AES BIOFLUX

Advances in Environmental Sciences - International Journal of the Bioflux Society

Landslide susceptibility in the Arieş Middle Basin – focus on Roşia Montană mining area

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Abstract. The paper assesses landslide susceptibility in the Arieş middle basin, with focus on the Roşia Montană mining perimeter. The study uses the existing Romanian methodology for landslide susceptibility mapping. The results illustrate the risk level of landslide occurrence: most of the Arieş basin is characterized by insignificant and low values of landslide susceptibility, while medium values are found in the mining perimeters. The Roşia Montană mining perimeter presents disequilibria at morphodynamic level especially in the area of the mining facilities, enhancing the occurrence of landslides risk, with significant impacts on the regional safety and security of mining works.
Key Words: landslide susceptibility, risk, mining, Arieş middle basin, Roşia Montană.

Zusammenfassung. Die vorliegende Arbeit bewertet die Rutschungs-Suszeptibilität für eine größere Gegend – das mittlere Arieş Flussbecken – mit Fokus auf die Bergbauindustriegegend Roşia Montană. Die Studie verwendet die rumänisch Ausarbeitungsmethode von Erdrutschrisikokarten. Die erhaltenen Ergebnisse veranschaulichen das Erdrutschrisiko: der größte Teil des mittleren Arieş Flussbeckens ist durch unbedeutende und niedrige Werte der Rutschungs-Suszeptibilität gekennzeichnet. Die Bergbauindustriegegenden verzeichnen mittlere Werte. Die Roşia Montană Gegend weist morpho-dynamische Unausgeglichenheiten auf, besonders im Bereich der vorhandenen Bergbauanlagen, was das Erdrutschrisiko erhöht, mit einer bedeutenden Auswirkung auf die Sicherheit der lokalen Gemeinden.
Schlüsselwörter: Rutschungs-Suszeptibilität, Risiko, Bergbauindustrie, mittleres Arieş Flussbecken, Roşia Montană.

Rezumat. Lucrarea evaluează susceptibilitatea la alunecări de teren în bazinul mijlociu al Arieşului – cu detalierea zonei miniere Roşia Montană. Studiul utilizează metodologia existentă de elaborare a hărţii de risc la alunecări. Rezultatele obţinute ilustrează nivelul de risc al producerii alunecărilor de teren: cea mai mare parte a suprafeţei bazinului mijlociu al râului Arieş se caracterizează prin valori nesemnificative şi reduse ale susceptibilităţii la alunecări de teren. Valori medii se înregistrează în zonele miniere. Perimetrul Roşia Montană prezintă dezechilibre la nivel morfodinamic în special în zona obiectivelor miniere existente, care amplifică riscul de producere a alunecărilor de teren, cu impact semnificativ asupra siguranţei comunităţilor locale din regiune.
Cuvinte cheie: susceptibilitate la alunecări, risc, minerit, bazinul mijlociu al râului Arieş, Roşia Montană.

1. Introduction. Susceptibility refers to the lack of inherent capacity of the elements in the investigated spatial extension to preserve their physical integrity and functionality in the course of the physical interaction with a generic sliding mass (Uzielli et al 2008).

"A slide is a downslope movement of soil or rock mass occurring dominantly on the surface of rupture or on relatively thin zones of intense shear strain" (Cruden and Varnes 1992, cited by Abramson et al 2002). According to the Romanian legislation, landslides represents "the displacements of rocks and/or earth masses which form the slopes of mountains or hills, of the hydrotechnical structures slopes or other land use planning works slopes, which could cause human victims and material damages" (Law no. 575/2001).

The causes of landslides can be divided into three major categories: preconditioning factors (slope steepness), preparatory factors (deforestation) and triggering factors (seismic vibrations) (Glade & Crozier 2005). One of the most important

factors conditioning the location of a landslide is the lithology. The leached, hydrated, decomposed, chloritic or micaceous shales, poorly cemented sediments, or unconsolidated materials are favourable to landslides. Precipitations represent also an important factor, as water-saturated and porous materials favour landslides. Finally, land use conditions landslide susceptibility: areas without vegetation favour landslides, while woodlands prevent mass movements.

Landslide susceptibility is the propensity of an area to undergo landsliding (Crozier & Glade 2005). It depends on two factors: the degree of inherent stability of the slope (indicated by the safety factor or excess strength) and the presence of factors capable of reducing the excess strength and ultimately triggering movement. The assessment of the classification, volume (or area), and spatial distribution of existing or potential landslides in an area are necessary for the complete evaluation of landslide susceptibility (Fell et al 2008).

2. Site description

2.1. The Arieş middle basin

The investigation area overlaps the Arieş middle basin. The surface of the middle basin measures 1,406 km^2, almost half (46%) of the entire surface of the Arieş basin (2,950 km^2). The Arieş river flows across the Apuseni Mountains, dividing them almost in half. The middle sector of the Arieş basin includes several units of the Apuseni Mountains: Muntele Mare, Metaliferi Mountains and Trascău Mountains. This region is defined by various relief forms (couloirs, depressions, mountains etc.), the geologic formations variety, the rich surface and underground water network, regional and altitudinal climatic differences, heterogenous vegetation and fauna. The Arieş middle basin is characterized by altitudes ranging between 400 m and 1,800 m. The lowest altitude belongs to the major riverbed of the Arieş, in Buru village (357 m), and the highest peak is situated in Muntele Mare (1,826 m). The study of topography concluded that surfaces between 400 and 600 m are predominant.

This basin includes an important mining region (Figure 1), abundant in valuable mineral resources: gold, silver, copper, base metals, generated by the local geologic background. The mining activities in the region induced major changes to the environmental components. The most visible changes are represented by the open pits and tailing ponds, resulted from mining operations.

2.2. Roşia Montană

Roşia Montană commune is found in the South-Western part of the Arieş middle basin. The Roşia rivulet flows across the commune, until it reaches its confluence with the Abrud river. The Roşia Montană mining region is situated within this commune and it includes several mining works: Cetate and Cârnic open pits, numerous waste dumps, Gura Roşiei and Valea Săliştei tailing ponds, Gura Roşiei processing plant. The location of these elements within the area can be seen in Figure 7.

In this area, landslides represent significant risk sources for the mining works. The main causes of landslides activation or reactivation in the Northern and Eastern part of the Roşia Montană commune and in the upper course of the Corna Valley are: the lack of a stabilizing vegetation cover, excessive grazing, changes of land uses or mining activities. The presence of artificial lakes called “tauri” in the area represents another favouring cause. Suffosion phenomena also occur in these areas.

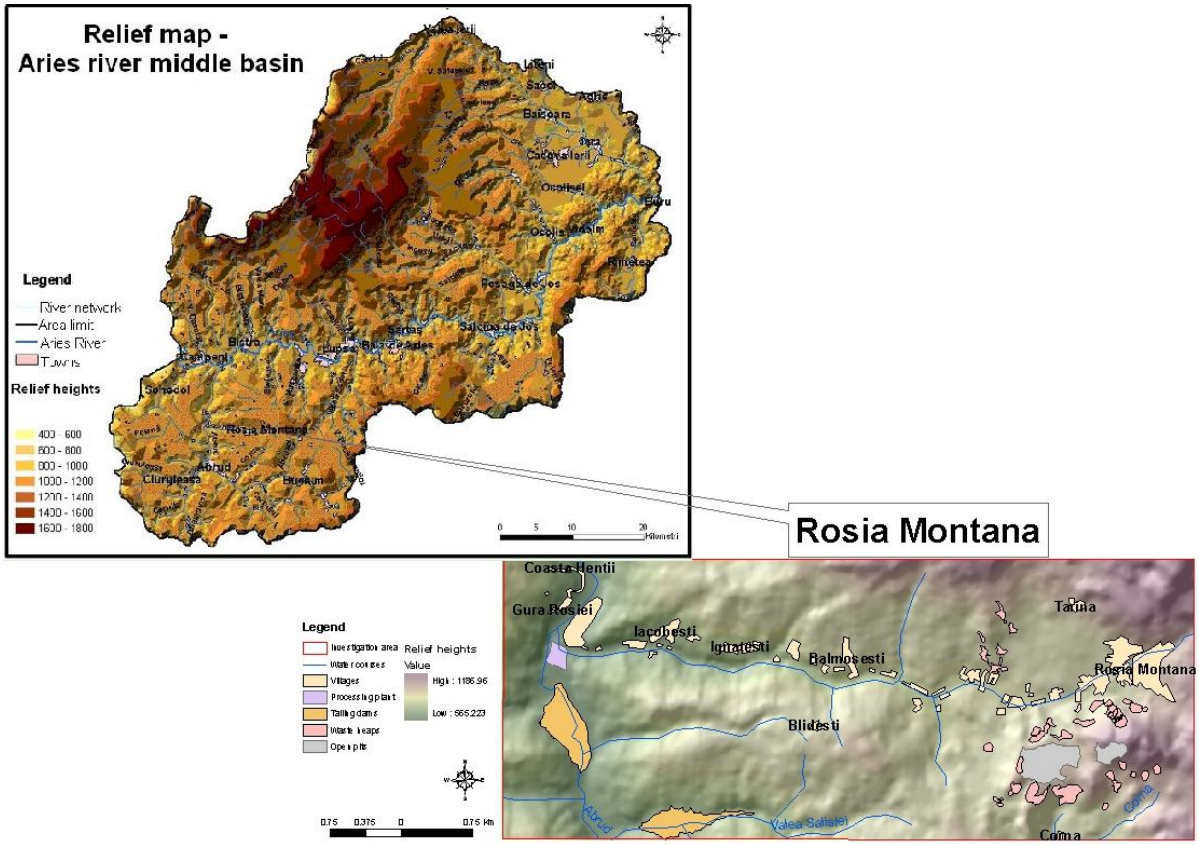

Figure 1. Location of the investigation area and of the Roşia Montană focus point.

3. Metodology of Landslides Susceptibility Maps

The assessment of landslide risk was performed by using the methodology included in the *Guide of landslide risks maps for the assurance of building stability – Indicative GT – 019-98* (Institute of Studies and Projects for Territorial Planning, 1998). The result is the landslide risk map.

The landslide occurrence potential was calculated based on several criteria which take into consideration different factors. These factors act singularly of interdependently, influencing the slopes stability. Based on these criteria, three classes of probability of landslides occurrence were identified.

For the elaboration of the landslide susceptibility map, the following methodology was used:

- factors which set the basis of adopted analysis criteria have been given the symbols a, b, c, d etc.,
- there are three degrees of potential corresponding to the landslide occurrence probability,
- according to the landslide occurrence potential and probability, the risk coefficient (K) is calculated (Table 1),
- the landslide occurrence potential is calculated based on the equation 1.

Table 1

The classes of landslide occurrence potential (Institute of Studies and Projects for Territorial Planning, 1998, 1998)

Low		***Medium***		***High***	
Probability of landslide occurrence (P) and the appropriate risk coefficent (K)					
Practically zero	Low	Medium	Medium - High	High	Very high
0	< 0.10	0.10-0.30	0.31-0.50	0.51-0.80	>0.80

The formula used for the elaboration of landslide susceptibility map is the following:

$$K_m = \frac{K_a * K_b}{6}(K_c + K_d + K_e + K_f) \qquad \textit{(eq. 1)}$$

Where:

K_m – potential of landslides occurrence
Ka – the litological criterion
K_b – the geomorphologic criterion
K_c –hydrologic and climatic criterion
K_d –seismic criterion
K_e –sylvan criterion
K_f –anthropic criterion

Scores are assigned to each criterion, ranging between 0-1, according to the three probability classes. According to the methodology described above, the following criteria were considered in the elaboration of the landslide risk map:

1. The lithological criterion - K_a takes into consideration the surficial lithology; scores are assigned based on the following considerations:

- *low probability* for massive, compact or unweathered bedrock,
- *medium probability* for most of the sedimentary superficial deposits (diluvium, colluvium and proluvium) and of other types of rock (banded clays, marls etc., metamorphic rocks),
- *high probability* for unconsolidated detritic sedimentary rocks (clay, sand, gravel and silt).

2. The geomorphological criterion - K_b takes into consideration the geomorphological characteristics; scores are assigned based on the following considerations:

- *low probability* for plain surfaces, affected by insignificant erosion, with old valleys representing the water system.
- *medium probability* for hills-type relief, specific to piedmont and plateau areas, fragmented by a water system in a certain level of evolution, with valleys surrounded by medium heighs with medium and steep slopes.
- *high probability* for hill and mountain regions, with a dense network of young valleys, with high and steep slopes; most of these valleys are parallel to the strata strike.

3. The hydrological and climatic criterion - K_c takes into consideration the characteristics of the climate and of the water system; the scores are assigned based on the following considerations:

- *low probability* for the arid areas, with low annual rainfalls. The flows of the rivers in the hill and mountains regions are generally controlled by rainfalls in these areas. The riverbeds are dominated by sedimentary processes, while erosion is present only sidewise during floods.
- *medium probability* for moderate rainfalls. The main valleys in the water system have reached maturity, while their tributaries are still immature. During floods, both vertical and lateral erosion occur. Significant processes of transportation and solid flow sedimentation occur.
- *high probability* for the long-term slow rainfall regions, characterized by high rates of rock water infilitration. During heavy rainfalls, the stream velocities are high, accompanied by solid flow transport. Vertical erosion prevails.

4. The seismic criterion – K_d takes into consideration seismic zoning; scores are assigned based on the following considerations:

- *low probability* for seismic intensity in M.K.S. scale less than 6 degrees.
- *medium probability* for seismic intensity in M.K.S. scale ranging between 6 and 7 degrees.
- *high probability* for seismic intensity in M.K.S. scale higher than 7 degrees.

5. The sylvan criterion – K_e takes into consideration the land use; scores are assigned based on the following considerations:

- *low probability* for lands with a degree of tree cover higher than 80% especially broad-leaved forests with large-sized trees.
- *medium probability* for lands with a degree of tree cover ranging between 20% and 80% (broad-leaved and coniferous forests of various sizes).
- *high probability* for lands with a degree of tree cover lower than 20%.

6. The anthropic criterion – K_f considers the built facilities or any other works affecting the stability of slopes; the scores are assigned based on the following aspects:

- *low probability* for slopes with no important buildings and no water accumulations.
- *medium probability* for slopes with certain works (road platforms and railways, coast canals and quarries) with limited extent and subjected to appropriate protection measures.
- *high probability* for slopes with dense network of water and seewage pipes, roads, railways, quarries, subjected to top overburding by waste dumps and heavy buildings or by the presence of lakes which water the lower part of the slopes.

4. Results and Discussion

4.1. The Arieş middle drainage basin

The occurrence and intensity of geomorphologic processes are influenced by several factors: slope declivity and exposure, relief fragmentation and fragmentation depth, climatic context etc. (Panizza 1996). Also, landslides are favoured by less cohesive, porous, colloids-rich and cracked rocks, which facilitate water infiltration. These types of rocks are clays and shales. Within the investigated region, these rocks can be found North of Arieş River, in small territories of Muntele Mare, in the upper Iara basin, South and East of Gilău Mountain, and in Baia de Arieş area. South of Arieş River the sedimentary rocks have a larger spatial extension, in the Metaliferi Mountains and West of Trascău Mountains.

From the geomorphological point of view, the investigated region is characterized by dynamic-balanced forms of relief and medium-intensity geomorphological processes. In terms of hypsometry, the investigated region ranges from 357 to 1,826 m, resulting in an altitude difference of 1,469 m.

The slope declivity was analyzed based on the areas classification in terms of slope degrees: 0-3°, 3–6°, 6-15°, 15-35°, >35°, having a geomorphologic significance (Figure 2).

The horizontal surfaces (0-3°) overlap extended areas and include river floodplains, interfluves, terraces and depression basins.

Low declivity surfaces (3-6°) overlap extremely small areas, located especially in the Iara river floodplain.

Medium declivity surfaces (6–15°) overlap the slopes in Muntele Mare, terraces and ridges, secondary interfluves.

High declivity surfaces (15–35°) characterize a large area in the Arieş middle drainage basin. The declivity map clearly demonstrates that most of the slopes vary within this range. These slopes are characterized by intense morphodynamic processes: landslides, surface erosion, gullies, rock falls.

Slope degrees >35° are specific to very small areas, on crystalline limestones, limestone klippes in Trascău Mountains, gorges and narrow valleys in Iara basin (Runcului, Poşegii, Pociovalştei).

From the morphodynamic point of view, it is considered that the 12-15° slope degrees represent the critical point generating landslides and earthflows (Gligor 2005). Thus, it can be concluded that a large area is exposed to these hazards.

The declivity specific to mountain steep edges can also be noted in the case of anthropic relief forms within the mining operations: open pits slopes (Roşia Poieni and Cetate – Roşia Montană open pit), waste dumps embankments (Valea Verde, Obârşia Muntari, Geamăna, Valea Cuibarului waste dumps) and the fall cones within the Afiniş mine (Baia de Arieş) (Gligor 2005).

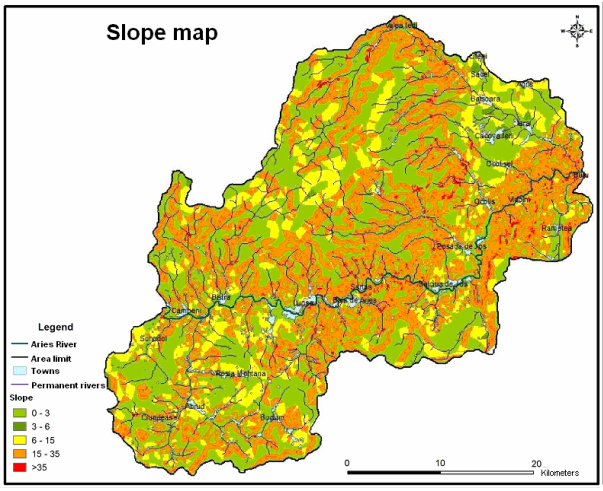

Figure 2. Slope map

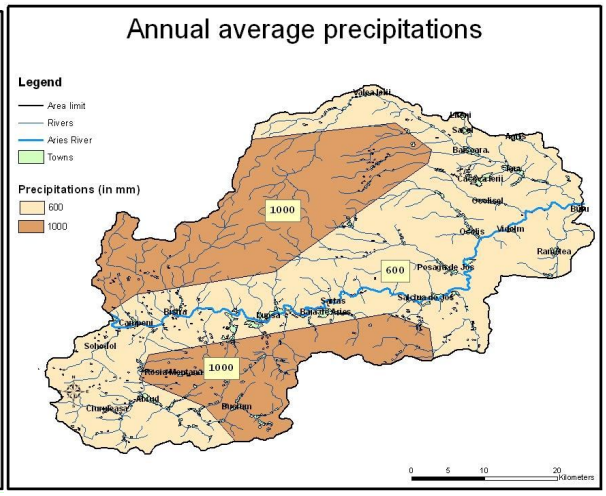

Figure 3. Annual average precipitations map

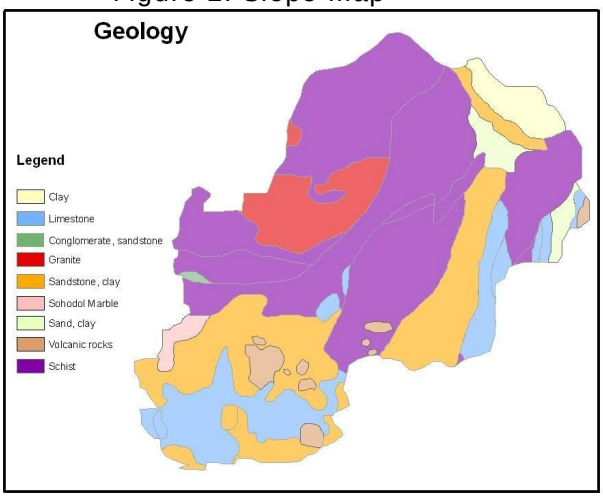

Figure 4. Geology map

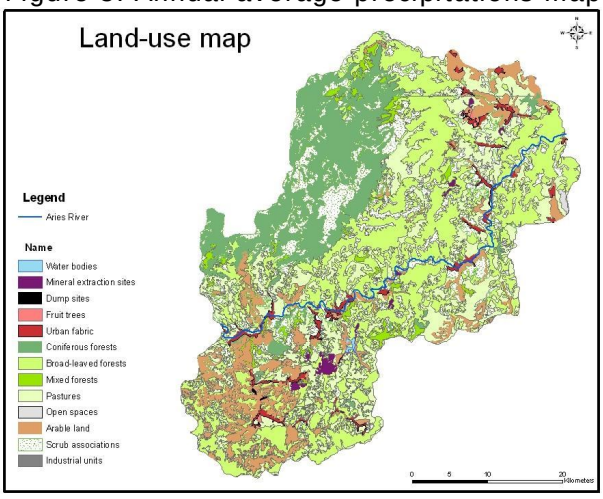

Figure 5. Land-use map

By combining the slope, lithology, annual mean precipitations and land–use maps (Figures 2, 3, 4, 5), using the Map Calculator in the ArcGIS 9.3 programme, the following landslide susceptibility map was elaborated (Figure 6). The indices values vary between 0 (the minimum value) and 0.36 (the maximum value) (or 0 to 36% probability of landslide occurrence) and they were divided into three classes of probability. Thus, the three landslide risk categories, according to indicative GT-019-98 are:

- *Insignificant landslide susceptiblity areas*. These areas cover wide spatial surfaces (for example, Muntele Mare, Câmpeni, Lupşa, Sălciua and Iara depressions, along the Rimetea, Iara and Bistra valleys etc.). The spatial extension is correlated to the presence of rocks resilient to external factors (granites, crystalline schist, marble and volcanic rocks), enhanced by forest extension (coniferous, broad – leaved or mixed forests);
- *Low landslide susceptiblity areas* cover small surfaces, in the Trascău and Metaliferi Mountains, Abrud, Poşaga and Ocoliş depression. These areas are characterized by

low slopes and 600 mm precipitations, the stability being influenced also by the land use (mainly agricultural land);

- *Medium landslide susceptiblity areas*. The moderate landslide risks are mainly determined by the land-use (agricultural land, meadows), correlated to the presence of rocks favoring landslides (sands, clays). Furthermore, the stability is influenced by the heavy precipitations. These areas can be found in Poşaga and Ocoliş depressions, in small areas in the Metaliferi Mountains, Southern Trascău Mountains and overlap most of the mining areas.

The three stability classes are represented on the landslide susceptibility map (Figure 6).

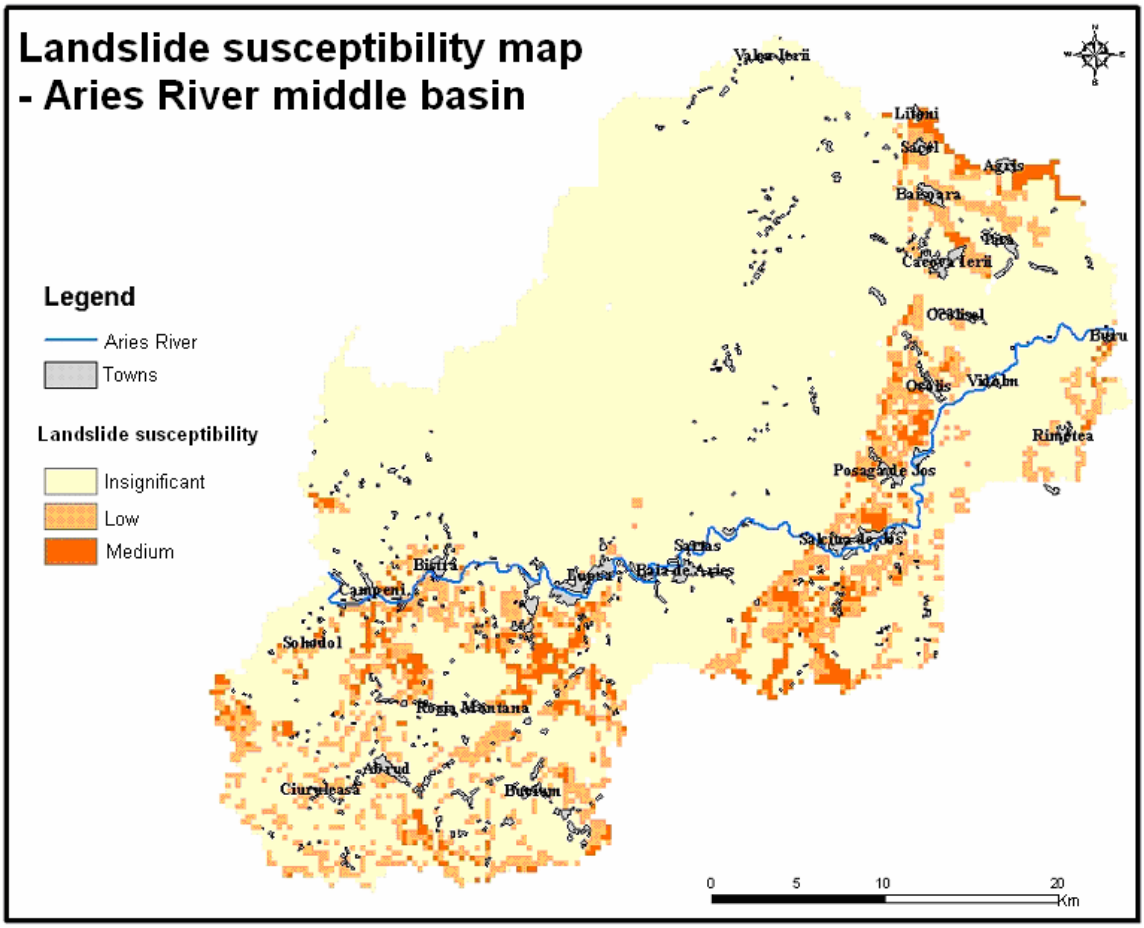

Figure 6. Landslide susceptibility map – Aries middle basin.

4.2. Roşia Montană

Slope declivity is a significant indicator for the landslide susceptibility, as slope is the main factor leading to the exceedance of the stability threshold. From the analysis of the slope map (Figure 8) the following slope classes were identified in the investigated area: 0-3°, 3-6°, 6-12°; 12-15°, 15-35° and over 35°.

Analysing the map, it can be observed that slopes ranging between 6° and 12° prevail. The surfaces with a 0-3° slope occupy areas including the interfluves, flood plains and terraces, the waste dumps and tailing ponds terraces.

Special attention should be paid to slopes ranging between 12-15°, as these represent the critical point in the pedogenesis process, the development of ravines and the beginning of flows and landslides (Gligor 2005). The 12-15° slopes are dispersed on small surfaces in the investigation region and especially in the area of the waste dumps and tailing ponds.

One can notice that the slopes ranging between 6° and 12° are predominant. The quasi-horizontal surfaces (0-3° slope) occupy the interfluves, riverbeds and river terraces, the terraces of waste dumps and of the tailing ponds.

The area of the open pit is dominated by slopes ranging between 15-35°. The Cetate pit has marginal slopes ranging between 25-32° in the SE and 32-45° in NE. The high declivity areas (over 35°) are fairly small.

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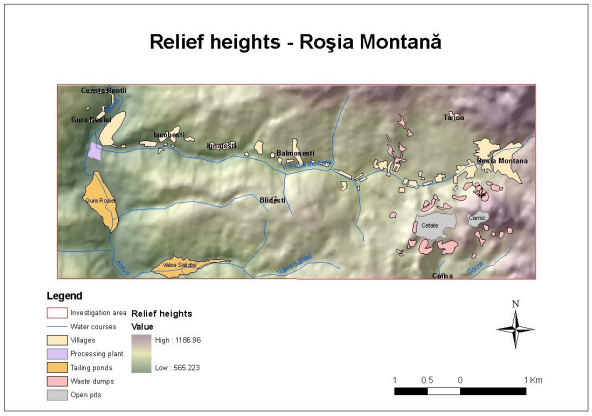

Figure 7. Relief map.

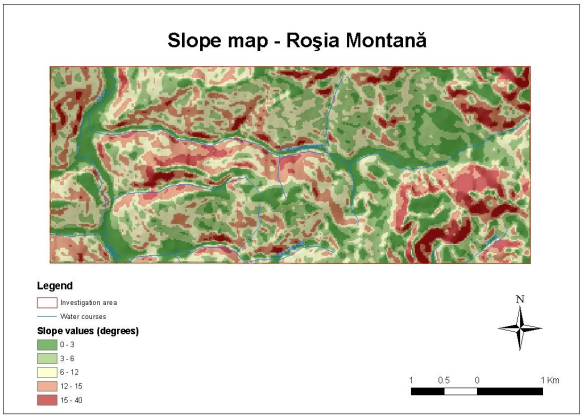

Figure 8. Slope map.

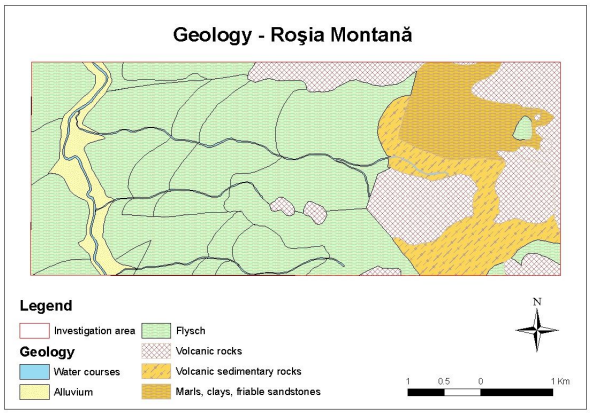

Figure 9. Geology map.

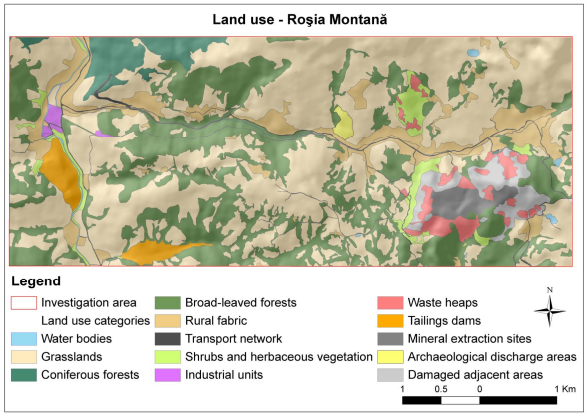

Figure 10. Land-use map.

The overlay of the previous maps (geology, slope, climatic and land-use map) resulted in the landslides susceptibility map, which indicates the landslide risk areas (Figure 11).

By classifying the values acquired as a result of the thematic maps, four classes of landslide susceptibility were identified, corresponding to the landslide risk areas. The highest values (0.30 – 0.51) corresponding to medium-high landslide risk are found on the Southern and Eastern slopes of the Cetate and Cârnic pits. The presence of the Hop and Valea Verde waste dumps in such an area of high landslides susceptibility, as well as proximity of residential areas, amplify the risks.

High values of landslides susceptibility occur punctually in the area of the two tailing ponds: Gura Roşiei and Valea Sălişte. Insignificant values of the landslide occurrence risk are associated to low slope areas in the riverbeds (below 3°). The low and medium landslide susceptibility areas are dominant within the investigated area.

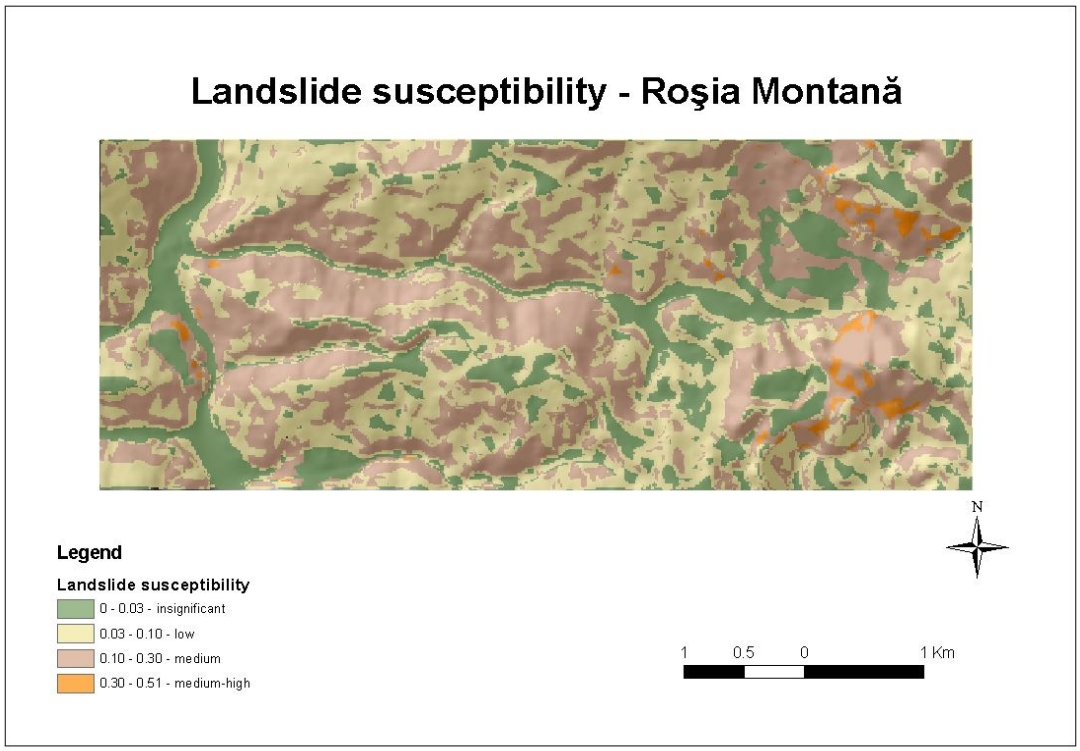

Figure 11. Map of the landslide susceptible areas.

Conclusions. The analysis of the morphometric features, correlated to the data regarding the geologic formations, rainfalls, vegetation and land-use indicated that the insignificant and low landslide susceptibility areas cover most of the Arieş middle basin. Medium landslide susceptibility is influenced by the favoring lithologic factors and the land-use. These areas overlap most of mining perimeters.

Regarding the Roşia Montană perimeter, the mining elements induce serious disequilibria at morphodynamic level, enhancing the occurrence of landslide risk, with significant impacts on the regional safety and security of mining works.

The identification of the landslide risk areas is of utmost importance in the future planning of the mining operations, as it clearly indicates the revegetation priorities, consequently obtaining adequate land stability.

Overall, the exogenous hazards can trigger disasters affecting the population and the environment. For the protection of the local communities and infrastructure, stabilization works are needed in several parts of the investigated region.

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Received: 23 May 2010. Accepted: 25 July 2010. Published online: 31 July 2010.
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How to cite this article:
Costan S. C., Ştefănescu L. N., Maloş C. V., Ozunu A., Vlad Ş. N., 2010 Landslide susceptibility in the Arieş Middle Basin – focus on Roşia Montană mining area. AES Bioflux **2**(1)81-90.