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COMPREHENSIVE VALUE ASSESSMENT OF SURFACES AFFECTED BY UNDERGROUND MINING

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ABSTRACT
Tuzla is one of the most densely populated urban areas in Bosnia and Herzegovina, that has a long history of coal and salt exploration leaving nowadays abandoned mines. These mines represent an hazard to the infrastructure and the population in this area due to severe ground deformation and sink holes. Hazard identification and risk management is the central core of any organization's strategic management. It is the process whereby organizations methodically assess the risks that threatens their activities, with the aim of achieving sustained benefit within each activity and across the portfolio of all activities. Assessment in Tuzla salt exploration case is derived based on series of geophysical and survey measurements, analyzed from the updated engineer-geological maps. Vulnerability zones were divided into 5 categories with downward evaluation of increase in hazard zones.
Keywords: risk assessment, urban area, surface deformation

1. INTRODUCTION
Established monitoring and management system by using the best available technologies (GIS, remote sensing procedures, hydrological measures and models, etc...) ensure the necessary base to local community in the planning of operations for the remediation and monitoring, as well as for the territorial and environmental management.

Initiatives in Tuzla area to implement the method of rapid consolidation of massif, depend on previous definition of real geological, morphological and hydrogeological conditions.

A second important goal from the monitoring system is the elaboration of specific guidelines that will take care of hazards and risks zonation, physical damages and costs observations for the repair or replacement of buildings and other infrastructures.

Implemented monitoring system bring together the huge amount of historical data on mining areas, their geotechnical and hydrogeological features, and integrate and produce an actual real picture of the situation by updating the existing geographical information system (GIS). The end-result is detailed risk maps for endangered areas that will provide the basis for a long-term planning to monitor and mitigate the risk.

2. RISK ASSESSMENT
The Risk is defined as the probability that harmful consequences (deaths, injuries, property losses, reduction on economic activities or environmental damages) occur in case of interaction between natural or man-induced hazards and vulnerability conditions of the environment and its elements (ISDR 2004). A well-known quantitative evaluation of risk was provided by Varnes (1984) as

$$R = H \times V \times E \qquad \dots (1)$$

In the Varnes's formula the terms Hazard (H), Vulnerability (V) and Exposure (E) are requested. H is defined as the probability that an event of a certain intensity occurs in a particular place and within a certain period of time. The V component represents the proneness by a unit or a set of elements to be injured by a specific event and could be expressed as the probability of loss sometimes reported as scale ranging from 0 (no loss) to 1 (total loss). Finally, the E component is a measure of the potential loss of assets (related to settlements, infrastructures, population, etc..), and it could be expressed as economic terms as the price to be paid for a restoration of the losses.

2.1. Evaluation of H (hazard) component: the ELECTRE-TRI multicriteria method

Generally, the evaluation of H component leads to a territory classification in a number of dangerousness classes based on the main hazards. In this specific study case four source of hazard were identified: sinking phenomena with related surface deformation, formation of deep and shallow fractures as a consequence of the ground motion, water table rises induced by brine pumping reduction. In particular, among those listed above, more attention will be reserved to the hazard concerning with fast water table rise that is playing a crucial role in the comprehension of complex mechanisms affecting the hydrogeological equilibrium.

Table 1. Reference profiles for each hazard and threshold of indifference (q) and preference (p)

Profile	Density of shallow fractures (m/ha)	Density of deep fractures (m/ha)	Average annual sinking rate (m/yr)	Time to groundwater flooding (yr)
5-4	2,6	2,6	-0,12	10
4-3	1,4	1,4	-0,07	40
3-2	0,8	0,8	-0,03	70
2-1	0,2	0,2	-0,01	150
q	0,05	0,05	0,001	10
p	0,1	0,1	0,005	20

In order to obtain the indices of concordance and discordance, the methodology requires a comparison between each action (cell) and a reference action. The concordance index is expressed in a 0 to 1 scale, assuming zero value if the value of action a on the criterion j-th is less than or equal to action b minus the preference threshold value. Instead it is equal to 1 when the value of action a on the generic criterion is higher than the value of action b less than the indifference threshold. The intermediate values are calculated by linear interpolation. The same procedure is applied to calculate the discordance indexes. The comparison of all the actions with the relative reference profiles leads to a classification of the actions into a 1 to 5 value scale with increasing danger in the higher classes.

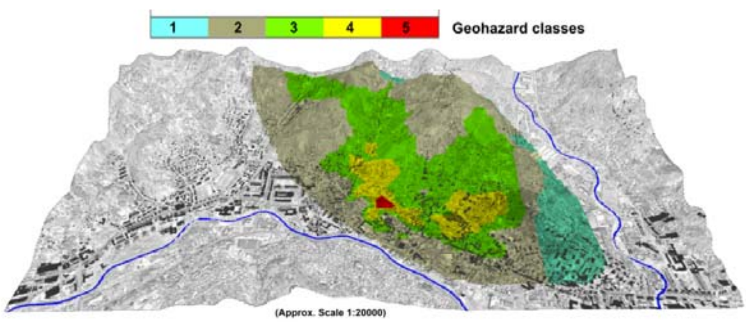

Figure 1. Overall geohazard affecting the town of Tuzla, divided into five classes and obtained using the ELECTRE TRI method

2.2. Evaluating V (vulnerability) component and the specific risk (RS)

In this paper several features of the urban settlement were taken into account to assess the vulnerability component: buildings with intended use, main roads, secondary roads, pumping stations for potable uses, railways line and terminal, mining areas.

Table 2 shows the building typologies defined in this work and the relative associated weights.

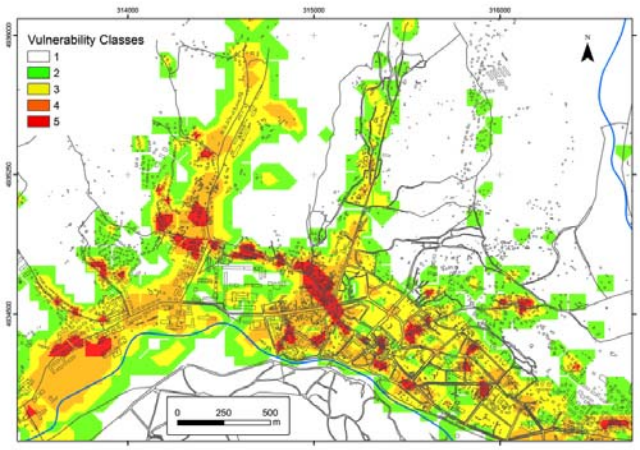

Figure 2. Vulnerability map produced by the ELECTRE methodology

Table 2. Weights associated to buildings depending on their intended use

Buildings intended use	Weights
Public	0,25
Religious	0,21
Residential	0,19
Accessory	0,15
Business	0,12
Miscellaneous	0,08

Table 3. Double entry table for the SR calculation

Hazard classes	Vulnerability classes				
	1	**2**	**3**	**4**	**5**
1	0,2	0,2	0,4	0,4	0,6
2	0,2	0,4	0,6	0,6	0,8
3	0,4	0,6	0,8	0,8	1
4	0,6	0,6	0,8	1	1
5	0,6	0,8	1	1	1

The vulnerability map derived from the application of the ELECTRE methodology is represented in figure 2. As reported in the legend of figure 4, the vulnerability scores have been divided into 5 reference classes with ascending magnitude (1: low; 5: high).

To obtain a risk assessment of the area the interaction between vulnerability and geohazard has been evaluated. This combination states the expected degree of loss as consequence of a particular phenomenon and is normally reported as Specific Risk, RS, (Varnes 1984). The relation has been quantified by means of a double entry table (Table 4) where the SR is expressed in a unitary scale.

2.3. Assessing E (exposure) component

The E component was assessed with reference to the building layer only. The map of exposure at building scale was produced by assigning an economical vale based on the indications delivered by the Cadastre of the Municipality of Tuzla. In particular, the Cadastre identified a zonation of the town and suburban areas into five classes with varying cost whenever a new property is officially recorded. Again, the information had to rasterized over the reference grid. The sum of the value of properties falling into each reference cell were assigned to the cell itself by a proportion based on the actual occupied area with respect to the elementary unit.

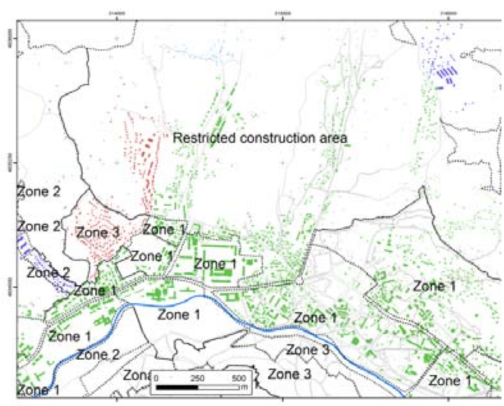

Figure 3. GIS interpretation of cadastral areas and allocation of buildings in terms of affiliation and proximity rules. Colors assumed by buildings are coded on the basis of the affiliation zone

3. RISK ANALYSIS

After producing the SR and E components the Risk map was obtained by a simple mathematical multiplication using the map algebra tools available in the GIS packages. The R map represents the economic loss that is potentially triggered by the occurrence of an hazard and could be compared to the expenses needed to compensate for demolition or damages suffered by buildings.

In the risk map of figure 4 the areas that exhibits major risk values are located in the downtown, where the density of buildings with relevant economic parameters prevails. Outside the boundaries of this central portion of the city the risk gradually decreases. The area most damaged by the historical deformation processes is currently interested by the presence of two artificial salt lakes intended for recreational purposes, and it is not associated to high levels of risk because of the high rate of buildings lost in the last decades that return an area free from vulnerable features. Another zone interested by significant risk levels is the abandoned mine area that has been excavated in tunnels with the classic mining methodology and is currently threaten by the flooding hazard because of the water table rises.

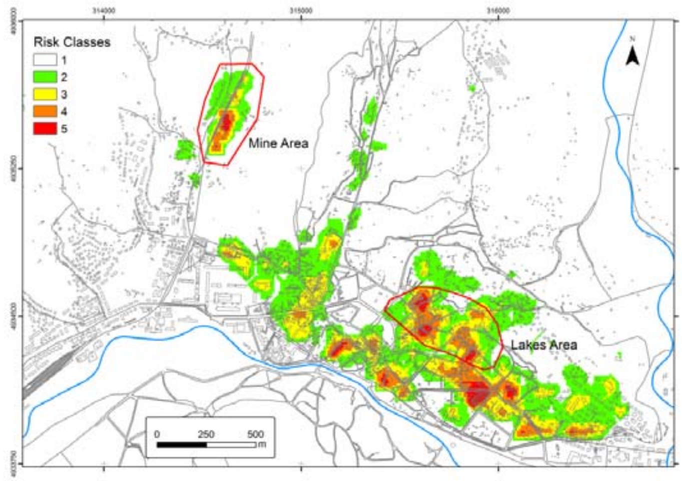

Figure 4. Map of Risk estimated for the town of Tuzla. Values expressed in Euros

4. CONCLUSIONS

The monitoring data and the investigations carried out in the area of Tuzla allowed to detect the ongoing phenomena and define the relationships between the involved variables. Finally a map reproducing Risk induced by the salt extraction from the underground has been drawn. The withdrawal of saltwater has triggered new hazards including the fast water table rise after the reduction in the extraction activities. The alarming rise of piezometric levels restarted a new evaporite dissolution process, which induced new subsidence phenomena and, indirectly, all the other hazard introduced throughout this paper. To mitigate the rising of piezometric levels a controlled withdrawals from the aquifers was undertaken.

In conclusion, the evolution of the phenomena described in this work it is very difficult to be predicted. Apparently, the water table rise seems unstoppable and determined to return to his equilibrium existing before the salt water pumping. This trend will lead to serious and even more frequent flooding problems in the most subsided areas. The derived Specific Risk map highlight the areas that are more prone to risk on the basis of the hazard and vulnerability factors impacting over the reference 50x50 elementary cell. Finally, a risk map has been produced and potential economic losses quantified after the appraisal of the elements at risk. Even though the products generated within this study does not help to restore a natural equilibrium, that looks seriously compromised, they could be very useful in the urban designing, land use planning and allocation of resources devoted to restoration and risk mitigation activities.

5. REFERENCES

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