GIS-based landslide susceptibility for environment protection of Black Sea Romanian coast

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Abstract. In the last decades the landslide assessment plays a crucial role in land use development in order to minimize the negative effect of economic live and people’s health. This paper present a GIS based landslide susceptibility assessment. This model is applied on the Littoral Coast line from Constanta to 2 Mai village, which is about 50 km along the Black Sea coast, crossing the Danube – Black Sea Channel at Agigea and passing through several resorts – Eforie Nord, Eforie Sud, Techirghiol, Costinesti and Mangalia. The data used are: geological map (lithology per geologic group), topographic maps of relevant scale to define slope angle ($\beta$), and some geotechnical parameters per geological group. For each of them a GIS map was produced. Based on the research results, we could conclude that Landslide Susceptibility Area (LSA) maps represent a great tool used in the identification of areas predisposed to landslides and could be used as support in the decision-maker process in order to propose environmental work protection or county planning.

1. Introduction

Landslide is a part of natural hazard which could produce negative effect to natural and social environment. According the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED) (EM-DAT), landslide represents 5.2% of natural hazard in terms of number of disasters for the 1997-2017 periods [1].

In Romania, the most affected area is the Sub Carpathian region, especially the Curvature Sector, Transylvanian Plateau and Moldavian Plateau [2, 3] where 50% of territory is affected by gravitational movement mass [4]. In Dobrogea region the most affected areas are Danube valley especially due to loess Quaternary deposits.

In this context, landslide mapping is an important tool for the risk management and improve the resilience of society against landslide disaster and protect the environment.

Earl E. Brabb [5], the pioneer in landslide mapping, in his publication entitled: “The World Landslide Problem” (1991) wrote: “[...] Landsliding is a worldwide problem that probably results in thousands of deaths and tens of billions of dollars of damage each year. Much of this loss would be avoidable if the problems were recognized early, but less than one percent of the world has landslide-inventory maps that show where landslides have been a problem in the past, and even smaller areas have landslide
susceptibility maps that show the severity of landslide problems in terms decision makers understand. Landslides are generally more manageable and predictable than earthquakes, volcanic eruptions, and some storms, but only a few countries have taken advantage of this knowledge to reduce landslide hazards.”

Despite all the efforts, the situation concerning the landslide cartography has not changed significantly. There are several methodological approaches to model the landslide hazard or/susceptibility. Firstly, a controversy exists between the terms landslide “susceptibility” and landslide “hazard”. Landslide susceptibility is the likelihood of a landslide occurring in an area on the basis of local terrain conditions [6]. Landslide hazard maps indicate the probability that a landslide of a given magnitude will occur in a given period and in a given area.

The goal of this paper is to assess the landslide susceptibility area maps (LSA) based on FEMA (Federal Emergency Management Agency) method on the Black Sea Littoral using GIS technique.

2. Materials and methods
FEMA (Federal Emergency Management Agency) method is used to assess the landslide susceptibility maps. According to FEMA methodology [7], landslide susceptibility of geologic groups under static conditions is described as a function of the site condition that refers to the topography, geology and groundwater level (table 1). Landslide susceptibility is measured on a scale of I to X where I is less susceptible and X most susceptible. Groundwater condition is divided in dry and wet condition.

| Geological Group | Slope Angle, degrees |
|------------------|----------------------|
|                  | 0-10 | 10-15 | 15-20 | 20-30 | 30-40 | >40 |
| (a) DRY (groundwater below level of sliding) |
| A Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c'=300 psf, Φ'=35°) | None | None | I | II | IV | VI |
| B Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c=0, Φ'=35°) | None | III | IV | V | VI | VII |
| C Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c=0, Φ'=20°) | V | VI | VII | IX | IX | IX |
| (b) WET (groundwater level at ground surface) |
| A Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c'=300 psf, Φ'=35°) | None | III | VI | VII | VIII | VIII |
| B Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c=0, Φ'=35°) | V | VIII | IX | IX | IX | X |
| C Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c=0, Φ'=20°) | VII | IX | X | X | X | X |

To apply these models at a regional scale, the following data are necessary: (i) geological maps of relevant scale (lithology per geologic group); (ii) topographic maps of relevant scale to define slope angle (β); (iii) some geotechnical parameters per geological formation must be estimated / calculated (Φ' - effective angle of friction of geomaterial (°), c' - effective cohesion of geomaterial (kPa), γ - specific weight KN/m³); (iv) groundwater level.

This methodology is applied on the Littoral Coast line from Constanta to 2 Mai village, which is about 50 km along the Black Sea coast, passing through several resorts – Eforie Nord, Eforie Sud, Techirghiol, Costinesti and Mangalia, shown in figure 1.

From a geological point of view, this area includes three tectonic units – Northern, Central and Southern Dobrogea, presented in figure 2. The tectonic units are separated by two major crustal faults, approximately oriented NW-SE: Peceneaga-Camena (between North and Central Dobrogea) and Capidava-Ovidiu (between Central and the Southern units). The common feature of the three units of
Dobrogea is the vast Quaternary cover, having various thicknesses of loess layers, as in figure 3. There are in small percentage: green schist, limestone and reddish clay.

An ASTER DEM (resolution 30x30 m) was used for generating the Digital Elevation Model, as in figure 1, which has been used for the processing that followed. Maximum elevation in the region is 168.2 m. The major part of the investigated area is flat (0-10 degree). The steeper slopes are on the coastline, on the Danube-Black Sea Canal and on the valley. The geological group was identified based on geological map, presented in figure 3; for the geological materials identified (figure 3) the effective angle of friction of geomaterial ($\Phi'$) varies between 19$^\circ$ and 35$^\circ$, effective cohesion of geo-material varies between 5-23 kPa and the specific weight is situated in the range 14.50-20.37 KN/m$^3$. Based on the groundwater level map we establish the condition: dry or wet.
3. Results and discussion
In order to assess the landslide susceptibility model under ArcView GIS, the methodology proposed is described in the figure 4:
- derived slope from DEM, figure 1, and reclassify the slope according FEMA method, as in table 1 and figure 4;
- developed geology map and a raster for the geological group described in table 1;
- developed water table map and divided the groundwater level in the two categories: dry or wet;
- intersection of all raster maps in order to obtain LSA map;
- reclassify the LSA raster map in the classes proposed by FEMA given the scales. All maps are presented in Stereo 70 projection.

Based by the methodology proposed, we obtained the landslide susceptibility map, in figure 5b and 5c (a zoom of Eforie area). This map shows that the area fall within V and VI class without the cliffs where the territory falls within VII class. The cliffs in Eforie Sud, 2 May and Vama Veche are the subject to landslide susceptibility (VII and IX classes). For evaluating the effectiveness of the LSA map this is compared with the landslide prone area identified by Constanta County Inspectorate for Emergency Situations (CCIES), as in figure 5a, using a method establish by Governmental Decision (447 from April 2003).

According this method, an average hazard coefficient (AHC) is calculated based on a large variety of data. The comparison of two maps (figure 5a and 5b) shows that there is a remarkable convergence in the location of landslide prone areas at regional scale especially for Eforie area (in rectangle – figure 5a and figure 5c), despite the fact that the two models have very different input data requirements and backgrounds.

Currently, the Eforie area is strongly affected by landslides and collapses of the cliff due to local geological conditions: the clay layer at the base of loess deposits. Some consolidation works and sand nourishment project are in developing in the Eforie area.

Taking into consideration that the FEMA models have minimal data requirements (ASTER DEMs, topographical data, geological map, groundwater map), this model can be used to reliably delineate landslide prone areas on a regional (1:25000-1:100000) scale with minimal data requirements in order to proceed with risk assessment in that scale.
Figure 5. Landslide susceptibility map: (a) landslide prone areas identified by AHC method; (b) using FEMA method for the Black Sea coast line. (c) zoom for Eforie area.

4. Conclusions
Landslides are a local phenomenon which depends on a large variety of factors (internal and external). The choice of the most appropriate method depends on data availability and investigation scale. We could conclude that the LSA maps at regional scale based on FEMA method, represent a useful tool in the identification of areas predisposed to landslides and could be used as support in the decision-maker process in order to propose environmental work protection or county planning. At a next stage, deterministic model based on calculating the stability factor of safety factor which can be used especially on site-specific (local) scales in order to determine the landslide hazard map, thus helping make decisions about designing effective preventive measures. Data requirements in this case, especially for highly detailed topographic data of the area, are very demanding.

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