21. Beterega; 22. Cicani); Podziemne granice górnictwa (kolor żółty)

dependent on the underground flow rate and the size of the open surfaces at the level where the aquifers are intercepted by the final slopes of the remaining gap. From this point of view, it is estimated that the size of these drainage surfaces is very large, especially in the case of open pits with multilayer aquifers, which contributes to an accelerated dynamics of flooding the remaining gaps. In turn, this dynamic can influence the stability of slopes.

In the literature there are several hydrogeological classifications (Salako and Adepelumi, 2018; Hunkeler, 2010; ***, 2003; Rotunjanu and Lazăr, 2014; Gheorghe and Bomboe, 1963; Enache, 1985) of useful mineral deposits, most of them taking into account a single criterion, such as the degree of flooding of the deposit (characterized by the position of the deposit relative to the local erosion base); the presence or absence in the vicinity of the deposit of superficial aquifer sources; lithological composition of rocks within the boundaries of the deposit; rock's aquiferity; the degree and intensity of the tectonics of the deposit; the size of the water inflow, etc.

In this context, a multicriteria classification of open pits (remaining gaps) according to their hydrogeological conditions is proposed. The criteria taken into account, individually and as a whole, define the hydrogeological conditions that may affect the flooding process. In this manner, the methods and technologies used within the flooding process can be conditioned so as not to have a major influence on the stability of the final slopes (Table 1).

Observations

Class I – Open pits with simple hydrogeological conditions

There are no problems with the stability of the slopes during the flooding process. Due to the reduced groundwater resources, the flooding duration of the remaining gap is long, so water inputs from nearby surface sources are recommended.

Class II – Open pits with average hydrogeological conditions

Slope instability phenomena may occur as a result of suffosion holes caused by water seepage from the slopes, which exerts a hydrodynamic action. Under these conditions, after the dewatering works are stopped, the groundwater resources can be partially or totally restored, which can ensure to some extent the flooding of the remaining gap.

Class III – Open pits with difficult hydrogeological conditions

In the absence of dewatering works and the existence of open slopes, there are risks of landslides occurrence in the final slopes of the remaining gap due to the appearance of suffosion holes, of hydrodynamic pressure and changes in the structure and properties of fine-grained rocks. On the other hand, the flooding (almost total flooding) of the remaining gaps is ensured.

Class IV - Quarries with complex hydrogeological conditions

Constructive and maintenance works (measures) are needed to ensure the stability of the slopes of the remaining gaps before and during their flooding (reduction of slope angles, consolidation of dumped rocks by dynamic surface or in depth compaction, reinforcements etc.). Flooding of the remaining gaps is ensured by the large water inflows due to groundwater resources and flow conditions.

As the hydrogeological parameters vary from one deposit to another and even within the same deposit, depending on its hydrogeological structure, the classification of open pits in one class or another is difficult and for this reason a qualitative and quantitative assessment of the weight in which the analyzed parameters influences the dewatering and flooding processes must be made.

Practical experience has proved that special problems, when flooding the remaining gaps, occur when in the exploitation perimeters there are horizons with water under pressure, in conditions of a large influx of water. For this reason, an open pit or a remaining gap must be included in the class corresponding to the most unfavorable values of these parameters. Another principle of framing the remaining gaps, according to the presented classification, is the one according to which a deposit belongs to the class indicated by the values of most of the studied hydrogeological parameters.

3. Classification of coal open-pits and their remaining gaps from Romania

On Romanian territory, Oltenia's Coal Basin develop in the area of the Getic Subcarpathians and the Getic Plateau, between the Danube and Olt rivers, within the counties of Mehedinți, Gorj, and Vâlcea. The basin covers an area of approximately 4500 km2 and stores over 95% of the country's lignite reserves (Fodor et al., 2003). It includes 5 mining basins: Rovinari, Motru, Jilț, Berbești, and Husnicioara, being divided according to geographical, geological (rock nature

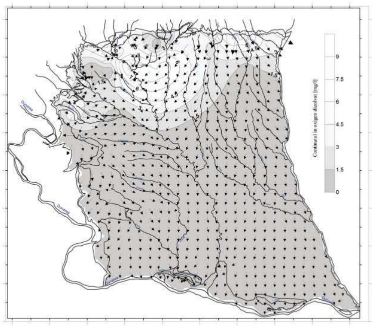

Fig. 2. The Dacian aquifer complex and the groundwater flow direction (vectors represent normal flow rates) (Palcu et al., 2008)
Rys. 2. Dacki kompleks wodonośny i kierunek przepływu wód podziemnych (wektory przedstawiają normalne natężenia przepływu) (Palcu et al., 2008)

and thickness of rock layers, depth of exploitation, degree of tectonization), hydrogeological, and economic criteria, and a total of 22 open-pit mining perimeters (Figure 1).

The lignite exploitation activity has ceased for 7 of the 22 perimeters, 2 of the remaining gaps resulting from the exploitation being currently flooded naturally (Urdari, which is located in the hilly area and South Peşteana, which is located in the meadow area of the Jiu river).

In order to verify the utility of the proposed classification and if the results confirm the real situation, the hydrogeological framing of the former South Pesteana and Urdari open-pits was carried out, which now form pit lakes. In addition, depending on the available data, some of the open-pits in the Rovinari mining basin and their remaining gaps were included in the proposed classes, as the exploitation is coming to an end (in maximum 5 years), being necessary to establish the direction of reuse and evaluate the potential risks, respectively the available water needed for flooding.

The hydrogeological research works have highlighted several groundwater horizons which, depending on the local erosion base, can be:

- groundwater with free level (phreatic aquifer);
- groundwater under pressure with ascending or artesian levels. Most of the aquifer structures in the southern part of Romania are located below or above the local erosion base, constituting hydrostructures with regional extension. (Palcu et al., 2008).

In the perimeter of the Getic Piedmont, the Dacian aquifer complex (consisting of sands with rare gravel elements and frequent sandstone concretions that pass to the top to fine sands with clay intercalations; Figure 2) is found at shallow depths in the western half of the perimeter, depths that gradually increase to the east. Also, there was a continuous increase in the thickness of the Dacian deposits from south to north (the aquifers reaching values of over 70 m). The bed of the Dacian aquifer complex consists of Pontic marls and clays or Meotian marls and sands, and the roof of Romanian clays and marls. The aquifer horizons in the coal complex do not have a continuous spread, the research boreholes highlighting their lens-like character. The variation of the hydrogeological facies takes place both vertically and horizontally, passing almost directly from permeable horizons to impermeable horizons. This situation is found especially in the upper part of the Dacian, in base the deposits being uniform. Therefore, in Oltenia, there is a strong artesian basin, which develops well below the Getic Plateau and the Oltenia Plain and which has important variations due to the granulometric constitution of the sands (ICSITPML, sb.810-537, 2012; ICSITPML, sb.820-710, 2012; MMAP, 2015).

The main exploitable lignite layers are the layers V to XII. The lower layers can not be exploited as a result of heavy and very heavy hydrogeological condition and high discovery reports (Fodor and Baican, 2011).

In the case of some mining perimeters located in the meadow area (North Peşteana, Roşia de Jiu), in order to exploit the V lignite layer, detensioning of artesian aquifer horizon was needed. This was made through free eruption boreholes. In meadow areas, generally, lignite layers V – VIII, and sometimes layers IX – X (except for South Peşteana perimeter were layers X – XII were exploited as to the south of the basin the upper layers have higher thicknesses and favorable discovery reports), are developed and can be exploited, while the upper layers (X – XII) can be found and exploited at higher levels, usually in hilly areas. Depending on mining perimeters, the exploitable lignite layers are as it follows (ICSITPML, sb.810-537, 2012; ICSITPML, sb.820-710, 2012; MMAP, 2015; ***, CEO, 2020):

- in South Peşteana mining perimeter – lignite layers X – XII;
- in Urdari mining perimeter – lignite layers X – XI;
- in North Peşteana mining perimeter – lignite layers V – VIII;
- in Roşia de Jiu mining perimeter - lignite layers V – XII;
- in Pinoasa mining perimeter – lignite layers V – XII;
- in Rovinari mining perimeter –lignite layers V – VIII.

The mixed (hilly and meadow) and hilly relief predominate in most of the mining perimeters in Rovinari. The development of deposits in the meadow area of the Jiu River, respectively in a region with aquifer horizons of impressive dimensions, has a positive influence in the conditions of restoring aquifer resources and flooding the remaining gaps, as it ensures the development of these processes naturally, without involving major financial investments. However, the presence of water in rocks is felt on the stability reserve of the slopes by increasing the volumetric weight of the rocks, reducing the resistance characteristics of the rocks (cohesion and internal friction angle), manifestation of pore water pressure and hydrodynamic pressure.

Tab. 2. Classification of open-pits and their remaining gaps in term of hydrogeological conditions
Tab. 2. Klasyfikacja wykopów i ich pozostałych luk pod względem warunków hydrogeologicznych

Classification criteria	South Pesteana		Urdari		North Pesteana		Rosia de Jiu		Pinoasa		Rovinari	
	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Hydrogeological structures	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II
Type of aquifers	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III	Deep with variable extension, with hydrodynamic connections between them and large water resources	III	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III	Deep with variable extension, with hydrodynamic connections between them and large water resources	III	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III
Type of aquifer rocks	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I
Number of aquifers	> 3 aquifers with variable extension with hydrodynamic connections between them important; inflow from Jiu river	III	> 3 aquifers with limited extension	I	> 3 multilayer aquifers with large extension, with/without hydrodynamic connections between them; inflow from Jiu river	IV	> 3 multilayer aquifers with large extension, with/without hydrodynamic connections between them; inflow from Jiu river	IV	> 3 aquifers with limited extension	I	> 3 aquifers with variable extension with hydrodynamic connections between them	III
Aquifer thicknesses	> 15 m	I	> 15 m	I	> 40 m	IV	> 40 m	IV	15 - 30	II	30	II
Piezometric pressure P [m H_2O]	50 - 150	IV	-	-	50 - 150	IV	10 - 200	IV	3.7 – 170.8	IV	50 - 150	IV
Permeability of aquifer rocks, k_f [m/day]	0.1 – 4.8	IV	0.46	IV	0.3 - 15	IV	0.1 - 10	IV	0.009 - 1	IV	0.3 - 3	IV
Transmissivity[3] T [m^3/m^*·day]	-	IV	-	IV	-	IV	-	IV	-	IV	-	IV
Water inflow per ton extracted q [m^3/ton]	12.87	IV	-	-	12.87	IV	16.32	IV	3.7	II	5.41	III
Class[2]	III/IV		II		IV		IV		III/IV		III/IV	

1 varies on vertical and horizontal and the most unfavorable values were taken into account;
2 Class I – Open pits with simple hydrogeological conditions; Class II – Open pits with average hydrogeological conditions; Class III – Open pits with difficult hydrogeological conditions; Class IV - Quarries with complex hydrogeological conditions;
3 The calculated values of the transmissivity are dependent on the filtration coefficient and the thickness of the aquifer layers, so they indicate high/low values depending on the values of the two parameters (ICSITPML, sb. 810-537, 2012; ICSITPML, sb. 820-710, 2012).

The supply of the aquifer horizons is made with the inflow of water from the atmospheric precipitations, from the superficial waters and from the neighboring aquifer horizons where there is a hydraulic connection between them. The Rovinari mining basin is located between the Jiu (to the east) and Jilț (to the west) rivers. The discharge of aquifers is made by natural drainage, in the southern area of Oltenia, by artificial drainage, in the dewatering systems of the exploitations, in the catchment fronts for water supply or by the ascending drainage, through the semipermeable formations. The physical-geographical conditions of the mining basins are favorable for the accumulation of significant groundwater reserves and their permanent renewal. (Vladimirescu, 1978; ***, CEO, 2020).

From one mining perimeter to another, depending on the extension of each aquifer, the number of aquifer varies. Three or more aquifers layers with variable extension and thicknesses are located in the studied areas. The main aquifers (in the region of Rovinari mining basin) are located as it follows (ICSITPML, sb.810-537, 2012; ICSITPML, sb.820-710, 2012; MMAP, 2015; ***, CEO, 2020; Nyari Apostu, 2019):

- in the bed of the lignite layer no. V with thicknesses between 21 ÷ 40 m which increases from north to south up to 70 m or even more;
- between V – VI lignite layers with thicknesses between 15 ÷ 28 m;
- between VI – VII lignite layers with thicknesses between 3,5 ÷ 31 m;
- between VII – VIII lignite layers with thicknesses between 0,3 ÷ 30 m;
- between VIII – IX lignite layers with thicknesses between 3 ÷ 15,5 m;
- between X – XII lignite layers with thicknesses between 3 ÷ 16,6 m.

Groundwater aquifers generally have thicknesses of the order of meters (with maximum thicknesses around 10 m).

Analyzing from a quantitative and qualitative point of view all the known data, the remaining gaps of the open-pits in the Rovinari mining basin were included in the proposed hydrogeological classes (Table 2). In the case of the Urdari remaining gap, the classification in the hydrogeological classes was made only on the basis of the criteria that could be defined according to the available data.

Overall, the remaining gaps of open-pits located in the Rovinari mining basin generally face difficult or complex hydrogeological conditions. Difficult and complex hydrogeological conditions are unfavorable in terms of stability during the flooding process, but are favorable in terms of water availability for natural flooding.

South Peșteana lake is flooded in a proportion of 80% (after its closure at the end of the 2015), the actual water level being maintained through dewatering boreholes and a discharge channel to protect the IInd step of the inner dump (on which are deposited the mining machineries and equipments) from submergence. The remaining gap of the South Peșteana open-pit is framed into the IIIrd/IVth class, meeting difficult and complex conditions from a hydrogeological point of view. During the flooding only the water level in the lake was monitored. During these monitoring activities, the manifestation of geotechnical phenomena was not reported, but it is possible that they occurred either underwater or above it, were not of large dimensions, so they were not taken into account. The aquifer horizon located between the lignite layers X – XII consists of sands with relatively low thickness (2–6 m, sometimes up to 10–12 m) that arise south of Cocoreni and Topoării localities, coming in direct contact with the alluvial formations from Jiu meadow, which favors the supply of the aquifer horizon directly from the phreatic aquifers (***, CEO, 2020). The result partially confirms the real situation. Indeed, the flooding occurred naturally and in a short period of time (in about 3–4 years the gap was flooded to the current level), but geotechnical problems were not observed and several scenarios can be taken into account:

- there was no system for monitoring the stability of slopes or changes that may predict the occurrence of negative geotechnical phenomena, so that any problems observed were not recorded on any support (paper, electronic);
- no changes were observed because they appeared below water level or above it, but were insignificant, small in size;
- there were no stability problems due to the relatively rapid submergence of the slopes knowing that this situation is favorable for stability due to the manifestation of hydrostatic water pressure on the slopes (water on the slope behaves like a support prism increasing the stability reserve).

The Urdari open-pit was definitively closed in 2003. After the closure, its natural flooding began, today being 100% flooded. A discharge channel was built to take over the surplus of water in the lake, this being the main way to discharge the lake. According to the proposed classification, the remaining gap of the Urdari open-pit belongs to the II class, meeting average conditions from a hydrogeological point of view. Considering the development of the aquifer horizons in the Urdari perimeter, the supply and discharge conditions, and taking into account the fact that in this open-pit only layers X and XI, located above the local erosion base, were exploited, it appears that the flooding process can be done naturally, but it can be lasting. The conditions are favorable in terms of stability and it is unlikely that problems will occur at the final slopes during the flood. The result confirms the real situation. Before, during, and after the flooding of the remaining gap of the Urdari open-pit, no geotechnical phenomena such as landslides, suffusions, etc. were observed and the flooding produced 100% naturally.

North Peşteana and Roşia de Jiu open-pits and their remaining gaps present complex hydrogeological conditions (IV class), meaning there are needed stability works in order to increase the stability reserve of the final slopes considering the flooding of the remaining gaps. On the other hand, the hydrogeological conditions are favorable for the restoration of the aquifers resources, respectively for the natural flooding of the remaining gaps. In the case of Roşia de Jiu open-pit, at the cessation of the activity it is possible that the inner dump occupies the entire remaining gap so may not result in a pit lake.

Pinoasa and Rovinari open-pits and their remaining gaps present difficult to complex hydrogeological conditions (III/IV class), meaning that geotechnical risks may occur such as landslides as a result of manifestation of hydrodynamic pressure and occurrence of suffosion holes or of changes in the structure of fine-grained rocks. On the other hand, due to these conditions the natural flooding of the remaining gap may be ensured.

As we can see, according to the proposed classification and to the results, when favorable flooding conditions exist there may occur geotechnical problems. The classification is useful as it offers indications regarding the interventions needed to reduce or even eliminate the possible risks and the available water resources to create a pit lake.

4. Conclusions

The hydrogeologcal conditions specific to an area influence the type of restoration and reuse of the degraded mining land. To determine the hydrogeologcal conditions of an area, exploration of local geology and hydrogeology is needed consisting in studying the aquifer formations, their extension, the way of supplying and discharging them, the hydrogeological characteristics of the rocks.

Based on the proposed classification which takes into account several criteria a better classification of open pits and their remaining gaps can be made. Therefore, the flooding possibilities can be evaluated as these are the most common types of reuse of the remaining gaps of former open pits. The costs of restoration of the former open pits can be estimated in a more rigorous mode.

Generally, the open-pits and their remaining gaps located in the Rovinari mining basin are characterized by difficult to complex hydrogeological conditions which means there are needed works to increase the stability reserve of the final slopes in order to reduce the geotechnical risks that may arise, but on the other hand these conditions are favorable to natural flooding and creation of pit lakes.

As the classification is based on qualitative and quantitative analyses it ensure a rapid and quite precise response (depending on the existing data and informations and their accuracy) and indications regarding the geotechnical problems that may arise during the restoration of aquifer resources and/or during and after the flooding process, available water resources and the possibilities of flooding.

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Nowa klasyfikacja kopalń odkrywkowych i powstałych wyrobisk pod względem warunków hydrogeologicznych

Ponieważ odkrywki zajmują teren tylko tymczasowo, planowanie prac po zakońzceniu eksploatacji w celu zrównoważonego ponownego wykorzystania gruntów stanowi ważny etap i można to zrobić już na etapie przedeksploatacyjnym.

W zależności od charakteru i lokalizacji złóż rudy istnieje więcej możliwości ponownego wykorzystania dawnych wyrobisk odkrywkowych. Odkrywki węgla są często ponownie wykorzystywane jako sztuczne jeziora. W zależności od lokalnej hydrologii i hydrogeologii proces zalewania byłych odkrywek może odbywać się w sposób naturalny lub sztuczny (łączony). Ponowne wykorzystanie pozostałych odkrywek wymaga dobrej oceny możliwości i ograniczeń specyficznych dla tego obszaru.

Klasyfikacja odkrywek i pozostałych wyrobisk pod względem warunków hydrogeologicznych jest niezbędna dla lepszego planowania terenu po zakończeniu eksploatacji.

W artykule zaproponowano wielokryterialną klasyfikację odkrywek i pozostałych wyrobisk z uwzględnieniem warunków hydrogeologicznych i oddziaływania niektórych parametrów hydrogeologicznych, które mają istotny wpływ na zapełnianie wyrobiska wodą. Badane są najważniejsze warunki hydrogeologiczne regionu (budowa hydrogeologiczna, rodzaje i liczba warstw wodonośnych, charakter skał wodonośnych, charakterystyka hydrodynamiczna regionu), a wyniki są przetwarzane w celu opracowania wielokryterialnej klasyfikacji. W zależności od wyników klasyfikacji hydrogeologicznej odkrywek i pozostałych wyrobisk, można ustalić możliwość naturalnego i / lub sztucznego zalania lub przeciwnie, konieczność rozważenia innego kierunku ponownego wykorzystania. Zaproponowana klasyfikacja jest innowacyjna, ponieważ w literaturze opisano do tej pory klasyfikacji wielokryterialnej, a większość publikacji skupia się na klasyfikacji jednokryterialnej. W niniejszej pracy więcej odkrywek i wyrobisk poeksploatacyjnych przeanalizowano z hydrogeologicznego punktu widzenia i sklasyfikowano w oparciu o zaproponowaną klasyfikację uwzględniającą ocenę wielokryterialną.

Słowa kluczowe: *odkrywkowe, wyrobiska poeksploatacyjne, warunki hydrogeologiczne, klasy hydrogeologiczne, wody podziemne, dopływ*