FLOODING OF THE REMAINING GAP OF NORTH PEȘTEANA QUARRY IN ORDER TO CREATE A WATER RESERVOIR FOR IRRIGATIONS

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Abstract. *Open pit mining exploitation involves a considerable change in the geomorphology of the region, especially through the development of deep qurries. The remaining gaps resulting from cessation of the open pit mining operations have impressive dimensions and a major negative impact. In addition to radically changing the landscape that causes a negative visual impact, open pit mining exploitation has a major impact on the land, which is manifested by diversion from its original uses, land quality degradation, destruction of ecosystems, affecting local communities and the worsening of the quality of life. One of the major problems arising from the exploitation of lignite in quarries is the quantitative damage to groundwater resources due to the need for aquifer dewatering, a process that leads to a lower water level and which has a significant impact on vegetation and local communities (incapacity of plants to supply water, wells drying up etc.). Water filling of the remaining gap is a method used frequently worldwide and has numerous benefits regardless of the use of pit lakes. The choice of remaining gaps that are suitable for water filling must be based on an appropriate assessment, taking into account a number of essential criteria for the success of obtaining safely, long-term beneficial results. Considering the location of the remaining gap of North Peşteana quarry, the type of use of the adjacent lands and following the climatic history that highlights many dry periods, but also their frequency in the past 8 years, this paper analyzes the necessity and the possibility of supplementing the natural water reserves by creating a water reservoir for crops irrigation in order to support the regional agricultural industry. The aim of the paper is to increase the level of recovery and reuse of degraded mining lands at national and global level and to highlight the many advantages that these practices have on the environment and human communities. Recovering the remaining gap of North Peşteana quarry and reintegrating it into the landscape as a waterreservoir for irrigation has major environmental and economic benefits, contributing to the sustainable development of the region.*

Key words: *crops irrigation, open pit flooding, remaining gaps, remaining gaps reuse, water reservoir*

INTRODUCTION

As a result of cessation of open pit mining activities, extensive degraded lands remain behind, revealing new forms of relief (remaining gaps and external dumps).

The remaining gaps of quarries are negative forms of relief to the natural surface of the land, which are much more visible in the meadow areas than in the hilly areas. As a result, the visual impact generated by their appearance in the landscape is determined by the morphology and geomorphology of the site.

The mining perimeter of North Peşteana quarry is part of the Rovinari Mining Basin. It is being located within the administrative teritory of the Urdari and Bălteni commune in Gorj county and occupies a total area of 1176.2 ha. North Peşteana quarry is located in the Jiu River meadow area and has an irregular surface of land with many positive and negative microforms of relief due to mining activities in the area.

An important aspect to be mentioned is that the mining perimeter of the North Peșteana quarry, located in a meadow area of the Jiu River, presents the necessary conditions for naturally flooding in an acceptable period of time. For example, the remaining gap of South

Peşteana quarry, which was closed at the end of 2015, was naturally flooded from aquifer infiltrations and precipitation more than 70% (Figure 1). It is mentioned that this process has not been monitored, so there is no information about the geotechnical status of the lake shores or the risk of sliding.

Figure 1. The lake formed in the former South Peșteana quarry

The lake formed in the remaining gap of South Peşteana quarry has a naturalistic value. In time, with the spotaneous installation of vegetation și the different fauna species, a new ecosystem will form. In order to sustain and accelerate the process of ecosystem restoration, anthropogenic interventions can occur.

The goal of recovering and reusing of the mining degraded lands is to harmonious restore the natural cadence and reintegrate into the landscape with the possibility of developing other types of activities that bring environmental or productive benefits.

MATERIAL AND METHODES

In order to evaluate the opportunity of flooding of the remaining gaps of quarries, a methodology was developed based on a series of criteria that influence this process, such as the morphology and orography of the area, the need for a water mirror, availability of water resources, stability conditions of the slopes, accesibility and distance from inhabited areas (Table 1). (NYARI AND AL., 2017)

Table 1

Assessment matrix for the opportunity of flooding the remaining gaps of open pits

Score* / Criteria	0	1	2	3
Morphology and orography	Hilly or mountainous area	Hilly area	Hilly and meadow areas	Meadow areas
Depth [m]	≤ 5	5 – 20	20 – 40	> 40
Necessity of a water mirror	Major importance for other types of reuse; flooding is not indicated	Flooding possibility is limited by aspects like the infrastructure	Isolated areas; appearance of a naturalistic lake to recreate natural cadence and biodiversity	Agricultural, residential or natural areas; the emergence of a pit lake has major importance
Availability of water resources	Limited or absent aquifer resources, the coefficient of underground water	Low availability of aquifer resources, low groundwater and surface water flows;	Medium availability of aquifer resources, medium groundwater and surface water	High availability of aquifer resources, large flows of groundwater and

	inflow < 1 m^3/t; absence of underground water resources	coefficient of underground water inflow 1-3 m^3/t	flows; coefficient of underground water inflow 3-8 m^3/t	surface water; coefficient of underground water inflow > 8 m^3/t
Slope stability conditions	In-situ and/or waste dump slopes with active movements involving significant volumes of material	In-situ and/or waste dump slopes that may develop dangerous movements duet o certain factors	In-situ and/or waste dump slopes with movements that may be limited trough specific measures	Stabilized in-situ and/or waste dump slopes, for which sliding phenomena are not likely
Accessibility and distance from inhabited areas	Limited access, large distance from interest areas (>10 km)	Limited access, relatively large distance from interest areas (1-10 km)	Relatively easy access, medium distance from interest areas (250-1000 m)	Easy access, small distance from interest areas (0-250 m)

** 0 – inopportune; 1 – reduced opportunity; 2 – medium opportunity; 3 – high opportunity*

Taking into account the established criteria and analyzing the characteristics of the remaining gap of North Peşteana quarry, the following assessment of the opportunity of flooding was made (Table 2). The final score is the arithmetic average of the scores awarded according to the evaluation criteria.

Table 2

Assessing the opportunity of flooding the remaining gaps of the open pits

Criteria		Characteristics	Score	Final score*
Morphology and orography	Relief	meadow area	3	2,83
	Depth [m]	80 m	3	
Necessity of a water mirror		agricultural and residential area, it is recommended the emergence of a lake for irrigations	3	
Availability of water resources		k_a = 12,87 m^3/t, Jiu river	3	
Slope stability conditions		stabilized in-situ and/or waste dump slopes, for which sliding phenomena are not likely	3	
Accessibility and distance from inhabited areas		relatively easy access, medium distance from interest areas (250-1000 m)	2	

For assessing the opportunity of flooding of the remaining gaps the following scale was established: [0 ÷ 1,5] – inopportune; (1,5 ÷ 2] – reduced opportunity; (2 ÷ 2,5] – medium opportunity; (2,5 ÷ 3] – high opportunity. (NYARI AND AL., 2017)

According to the results, the remaining gap of North Peşteana quarry presents high opportunity for flooding. Taking into account the Regional Development Plan (***, 2014) and the requirements of local communities, it is advisable to create a water reservoir for crops irrigation to support the local agricultural industry during drought periods. (NYARI AND AL., 2017)

Need to create a water reservoir for irrigation

Gorj County is one of the counties known for practicing agriculture. The largest arable land area was cultivated with cereals, around 70-80% of the total area, especially maize and wheat. Therefore, the present paper will highlight periods of drought and water scarcity for wheat and maize crops recorded over the last 8 years (2010-2017).

It is important to identify risk situations generated by extreme climatic phenomena such as scarcity/excess rainfall, low/very high temperatures, since extremes of this type have unfavorable effects on agricultural productivity, leading to plant disease, drying/drowning of plants and crop loss.

Amount of rainfall and rain index

The analysis of the annual rainfall quantities in Gorj County over the past 25 years (except for the mountain area, where there are no pluviometric posts) shows an average of 685.3 l/m^2. (***, 2008)

In order to facilitate the assessment of a region according to the precipitation regime, the monthly rainfall index (rain index) is calculated which is defined as the ratio between the monthly average precipitation and 1/12 of the region's average annual rainfall. Thus, for an index value greater than 0.6, it is considered that the month is rainy and otherwise it is considered being drought. (ROTUNJANU AND LAZAR, 2014; MOISELLO, 1996)

In Table 3, are presented the average monthly rainfall in the growing months of wheat (march - june) and maize (may - august) and rainfall index values for the 2010-2017 period.

Table 3

Monthly average precipitations values and the rain index for Gorj county (2010-2017) (mm/m^2)

Month	Year							
	2010	2011	2012	2013	2014	2015	2016	2017
III	65 (1,14)	35,5 (0,62)	≤10 (0,18)	88 (1,54)	88 (1,54)	63 (1,1)	113 (1,98)	15,5 (0,27)
IV	75 (1,31)	15,5 (0,27)	88 (1,54)	63 (1,1)	163 (2,85)	25,5 (0,47)	45,5 (0,8)	63 (1,1)
V	112,5 (1,97)	35,5 (0,62)	188 (3,3)	63 (1,1)	188 (3,3)	63 (1,1)	88 (1,54)	63 (1,1)
VI	112,5 (1,97)	63 (1,1)	35,5 (0,62)	45,5 (0,8)	163 (2,85)	63 (1,1)	88 (1,54)	≤10 (0,18)
VII	65 (1,14)	88 (1,54)	88 (1,54)	≤10 (0,18)	163 (2,85)	15,5 (0,27)	88 (1,54)	63 (1,1)
VIII	45 (0,79)	≤10 (0,18)	≤10 (0,18)	88 (1,54)	63 (1,1)	63 (1,1)	35,5 (0,62)	≤10 (0,18)

* *droughty/at the limit/rainy*

There are major variations from one year to the other and from one month to the other. It is also noted the relatively high incidence of drought periods.

In practice, they are important as the total amount of water that passes into the atmosphere through the evapotranspiration phenomenon, and in the conditions where there is a lack of precipitation water it is recommended to irrigate the crops.

Actual maximal estimated evapotranspiration of agricultural crops

Reference evapotranspiration (ET_0) is an important indicator used in the hydrological and climatic studies characterizing water balance in the soil and water requirements of crops. However, ET_0 does not provide sufficient information on the hydrological-climatic status of the months of practical interest for water consumption of plants, which form the vegetation period and ranges from April to October. (PĂLTINEANU AND AL., 2007)

Thus, more concrete values provide the actual maximal estimated evapotranspiration (ETc-est) of agricultural crops. During the wheat and maize vegetation period in the Rovinari area, ETc-est records significant values: 320 mm/m^2, respectively 440 mm/m^2 .

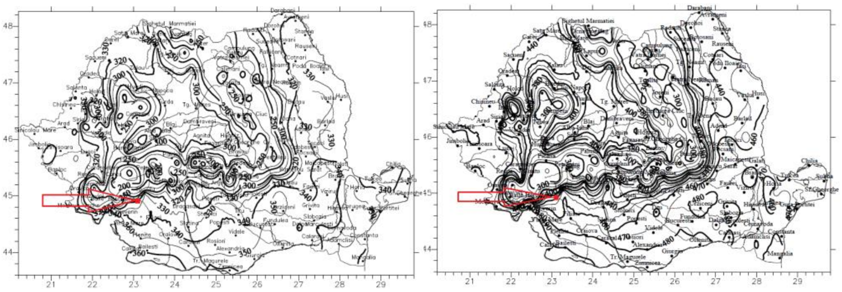

Figure 2. The geographical distribution of ETc-est (mm/m^2) for wheat (left) and maize (right) during the growing season around Rovinari city (PĂLTINEANU AND AL., 2007)

The reference evapotranspiration term is used to identify regions prone to drought. In spring and summer, in the areas at altitudes not exceeding 1000 m, the reference evapotranspiration intensity reaches the maximum level, surpassing even the amount of precipitation in the area. (CROITORU AND AL., 2013)

RESULTS AND DISCUTIONS

The climatic conditions (precipitation and evapotranspiration) specific to the studied area are based on the estimation of the water deficit during the vegetation period of wheat and maize crops and the frequency of the dry periods.

Knowing the need for water for wheat and corn crops is important in calculating the amount of water needed to irrigate crops.

Calculation of the irrigation requirement is based on the assumption that the sum of the amount of rainwater and irrigation water must be equal to the sum of water consumption of crops in optimum conditions and the amount of water lost (through surface drainage, through evapotranspiration). (ROTUNJANU AND LAZAR, 2014)

Estimation of rainfall water scarcity for crops

In order to estimate the rainfall water deficit, the amounts of rainfall in the region and the actual maximum estimated evapotranspiration of the crops shall be taken into account. The supply from underground formations is neglected until they are restored in time (this is done gradually with the flooding of the quarry). Under the current conditions, the roots do not reach the depth of the underground waters after the sowing. Also, in drought periods, interception and superficial runoff can be neglected.

In Table 4 are presented the values resulting from the determination of the rainwater deficit for the 2010-2017 period. The deficit is presented with a negative sign (and highlighted on a red background), and the values with a positive sign characterize the surplus water.

Table 4

Determination of water deficit (DEF)/excess (EXC) in wheat and maize crops on 2010-2017 period

Year	Wheat			Maize		
	P_T	ET_{c-est}	DEF(-) / EXC(+)	P_T	ET_{c-est}	DEF(-) / EXC(+)
	(mm/m^2)					
2010	365	320	+45	335	440	-105
2011	149,5		-170,5	196,5		-243,5
2012	321,5		+1,5	321,5		-118,5

2013	259,5		-60,5	206,5		-233,5
2014	602		+282	577		+137
2015	214,5		-105,5	204,5		-235,5
2016	334,5		+14,5	299,5		-140,5
2017	151,5		-168,5	146		-294

The results highlight the years and the high frequency of the years when there was recorded deficit of water for the wheat and maize crops for crop specific period (for wheat: march - june; for maize: may - august) in 2010-2017.

Based on these analyzes, it is clear that is important to have an additional source of water in the vicinity of the remaining gap of the North Peșteana quarry for crops irrigation during droughts periods.

Recovery of the remaining gap in order to create a water reservoir for crops irrigation

During periods of drought, the flow of the Jiu River decreases, so the possibility of capturing water for irrigation of large agricultural areas is reduced. Other surface water courses with higher flows and at acceptable distance to agricultural crops in the area do not exist. Therefore, the possibility of flooding the remaining gap of the North Peșteana quarry (Figure 3) offers many advantages:

- additional source of water for dry periods;
- relatively small distance from agricultural land;
- ecological benefits as a result of reintegration into the landscape.

Figure 3. The boundaries of North Peșteana mining perimeter and the final (hypothetical) position of the remaining gap

Thus, the remanent void can take on a major utility function: a water reservoir for irrigation, to support agriculture and the local economy, but also for the recovery and rehabilitation of the land degraded by the mining activity.

The recovery and rehabilitation process of a remainig gap for the aim of creating a water reservoir for irrigation of crops comprises two important steps:

- evaluation of the possibilities of flooding the remaining gap;
- flooding of the remaining gap.

Evaluation of the possibilities of flooding the remaining gap

Once the mining activity ceases, the dewatering works are stopped. As a result, the underground and surface waters leak to the remaining gap and flood it until the level of water in the lake and the level of the underground water reaches a new state of equilibrium. To this floodind process the precipitations have an significantly contribution. Depending on the flow rate of groundwater or surface water and the amount of precipitation, the period of water filling of a remaining gap can vary between a few years and several decades. (CASTENDYK AND EARY, 1999)

Precipitations and groundwater inflow from aquifer formations are the main source of flooding for the remaining gap of North Peșteana quarry.

The physico - geographic conditions of the North Peșteana mining perimeter are favorable to the accumulation of significant groundwater reserves and their permanent renewal. (VLADIMIRESCU, 1978) The factual data show that aquifers can be partially restored, even within a year of significant rainfalls. (HUIDU, 2012)

Table 5 describes the North Peșteana perimeter from a hydrogeological point of view.

Table 5

Hydrogeological parameters - North Peșteana quarry (ROTUNJANU AND LAZAR, 2014)

Aquifers	Filtering coefficient, k_f (m/zi)	Release capacity coefficient, kc (%)	Water inflow coefficient, k_a (m^3/t)	Specific debit, q (m^3/zi)
Phreatic horizon	15,0 – 20,0	0,2 – 0,3	12,87	30 – 200
Complex V – VI	0,3 – 1,0	0,05 – 0,1		5 – 50
Beneath the V^{th} layer and artesian	1,0 – 3,0	0,15		10 - 70

When classifying the deposits according to the size of the water inflow, the water inflow coefficient is taken into account, which represents the ratio of the volume of water discharged per tonne of useful mineral subtances. The high water inflow coefficient of 12.87 m3 / t, characterizes a deposit with high degree of flooding . (ROTUNJANU AND LAZAR, 2014)

The current volume of water discharged from the North Peșteana perimeter in conditions without atmospheric precipitation and under the operation of a number of 4 dewatering drillings, is 16.500 m^3/day. With the cessation of mining activity in the quarry and stopping the dewatering systems, this volume will contribute to the flooding of the remaining gap.

For conducive hydrogeological conditions to aquifers formation, total infiltration can be 15% - 20% of precipitation. (SCRĂDEANU AND GHEORGHE, 2014) Thus, the amount of water that infiltrates and contributes to the restoration of the aquifers varies between 100-140 mm/m^2/year.

The negative effects of hydrotechnical and dewatering work consist in changing the conditions of groundwater and surface water formation. Thus, surface leakages are reduced in favor of underground leakages, increasing the amount of infiltrated water that restores aquifers. (***, 2012)

The location of the remaining gap of the North Peșteana quarry in the Jiu River meadow area, respectively, in a region with impressive aquiferous horizons, has a major positive influence, contributing to the restoration of the aquifer formations and to the flooding of the remaining gap faster, reducing the flooding period (Figure 4).

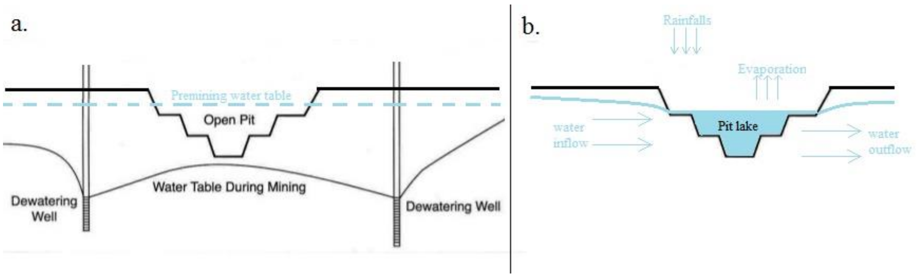

Figure 4. Dewatering of aquifers (left); restoration of aquifers and flooding of the remaining gap after cessation of the dewatering works (right)

The lake is supplied with water from the underground infiltration and precipitation, and discharge of the water from the lake is achieved by natural drainage and by the evaporation process. In this way, a balance is achieved between the water supply and the water losses of the newly formed lake.

Flooding of the remaining gap

At the end of the mining activity and before stopping of the dewatering systems it is essential to establish and apply the necessary measures in order to ensure the stability of the final slopes of the remaining gap.

The remaining gap of the North Peșteana quarry is bordered on one side by the definitive slopes of the quarry, and on the other side by the slopes of the inner dump. The dumps are formed by loose rocks, at the first saturation. As a result of the homogeneity of the dump material on certain portions, there is a significant risk of sliding by liquefaction of the sandy or predominantly sandy fractions. At the same time, the inflow of underground water that crosses the in-situ slopes can train the fine particles from the massive, creating gaps that can favor the occurrence of the sufosis phenomenon, causing the risk of a landslide.

The landslides that occur during the flooding or even after the flooding of the remaining gaps can generate waves with very high heights and speeds. These, depending on the magnitude they have, can have devastating effects, flooding and destroying all of the natural or anthropic targets in the influence areas.

Therefore, it is important to apply the measures to stabilize the final slopes of the remaining gap. Based on the literature and field observations, the following measures are recommended to stabilize the final slopes of the remaining gap of the North Peșteana quarry and to increase the degree of safety in adjacent areas:

- Release of land from its technological tasks and decommissioning of premises, use of other premises in future economic activities. For example, North Peșteana Mining Quarry Unit can become a monitoring station for the irrigation system (Figure 5).

Figure 5. Location of North Peșteana Mining Quarry Unit

- Respecting the geometrical elements of the final slopes of quarry and inner dump.
- Removal of gullies, ravines and cracks existing on the slopes (Figure 6) by filling them with material.

Figure 6. Gullies and ravines (left), sufosis phenomenon (middle), cracks (right)

- Leveling and compacting the platforms to consolidate the dumps and reduce the possibility of water infiltration in the dump.
- Ensuring appropriate slopes for natural drainage of the rainwater on the upper and non flooded part of the inner dump and on the external dump, in order to avoid rainwater erosion.
- Remodeling of shores and expanding the coastal areas (Figure 7), as follows:
    - Reshaping, so that the water depth does not exceed 1-2 m on a few meters or tens of meters. This increases safety and in the case a person accidentally slides in the lake, it can return safely to shore.
    - Modelling the edge of the remaining gaps to avoid regular geometries for harmonious framing in the landscape.

Figure 7. Remodelling of the remaining gap

- Rehabilitation of sterile dumps and their reintegration into the forestry circuit (afforestation has positive effects on the slope stability) or even into the agricultural circuit.
- Post-closure monitoring. Surveying the sterile dump geometry to observe the occurrence of possible deformations, cracks, etc. and conducting geotechnical studies, if necessary.

In case of recovery and rehabilitation of the remaining gap of North Peșteana quarry by filling with water and creating a water reservoir for irrigation of crops in the area, to the detriment of its abandonment, are ensured the necessary conditions for the sustainable development of the region. Investments are acceptable taking into account the long-term benefits of this type of use both on the local economy and on the environment and, implicitly, on human health.

CONCLUSIONS

The new practice of recovering and rehabilitating degraded land by mining activity, particularly applied in the 21st century, has a significant and positive contribution to the environment, offering the possibility of land reintegration and re-use for the purpose of sustainable development of the affected regions.

The method of flooding of the remaining gaps of former quarries is a commonly used, but less widely applied at national level. This method involves the formation of an open pit lake, which can take on different functions and which has numerous environmental benefits both from the naturalistic and the productive point of view.

The remaining gap of North Peşteana quarry is located in a region where climatic history has highlighted many drought periods or drought years that have adversely affected agricultural productivity. Determination of the rainfall deficit for wheat and maize during the years 2010-2017, taking into account the water losses from the evapotranspiration process of crops, has also highlighted many periods of drought, so it is very important to create a water reservoir in the remaining gap of the North Peșteana quarry intended for crop irrigation in the region.

The remaining gap of the North Peșteana quarry presents the necessary conditions for naturally flooding with an inflow of water from aquifers and rainfalls, within an acceptable period of time, so the essential works that involve effort and financial resources are the stabilization of the definitive slopes of the remaining gap and the modeling and harmonious integration into the landscape.

The recovery and reuse of the remaining gap of the North Peșteana quarry as a water reservoir for irrigation of the crops in the region is a judicious solution that contributes to the sustainable development of the region, with major and long-term benefits both from the productive and environmental point of view: additional water supply for irrigation to support the agriculture in drought periods, the formation of a new ecosystem and the integration of degraded land into the landscape.

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