Integrated Slope Process Susceptibility Analysis and Risk Management in the Rural Settlements. Case Study: Cheia Village

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Introduction

Susceptibility is defined as the likelihood that a process will occur in an area based on the local terrain conditions (Soeters, van Westen, 1996). It is a complex, multivariate problem involving extrapolation of the data to larger areas (Crozier, 1995). Thus, this practice involves a high level of uncertainty as it demands a large amount of assumptions. They are based on previous events and they will be validated by future ones that will occur at a certain moment in time.

This type of analysis represents the spatial component of hazard, depending on how prone the slope is to fail in relation to the expected extent of the phenomenon (Corsini et al, 2005), together with the presence and activity of causative factors capable of reducing the excess strength and ultimately triggering movement (Crozier, Glade, 2005).

The analysis that was carried out was based on the pattern presented in figure 1. Data collection included both field monitoring and measurements (identification and mapping of the erosional processes, underground water measurement, establishment of pressure gradient on slopes due to the presence of artificial structures such as buildings, industry) and lab evaluations (geotechnical analyses), as well as GIS techniques (morphometric data).Using the GIS tools the data obtained from the field and lab were processed and transformed into metadata. They were subsequently used as data for integrated factor analysis. The next step was to perform the susceptibility assessment, which provides a measure of the propensity of a site or area to produce landslides based on the presence of known causative factors or on historical data (Crozier, Glade, 2005).

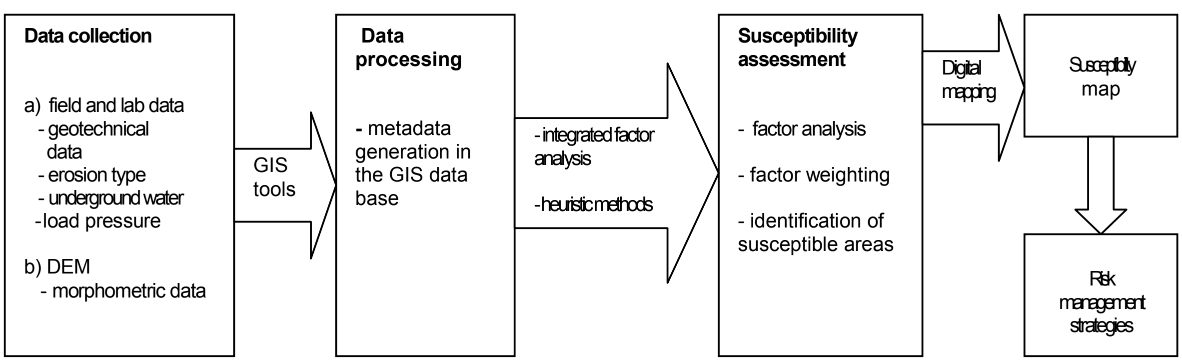

Figure 1. Methodological approach.

The susceptibility assessment was based on factor (parameter) analysis by means of factor weighting points and it led to the identification of areas prone to landslide processes. They were mapped and the susceptibility map is the starting point for future planning as regarding slope management.

The approach presented here has been applied to Cheia Village, an area that is very affected by landslides.

Factor (parameter) analysis

If there is evidence of past or present landslides, either prone to reactivation or active, then it would be useful to apply a precedence approach (Crozier, Glade, 2005). Based on past events, a well experienced specialist (heuristic approach) can make the distinction between factors that play an important role in landslide activity and factors that are related to stable ground. Thus, the identification of the causative factors is the basis of susceptibility analysis.

It is well-known that the slopes adjacent to Arieş Valley are very prone to mass movements and soil erosion, as in the case of Cheia. Thus, historical data on landslides are accessible. As a result we only considered lithology, clay characteristics, slope steepness and the hydro geologic attributes as pre-conditioning factors. The study area is characterized by the overlaying of new Quaternary landslides over paleo-landslides (Badenian, Sarmatian). This situation is shown by the following overlay of *lithologic strata*: yellow clays, clay marl, sandstones, gypsum, and ophyolites. The lithology is uniform (figure 2).

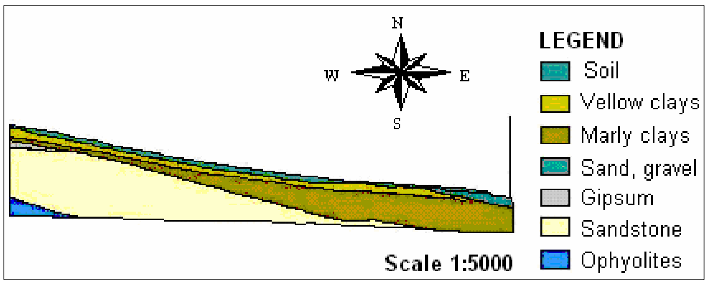

Figure 2. Sketch of the lithological profile of the area studied.

The *geotechnical parameters* of the clays were determined on undisturbed samples that were collected up to 18 m depth. The granulometric results showed that they belong to the following classes: very fine clays, sandy clays and dense clays (particle diameter less than 0,005 mm varies between 35-70%). The hydraulic conductivity ranges from medium (15%) to very high (60%). The friction angle (φ) has medium to high values (φ=9-20º) and the cohesion of the particles ranges from 10 to 30 KPa.

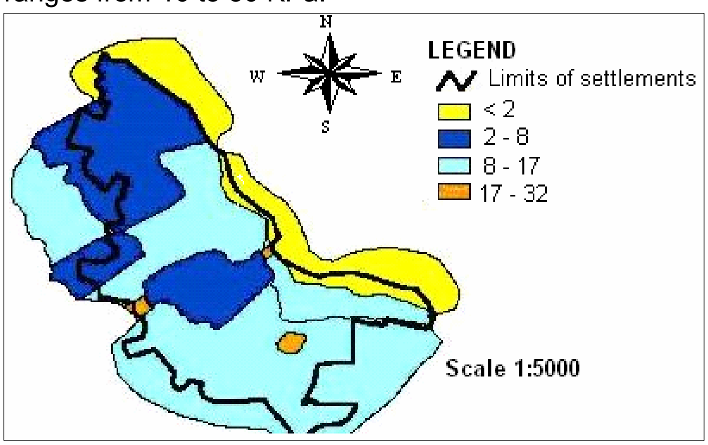

Figure 3. Slope steepness.

Regarding *slope steepness*, the values of 6-17º prevail (figure 3). This is the domain where most of the slope processes occur. For landslide processes for instance, gentle slopes are more favorable than very steep ones because water needs time to get into the soil and not to flow rapidly down slope as in the case of steep slopes. These differences lead to different types of slope processes. Some processes also occur on steeper slopes (17-32º). Areas with slope values lower than 2º represent the riverine areas and they are prone to floods and marsh formation.

The *underground water* level was found from 0 to 6 m depth. It is very sulfurous because of the presence of the gypsum deposits in the nearby and it gets loose towards the floodplain. There were some springs identified at the bottom of the slopes, which increase the quantity of water in the clay deposits, thus increasing their proneness to mass movements.

Susceptibility assessment

Stability assessment of natural slopes, the analysis of the causes of slope failures and the evaluation of slope processes are very delicate and complex, because the geomorphic processes occur at the temporal conjunction of several factors. In order to accomplish a qualitative assessment, they must be graded according to their influence on the processes. The weighting points that were given are based on the previous experience of the specialists that worked in the area. Thus, some assumptions are being made and this induces a certain degree of uncertainty as regarding the results, which is the main shortcoming of such an analysis.

Five indicators were considered as being crucial in preparing and triggering the slope processes (table 1). They were assigned weighting points from 1 (the highest) to 5 (the lowest) according to five susceptibility classes. Thus, three main categories can be emphasized: areas that have a susceptibility index (SI) below 14 have a high susceptibility, areas with SI=14-20 have a medium susceptibility and areas with a SI>20 have a low susceptibility to slope processes. We have also considered the floodplain area which is subject to floods, but that was not graded according to the above mentioned methodology.

Table 1. Susceptibility classes.

Susceptibility	Very high	High	Medium	Low	Very low
Weighting points	*1*	*2*	*3*	*4*	*5*
Slope	17-32º	6-17º	2-6º	< 2º	-
Hydraulic conductivity	>35	20-35	15-20	-	-
Erosion type	basal	linear	sheet erosion	local	no erosion
Underground water level	at surface	1-3 m	3-5 m	5-10 m	>10 m
Pressure on slope	vibrations	>150 KPa	100-150 KPa	50-100 KPa	<50 KPa

In figure 4 it is showed that the highest values of the SI correspond to the hearth area of the village. The houses are situated at the bottom of the slopes, their expansion being restricted by Arieş Valley. The slopes in the nearby area are characterized by active landslides and economical use (a gypsum quarry), which induce vibrations and increase the instability of the slope.

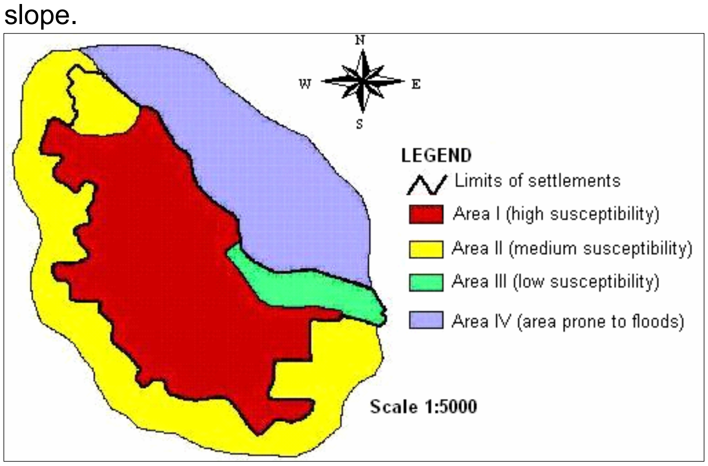

Figure 4. Susceptibility areas.

Risk management frameworks: guidelines for decision makers

General issues regarding landslide mitigation. Landslides are a worldwide hazard to life and property. They cause millions of dollars of damage to roadways and structures every year and threaten public safety. Thus, the policy that is being enforced is the so-called "caveat emptor" (let the buyer beware), so that population is aware of the danger when they buy a property in a landslide prone area (Smith, 2001).

Landslide control is much more effective when combined with rural/urban risk assessment and land planning. Planning and zoning can be an effective means for local authorities to divert development from unstable areas by incorporating landslide hazard information into long-term plans, they give developers advance notice of land use policies and the reason for those policies.

As reported in literature (Olshansky, 2001; Smith, 2001; Crozier, 2005) there are some approaches to be followed when landslide management is considered. The first one is the *slope-density regulation* (Olshansky, 2001). It presumes that landslide hazard is directly related to slope steepness, which is not necessarily the case. Slope-density regulations can specify minimum parcel sizes or overall density. Regulation that emphasizes percent open space rather than parcel size is more tightly linked to landslide hazard mitigation in that it encourages the clustering of dwelling units. But, because slope is not necessarily the best predictor of landslide hazard, this approach is more effective when supported by a geologic map or technical advice from specialists.

A variation of this approach is to have *strict uniform building regulations* for potentially hazardous areas, but to allow site-specific engineering reports to waive some of the restrictions.

A structural approach (Crozier, 2005) is to *implement physical methods* that stabilize the slope (slope reinforcement: bolts, anchors, pins; grouting fissures and joints; bioengineering etc.) or *hydrological methods* (effusing surface water away from the site, drains, impermeable textile covers etc.).

For a good mitigation strategy, the above mentioned measures should be sustained by (Crozier, 2005): *well-established warning systems* (periodic survey, alarm systems based on the triggering event etc.); *fiscal incentives* (tax incentives to leave areas undeveloped, lending policies to discourage development); *land use planning schemes* (hazard zoning); *education* (communication, education and advocacy); *loss-sharing schemes* (insurance).

Risk management strategies for the study area. As regarding the management strategies that are to be applied to the study area in order to mitigate the effects of the natural hazards, there is a distinction to be made between the structural and the non structural ones. It is difficult to decide which ones are more important. Thus, they should be both correlated and implemented by the local authorities.

The *structural approaches* are presented in table 2. Their management should focus on restrictions that must be implemented as well as on alternatives in order to provide sustainable development.

Table 2. Structural management strategies for landslide risk mitigation.

Susceptibility areas	Characteristics	Management	
		restrictions	options
Area I (high susceptibility)	- active landslides having the sliding plane at 3-10m - underground water at 0,1-0,5 m	- no ploughing - no grazing - no buildings	- plantations of pine (Pinus Sylvestris) or acacia (Robinia Pseudo-acacia) - decreasing of human impact - management of pluvial water - slope ballasting
Area II (medium susceptibility)	- stabilized landslides - rill and gully erosion - underground water at 1-6 m	- uncontrolled grazing - plough works along the slope	- sustainable grazing - slope ballasting - grass sowing - gully consolidation - supervised building extension
Area III (low susceptibility)	- glacis area with gentle slopes (2-6º)	-	- ballasting and sowing on the slopes - detailed geotechnical studies when construction is intended - tree and bush plantations
Area IV (area prone to floods)	- aggressive underground water, which get to the surface - frequent marsh areas and floods	- restricted area for building	- water absorbent trees

The *non structural approaches* should address some periodic surveys of the landslide activity on the slopes.

The development of some hazard zoning maps should be very useful for future land use planning schemes.

These maps should be renewed according to the above-mentioned periodic surveys. The results of the surveys made by the expert panels should represent the basis for developing local building codes. This is an effective measure to reduce loses caused by landslides as well as by man made activities.

Population's education should also be the target of the local authorities' concern. The more educated the population would be regarding natural hazard, the less damages to be paid.

By implementing a culture of risk, local and national authorities can delegate the risk towards the population that is aware of it, thus being absolved to pay damages in case that someone builds houses in a landslide prone area.

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