Assessment of Soil Erosion Using Usle and GIS (Case Study: Vărzari Coal Quarry, Romania)

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Abstract: *This paper was exclusively thought of as a case study in the field of soil erosion assessment, aiming at creating a correct GIS-based methodology for a former coal quarry (Vărzari), located in the NE part of Romania, in Bihor County. Thus, it is attempted a combination of both traditional methods (Universal Soil Loss Equation) and the new means of analysis enabled by the new technology, i.e. Geographic Information System (GIS). This study aims at carefully analyzing the present situation of soil erosion in the Vărzari Coal-Quarry. The main outcomes of this study are thematic maps (i.e. landslide prediction map, flow direction map, soil erosion map) viewed as tools for planners and policy-makers at local and regional level.*

Keywords: *soil erosion, GIS methodology, methods, thematic maps.*

1. Vărzari Coal-Quarry – environmental conditions

From the geographical point of view, Vărzari Coal-Quarry is part of the territorial unit called Western Hills, precisely located in their northern division known as Criş Hills between Barcău River and Criş River. The stream of water which sweeps through the area is called Varvizel River, flowing into Bistra River and then into the larger Barcău River (Figure 1).

From the administrative point of view, this coal-area is located in the NE part of Bihor District and it comprises the territorial unit between Vărzari Village and Borumlaca Village but it was divided in such a way that 60% of it falls under direct administration of Popeşti Village and only 40% under the administration of Suplacu de Barcau Village (see the location map).

From the morphological point of view, there are three major hills: Borumlaca Hill, Viilor Hill (the most dramatically affected by mining) and Dubina Hill. Geologically, the first two consist mainly of shale (bedrock) with thin layers of clay whereas the third hill is made up of Mica-schists with clay protrusions (see geological map).

The whole coal-area stretches on 69508 m^2 (69,5 ha), the quality of the brown-coal is not very high but nowadays almost the entire area is covered with sterile heaps which, due to their frail nature, favor powerful erosion, land flows, and landfalls.

a. The Impact of Mining over the Physical Environment

Surface mining started in 1985 but it was not the first attempt of this kind because 40 years earlier an extensive underground mining initiative had been made and given up after 13 years. It left behind long hollow underground channels, which gradually filled up with ground-water and lead to a swift destruction of the area.

The second attempt started in 1985, it centered on surface mining, each year almost 4.5 ha of land were dug out but since the methods used were not very progressive it only destroyed the coal-quarry even more. In 2000, the coal-quarry was closed for good but no "mending" plan has ever been put in place.

Thus, the process of degradation has constantly advanced and it has even started to threaten the neighboring areas and human activity. It is widely accepted that physical environment is the base which holds together all the other components of the surrounding world. That is why, its structure plays a key role in the way human activity and natural environment is organized.

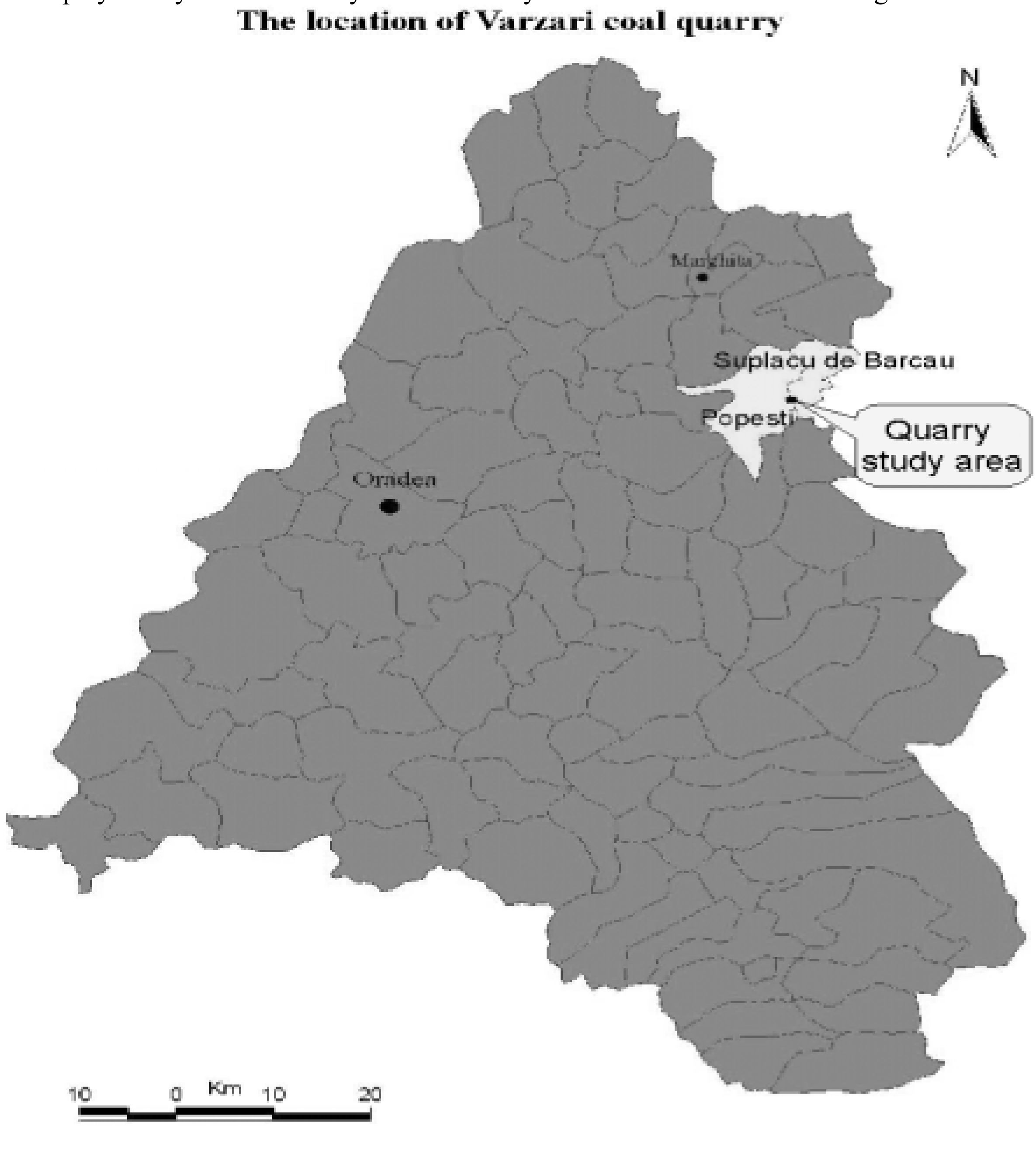

Fig. 1. Geographical location of Vărzari coal quarry

b. Geology of the Vărzari Coal-Quarry Area

The deepest layer dates back to the Quaternary Period and consists predominantly of shale deposits mingled with clay layers. In the SW part of the area Mica-schist's emerge also (Figure 2). This structure has been largely damaged by mining because in order to reach the brown-coal located beneath the sedimentary layers and formed during the Carboniferous Period, huge amounts of material had to be removed and chaotically placed aside.

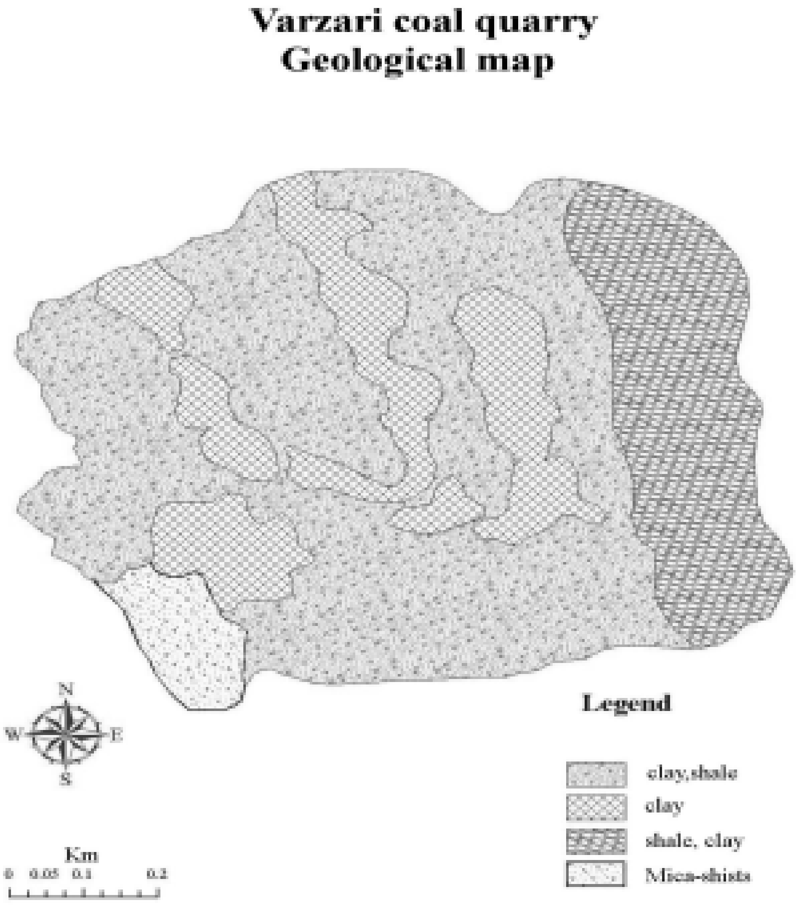

Fig. 2. Geological map of study area

The previous layered structure was completely destroyed so it resulted in a “mixing pot” of clay, shale, sand, brown-coal, rocks. The new emerging land structures looked and reacted differently than the initial ones. They were far-reaching easier attacked by erosion and other degradation processes (landslides, landfalls). The hollow channels left behind by underground mining crashed down and turned into ditches where rain water has accumulated.

Geology is important for territorial planning from two perspectives:

- Geological material dictates the possibilities of construction (the softer the rock, the more diminished are the building options). This property is called “support capacity” and it can be influenced by humidity, temperature, physical properties, etc. Figure 3 shows the direct relationship between different types of geological material and their support capacity. This is expressed in tones/m3 and has to be understood as the capacity of geological structures to “bear” human-made structures without the latter display any negative effects (sinking, wall cracks, etc) in a certain sequence of time.
- Geological faults/ruptures impose restrictions as far as the extension of human habitats is concerned. They pose human life at risk (earthquakes, floods, landslides, etc). But in the Vărzari Quarry Area has never been evidenced of such a geological behavior.

It is now obvious that due to the local geology, it is very unlikely that any high buildings or industrial centers will ever be built in this area. The support capacity of shale clay deposits is very low but combined with coal and loose rocks this capacity lowers even more.

That is why, it is recommended to avoid any very tall or very heavy constructions in this area. Also, there have been discovered multiple land-patches with hollow underground structure which could not be put in use again unless several low-scale explosions are caused which would level the ground.

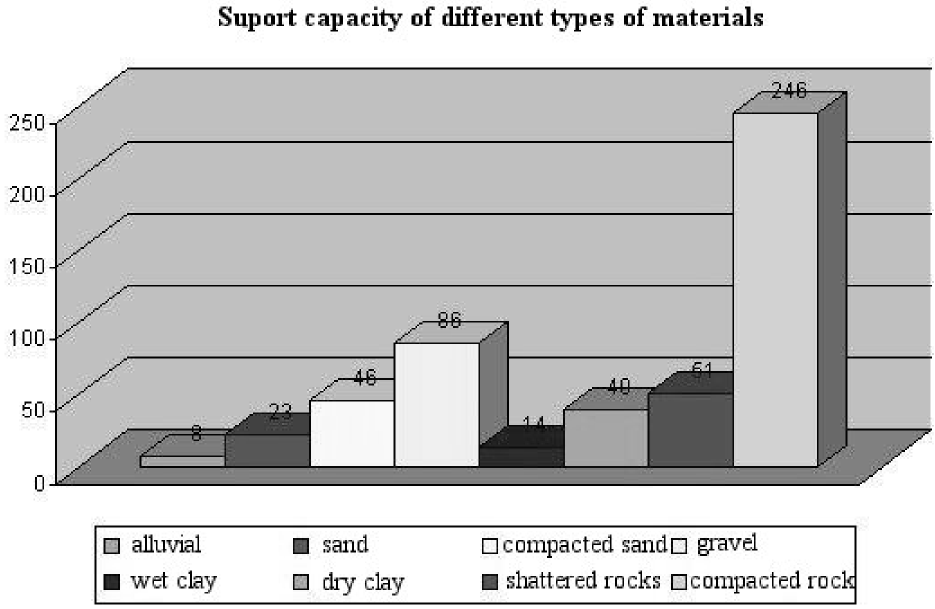

Fig. 3. Support capacity of different types of materials (Beer, 1990)

c. Topography and Geomorphology

The present outlook of the coal-quarry area is the result of long lasting mining activity. Where once directions used to converge (e.g. streams of water), a divergent display is encountered nowadays and the other way around. The entire morphology of the place has been disastrously modified.

Landslides were not common for this area before mining started. Lots of landslides appeared and extended suddenly after the worked had stopped, due to the huge amounts of soft mixed material.

The probability to develop landslides is a very good indicator of how stable-unstable a piece of land is. This indicator has been analyzed with the help of so-called GRID Module from the ARC/INFO GIS Software using the mathematical *model of regression (prediction)*.

This model states that there's a relationship between a "dependent" variable and several "independent" variables acting in a certain circumstance, in this case between the place where the landslides occurred, on the one hand and slope, geology, relative humidity, profile curvature on the other.

Here is how this relation is expressed in the GRID Module of ArcInfo GIS:

Grid: sample file = sample (slope, shape, geogrid, humidity)
List grids ... 100%

Grid: regression fall logistic brief

coeff. No	coeff
0	16.273
1	0.31
2	-.337
3	-22.970
4	-.292

coefficient of regression (prediction)

Error Value = 0.107 (r^2)
Chi-Square = 321.702
*Grid: predlog = 1 div (1 + (exp (- (16.273 + (0.310 *slope) + (-0.337 *shape) + (-22.970 * geology) + (-0.292 * humidity)))))*

The result of this model of regression provides us with the *map of landslides probability (*Figure 4). The map is intended to be used as a general guide to landslide occurrence, not as a predictor of hazard at specific sites.

The map depicts the potential for landslide occurrence from hillslope source areas but does not depict slide paths or areas of landslide deposition. The map does not take the place of an on-site survey or professional judgment of a geologist of geotechnical engineer. Appropriate uses of the map include storm preparedness planning for emergency access and response.

All the values close to 0 indicate very low risks of landslides, whereas all the values close to 1 point at regions with high risks of landslide occurrence. In mathematical terms, the relationship between the dependent and independent variables are expressed as follows:

$$y = 1 / (1 + (- ((a_0 + a_1x_1 + a_2x_2 + a_3x_3 + \ldots\ldots a_nx_n)^{e})))$$

Where: y – the dependable variable

$a_0, a_1, a_2, a_3 \ldots\ldots a_n$ - coefficient of regression

$x_1, x_2, x_3, \ldots\ldots\ldots x_n$ - independent variable

It comes out that in this case the most important factor which influences the probability of developing landslides is the local geology, immediately followed by profile curvature, slope and soil humidity.

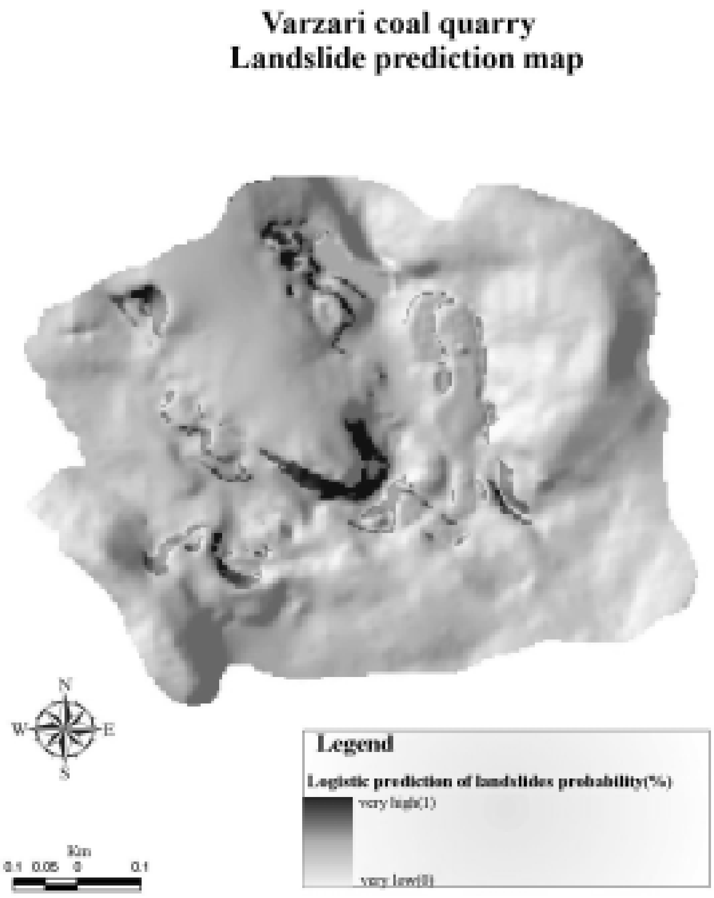

Fig. 4. Landslide prediction map of coal quarry

2. Material and method

a. GIS-based work method

According to ESRI (1994), GIS (Geographical Information Systems) means "an assembly of hardware, software, geographical data and specialists, whose main target is the creation, updating, analyzing and visualization of geographical information". Thus, territorial elements come to be represented in two basic forms:

a) using the vector system (vector GIS) (i.e. territorial objects like a house, river, place, forest are represented using only points, lines or polygons);

b) using the raster system (raster GIS) (i.e. elements like a house, a river, a place, a forest are represented by means of digital cells, which could have different dimensions). Each system has its own advantages and disadvantages. For instance, if we desire to represent the elevation of a territory, it is recommended to use the raster GIS but if we aim at showing the land-use in a territorial unit, then it is advisable to use the vector GIS. The main idea behind GIS is that a territorial unit is seen not as an indivisible compact block but as a collection of horizontal layers which make up the whole.

A layer is "a thematic map" (Imbroane, 1996). Each layer is associated with an "attribute table" where every single object of the "map" has its features **registered**. These multitudes of "maps" or layers are eventually overlaid (put one over the other one) and what comes out is the reality represented in a digital form (Figure 5). These results are then combined with other information from the field of statistics, spatial correlations, mapping in order to have an extremely complex outcome.

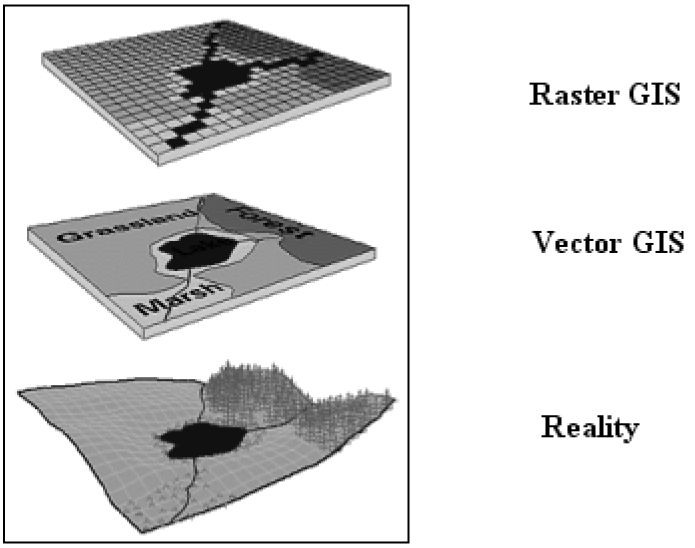

Fig. 5. The representation of geographical elements in the two systems (ESRI, 1994)

b. Universal Soil Loss Equation and Soil Erosion Assessment

Soil Erosion is also a process which can be evaluated and estimated in mathematical terms. In the Vărzari coal quarry the original sequence of soil layers was disrupted, resulting in a chaotic mixture made up of shale, clay, coal.

The Universal Soil Loss Equation (USLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites.

A correct equation has to take into account all the participating elements in the process of soil erosion:

$$E = K * I^{1...5} * S * C$$

Where:

E – The quantity of sediments resulted in the process of erosion (t/ha/year)

K – Climatic aggressiveness (for the Western Hill this value is 0.067 according to M. Dârja)

$I^{1...5}$ - average slope value
S – Soil erosion coefficient influenced by the type of geological material
C – Coefficient indicating to what extent land-use influences soil erosion

This formula is called *Universal Soil Loss Equation (USLE)* and it was adapted to the Romanian climatic conditions by Moțoc et al.

In the ARCINFO software, soil erosion could be precisely pointed out only after a series of layers were created (each with its own attribute table) and then overlaid in the vectorial system (Figure 6). Five distinctive areas are being analyzed in the underneath table. If surface value (expressed in ha) is multiplied (x) by soil erosion coefficient, then the result shows the approximate value of eroded material (expressed in tones) during a one-year period (Table 1).

Table 1. Erodability areas as calculated from USLE

Nr. Crt.	**Surface (ha)**	**Soil Erosion (t/ha/year)**	**Degree of Soil Erosion**	**Quantity of eroded material (tones)**
1	12	0.1 - 2.0	very low	12.6
2	18	2.1 - 4.0	low	54.9
3	26	4.1 - 6.0	intermediate	131.3
4	11	6.1 - 8.0	high	77.5
5	2	8.1 - 9.8	very high	17.9

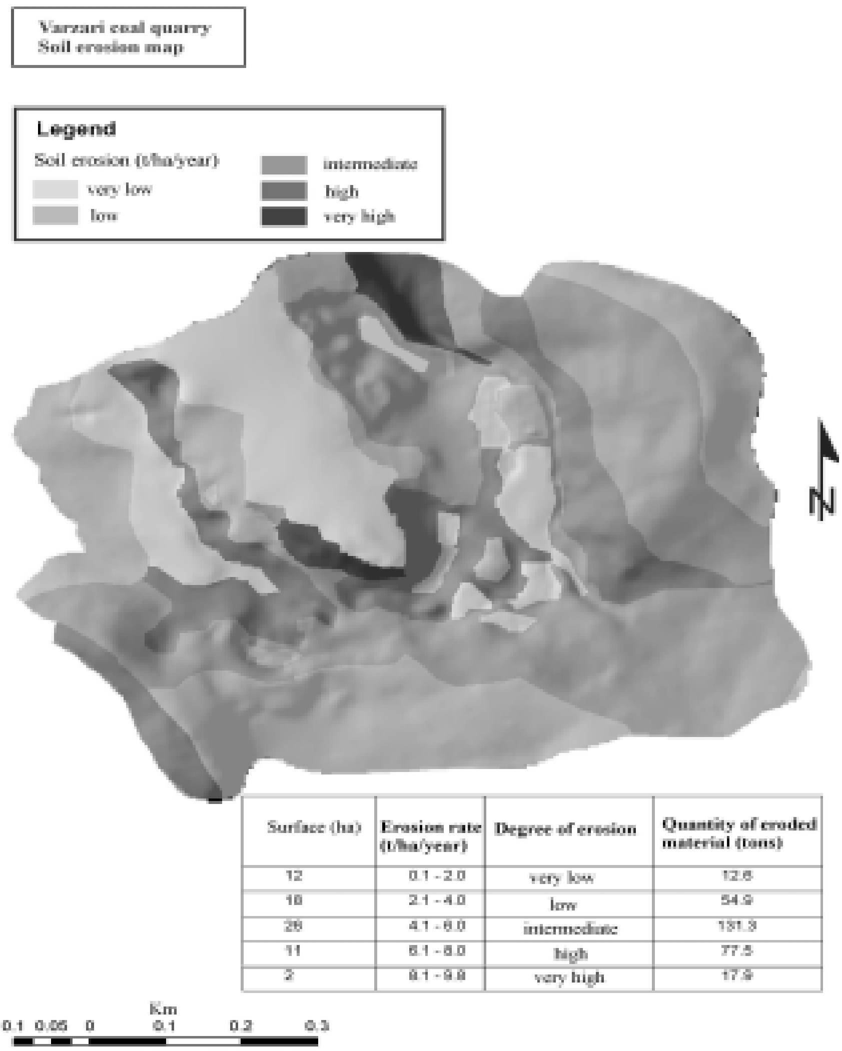

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Fig. 6. Soil erosion map of coal quarry

c. Flow direction and flow accumulation assessment

The local climate in the Vărzari Coal-Quarry Area is influenced by its geographical position within the country, being permanently exposed to the Western winds which cater for an average temperature of $8.7\ ^{\circ}C$ degrees. Even the nearby mountains (Plopiş Cliffs) do not modify this value to any significant degree. The average precipitation value is of about 620 mm/year but the runoff has been hardened by the changes caused by surface and underground mining activities.

There are two elements which have been greatly modified: the *flow direction* and *flow accumulation*. By a close analysis of the maps made before and after the mining, it could be concluded that the flow direction had suffered obvious high-scale changes due to intense mining activities. Precipitation would not drain all the way to the bottom of the slope but accumulate at different levels of the newly formed landscape and generate isolated water ponds with temporary existence.

Flow direction can be determined using the Grid Model from the ARCINFO Software package. First, a digital elevation model (DEM) has to be created and then correct any possible hydrological territorial inaccuracies by using the TOPOGRID Function (Figure 7). According to ESRI (1997), flow direction is a parameter in hydrological modeling that is determined by finding the direction of steepest descent from each cell. The distance is determined between the elevations of the cell centers.

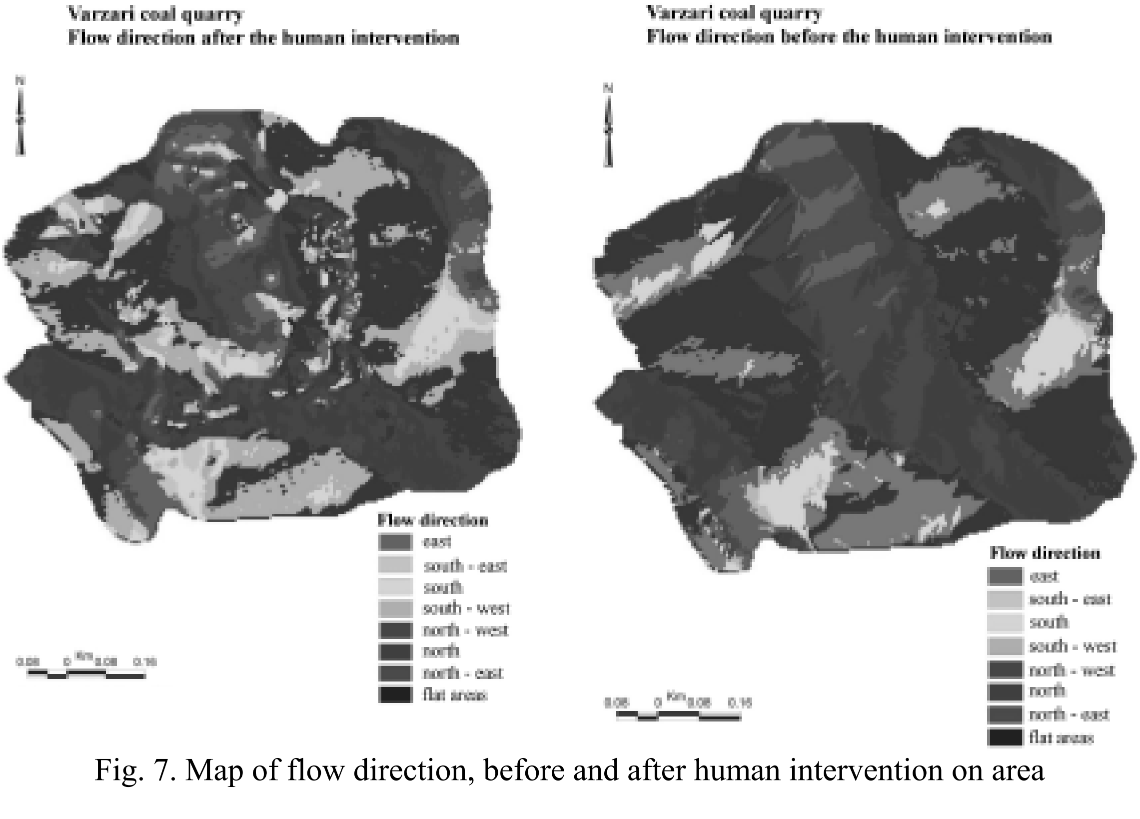

Fig. 7. Map of flow direction, before and after human intervention on area

Flow accumulation is the area where flow direction generates a concentration of runoff water. In GRID Model terms, flow accumulation is the number of upslope cells that flow into each cell. The precision of the final results highly depend on the accuracy of the DEM (Digital Elevation Model) and also on the value of the resolution it is worked with (Florinsky, 1998). In this case, a 5 meter resolution has proved to be the most suitable (Figure 8).

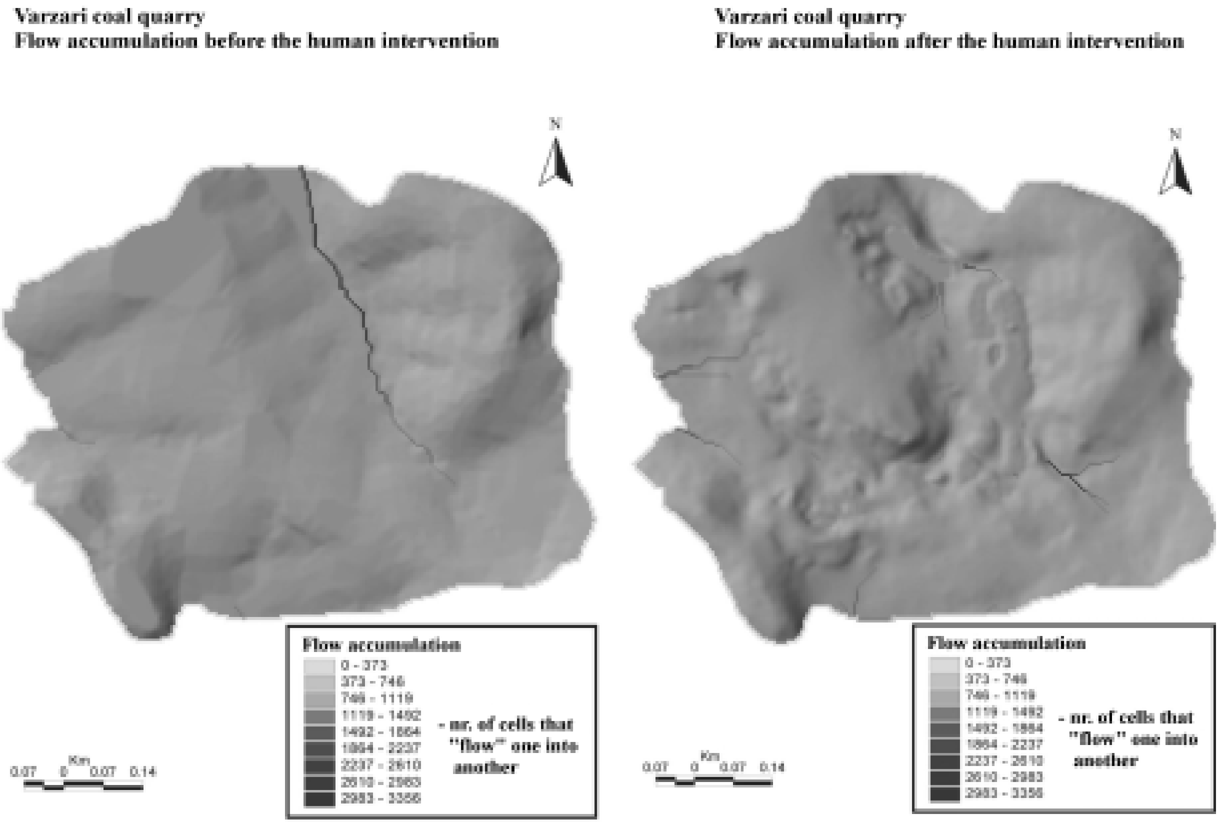

Fig. 8. Map of flow accumulation, before and after human intervention on area

3. Conclusions

The previous considerations have offered a very complex image of the soil erosion in the Vărzari Coal-quarry area. The main problem remains land degradation, which if not treated continues to intensify and extend. It has been determined with the help of GIS which areas are prone to landslides and which patches are likely to slide down within a short time period (values close to "1" in the binary system). Linking the type of soil with the position of these landslides, we can reach the conclusion that those patches sustained by clay underground are most likely to slide.

The land-slope located next to Şes River is on the verge of sliding at any immediate time because of the existence of very steep slopes and thick layers of clay. Thus, surface mining lead to erosion (in the upper part of the soil-structure) and landslides. Huge amounts of material have been displaced and mixed in the Vărzari Quarry Area, which made it extremely vulnerable to erosion. The steeper the slope, the higher the risk of erosion. Again, the left side of Şes River will be the earliest eroded followed by its right side. Here, the steep slope is combined with the speed of the river coming down.

As a rule, the values of erosion are influenced by geology, soil type, and slope declivity. When these three are set, then is easy to deduct the mathematical value of soil erosion. Geological maps clearly show that flow direction has changed a lot in the last couple of decades because of material displacement. New flow accumulations have come to light and new small-scale ponds formed behind it.

This study will be developed and some problems still remain to be solved in the future. The first challenge is the validation of the methodology and results in practice by calibrating the environmental rehabilitation model of area. This model will be accomplished with the help of the 3D Analyst extension, part of the ArcInfo Software, which offers a 3D visualization of spatial data.

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