Landslide susceptibility in Zalău Municipality

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Abstract. Due to the city's geographical context and human intervention, landslides occur in Zalău Municipality on extended areas. With a medium reactivation potential, some of these processes repeatedly affect dwellings, elements of infrastructure or agricultural terrains. The main purpose of this paper is to identify and locate the landslide prone areas from Zalău based on the landslide susceptibility assessment performed with the help of the semi-quantitative method included in the Governmental Decision 447/2003 – Mapping methodology and content of landslide and flood risk maps. The estimation of the value and the geographical distribution for each susceptibility coefficient was performed separately for the lithologic, geomorphologic, structural, hydrologic and climatic, hydrogeologic, seismic, sylvic and anthropic factors. Using GIS techniques, the thematic maps representing the contribution of each factor to landslide occurrence and evolution were used to determine the map of average susceptibility coefficient. The validation was achieved by comparing the results with the location of active landslides identified in the field and through cartographic analysis of topographic maps and satellite images. Identifying landslide prone areas is a necessary stage in the process of landslide prevention and mitigation of negative effects.

Keywords: landslide, susceptibility, Zalău, GIS, validation rate

1. Introduction

Landslides are mass movement processes affecting the stability of slopes and included in the category of geomorphologic hazards. In Zalău municipality there are both areas affected by landslides and areas susceptible to landslide activity. The landslide causes in this urban area are related both to natural processes and anthropic activities.

2. Data and methodology

The objectives of this paper are represented by landslide identification and landslide susceptibility mapping in Zalău built-up area, using the semi-quantitative method described by the legislative document H.G. 447/2003 and GIS techniques.

Several thematic maps were created considering the landslide susceptibility coefficients and the contribution of each factor to landslide activation and evolution led to the final map of the average hazard coefficient.

Susceptibility refers to spatial probability or to what extent a territory is prone to a specific extreme phenomenon and is based on the presence of a set of known causing factors or the history of events affecting a specific area (Crozier & Glade, 2005, Irimuş et al, 2005, Rădoane & Rădoane, 2006). It can be represented through various classes describing the occurrence probability which characterises a specific territory (Surdeanu, 1998, Irimuş, 2006, Măguț, 2013).

The susceptibility assessment of any process can be performed by applying a variety of spatial analysis models using GIS techniques, which statistically or heuristically combine causing factors represented through thematic maps and the map describing the spatial distribution of the analysed process (Fabbri et al., 2003; Guzzetti et al., 2006; Rossi et al., 2009; Kouli et al., 2010 cited by Măguț, 2013). This can also be achieved directly through expert opinion, when experts use mapped inventories of the process or previous knowledge related to causing factors and the studied area in order to delineate hazard zones (Van Westen et al., 1999; Cardinali et al., 2002, cited by Măguț, 2013, Fell et al., 2008, Petrea et al., 2014).

Landslide susceptibility research has recently been represented by a series of scientific papers applying this type of analysis among which Manea & Surdeanu (2012) and Măguț et al. (2012) have analysed the landslide susceptibility at administrative level.

The landslide susceptibility assessment was done using the semi-quantitative method described in the Romanian legislation H.G. 447/2003 – Mapping methodology and content of landslide and flood risk maps, including a series of work stages illustrated in Figure 3: data base generation for the landslide susceptibility coefficients, susceptibility assessment and validation of results using the map of active landslides.

Using GIS techniques, the thematic maps representing the contribution of each factor (coefficient) to landslide activation and evolution were generated. The estimation of value and spatial distribution of each coefficient was made individually for the lithologic, geomorphologic, structural, hydrologic and climatic, hydrogeologic, seismic, sylvic and anthropic factors. These were eventually used to generate the map of the average hazard coefficient.

3. Results and discussion

Zalău Municipality, the capital city of Sălaj County, is located at the contact of the Meseş Mountains with Silvaniei Hills in the southern part of the Zalău Depression (Fig.1). The administrative territory of Zalău has a total area of 90.09 km², including the settlement Stâna which is located south-eastern from the Meseş (Nicoară & Puşcaş, 1999). The municipality is limited to the south-east by the steep slope of Măgura Stânii (716 m), to the east by Peringaru Hill, to the north by Ceacău Hill (410 m), to the south-west by Labului Hill (403 m) and to the west by Zalău Vest Hill (400 m).

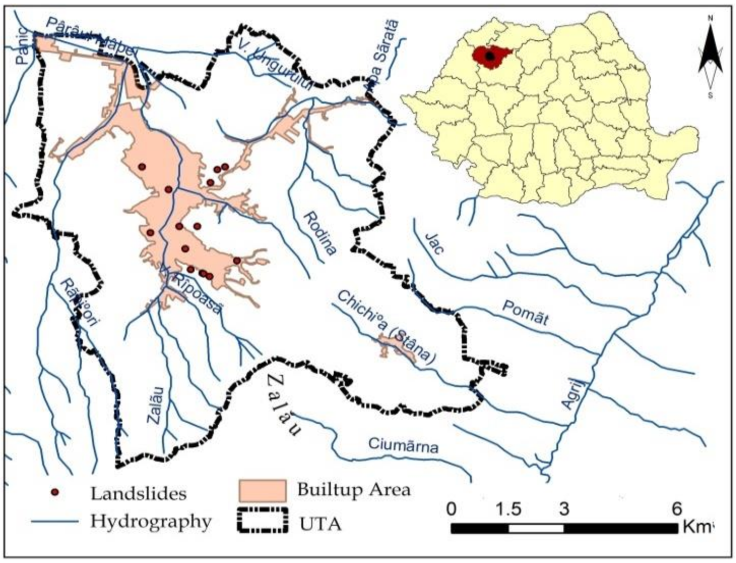


Fig. 1. **Geographic location of study area**

The study area has the form of a depression which is crossed from south to north by the Zalău River. The territory on the right side of the valley includes the north-western steep slopes of the Meseş with streams cutting down into friable Neogene sediments. The territory on the left side of the Zalău Valley has a wavy landscape with rounded hills being fragmented by streams with longitudinal profiles having a smaller slope angle (Popşe et al., 2010).

The fluvial topography, which includes floodplains, terraces and alluvial fans, is characterised by sedimentary formations found on vast areas. These are represented by marls, sand and gravel, with local clays, conglomerates and sandstones. All these sediments are geomorphologically susceptible to downslope movement through landslide processes. The slopes flanking the Zalău River and its tributaries have been constantly being affected by gravitational processes, including landslides (Mac and Hosu, 2010).

The cause leading to landslide activation in Zalău Municipality is related both to natural conditions and anthropic activities. Thus, one of the areas affected by landslides is the neighbourhood Ortelec. The landslide causing factors in this area are represented by water accumulation in the clay strata as well as the clay exploitation performed by SC Cemacon SA. Although a variety of measures have been undertaken over the years, including giving up the water pipe of the water distributor SC Publiserv SA, the building of taluses by Cemacon, these were not able to prevent a landslide affecting 10 Ha. This landslide caused damages to the road (Porolissum Street) connecting Zalău and Ortelec (DJ 191C) and the water tanks used for supplying the neighbourhoods Brădet and Stadion (Fig. 2).

3.1 Susceptibility coefficients

Using the method described in the H.G. 447/2003 and the factorial coefficients, the average susceptibility coefficient was calculated for the area of Zalău municipality (Fig. 3).

Fig. 2. **Landslides in Ortelec area**

The lithologic coefficient was determined using the geological map 1:200 000 (1970) where the lowest coefficient value (<0.10) was attributed to massive rocks, while the highest value (0.51-0.80, >0.80) was attributed to saturated clays, to silt and to small and average aerated sands

The geomorphologic coefficient was calculated starting from the topographic map 1:25000 (1970), which was used to generate the digital elevation model, the hypsometric and the slope angle maps needed for determining the spatial distribution of the geomorphologic coefficient.

The structural coefficient, Kc=0.35, corresponds to a medium-high probability.

The hydrologic and climatic coefficient (Kd) was determined using the multiannual average precipitation map of the Romanian Climatic Atlas (2010). According to the meteorological data, the average precipitation is around 600 mm/year, corresponding to a coefficient value of 0.6 and a high probability of landslide occurrence.

The hydrogeologic coefficient has been attributed the value Ke=0.4 due to a predominance of areas where the phreatic level is up to 5 m, corresponding to a medium-high probability of landslide occurrence.

The seismic coefficient (Kf) has the value 0.7 and is correspondent to high landslide probability as the study area is included in a 6° MSK seismic intensity area.

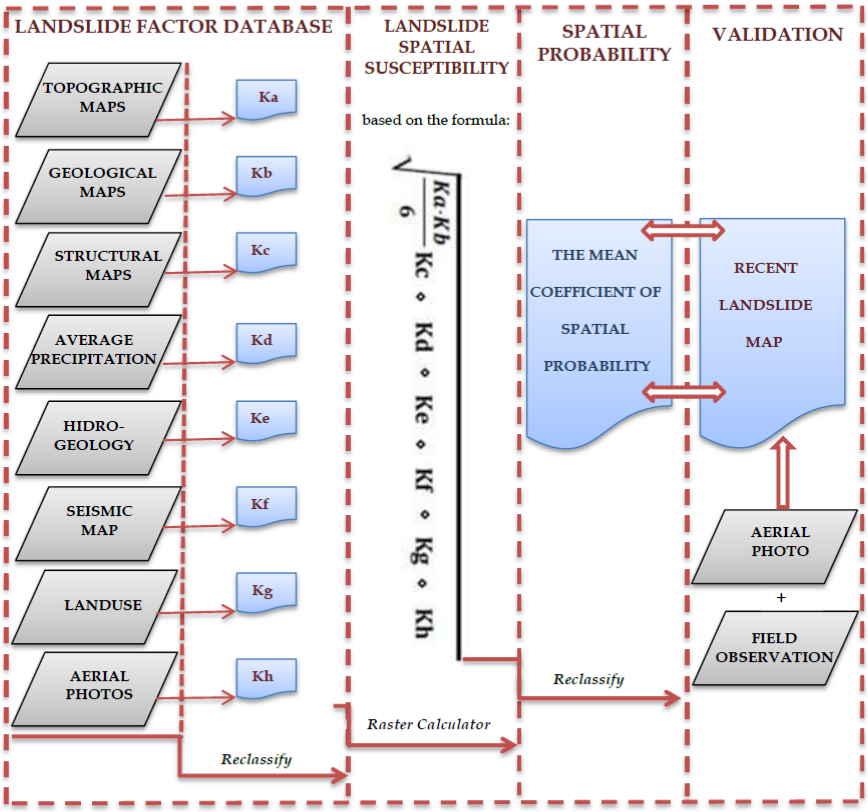


Fig. 3. **Model schematics for landslide susceptibility assessment**

The sylvic coefficient (Kg) was determined starting from the Corine Land Cover data: the areas covered with broad-leaved forests received the value 0.1, orchards and vineyards – 0.5, complex agricultural areas – 0.5, non-irrigated arable lands – 0.9 and deforested areas and pastures received the highest value of the coefficient - 0.95.

For the anthropic coefficient (Kh) a value of 0.1 was attributed to areas without any infrastructure, while the other areas, occupied with different constructions, received a high value of 0.95, corresponding to a high probability of landslide occurrence.

3.2 Probability of landslide occurrence

After analysing each factorial coefficient (Fig. 4), by using ArcGis 9.3, they were combined in order to generate the average hazard coefficient using the expression:

$$K(m)=\sqrt{\frac{K(a)\times K(b)}{6}\times\left[K(c)+K(d)+K(e)+K(f)+K(g)+K(h)\right]}$$

in which: K(m) – average susceptibility coefficient, K(a) – lithologic coefficient, K(b) – geomorphologic coefficient, K(c) – structural coefficient, K(d) – hydrologic and climatic coefficient, K(e) – hydrogeologic coefficient, K(f) – seismic coefficient, K(g) – sylvic coefficient, K(h) – anthropic coefficient.

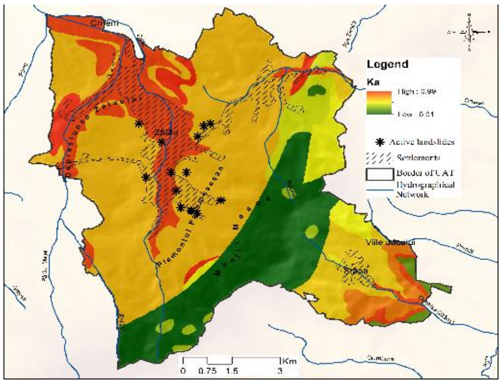
Depending on the values of the average hazard coefficient, the probability of landslide occurrence was determined (Fig. 5) through reclassification, the study area being described as having:

-A *low probability* of landslide occurrence when the average landslide susceptibility coefficient has the values between K(m) = 0.01 – 0.10;

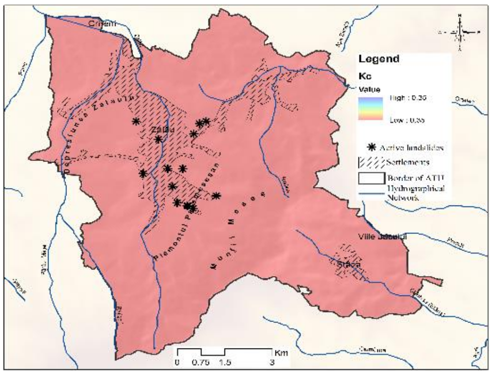
- A *medium probability* of landslide occurrence when the average landslide susceptibility coefficient has the values between K(m) =0.11 – 0.26.

The average hazard coefficient (Fig. 6) has values between 0.003 and 0.26, the highest values characterising the built-up area of Zalău, in the north-eastern part of the city (Dealul Malu, Dâmbul Ciobanului), in the western part (Zalău west), as well as in the south-eastern part of Zalău.

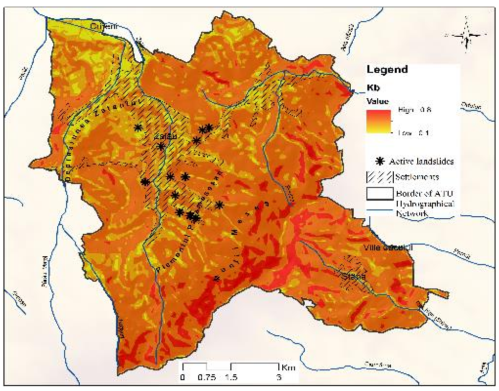
The Meseş Mountains and the north-western part of Zalău municipality are characterized by low values of the average hazard coefficient, due to the stable lithology and the forested areas which determine a high stability of the slopes.



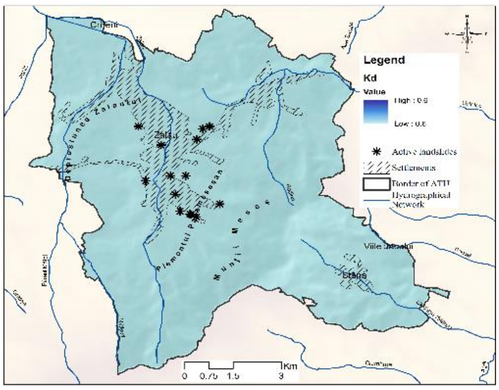
a. Lithologic coefficient map



c. Structural coefficient map

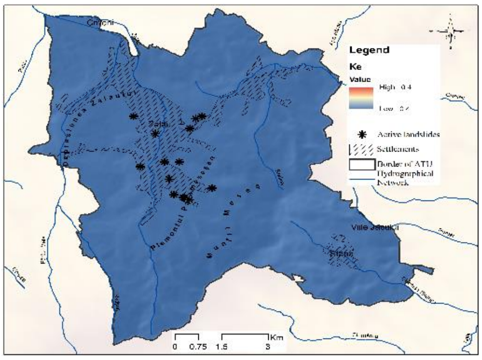


b. Geomorphologic coefficient map

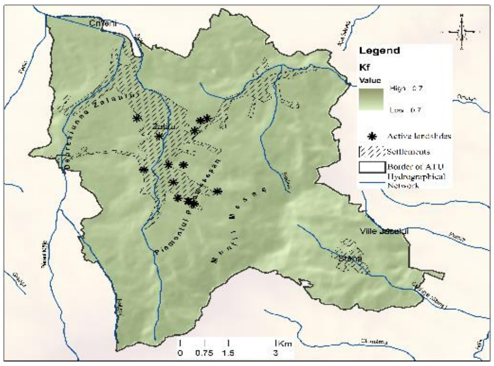


d. Hydrologic and climatic coefficient map

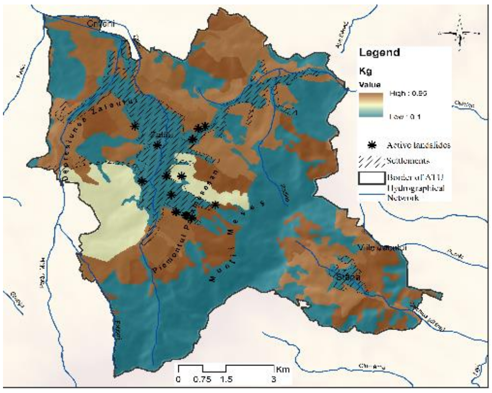
Fig. 4. **Maps of factorial coefficients**



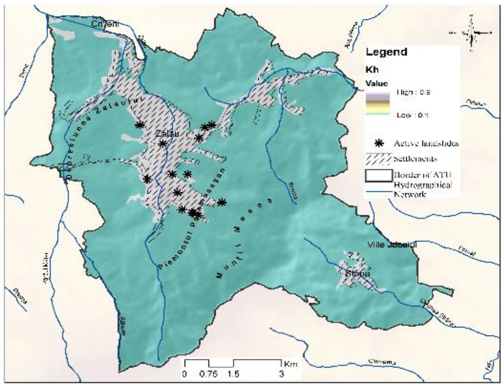
e. Hydrogeologic coefficient map



f. Seismic coefficient map



g. Sylvic coefficient map



h. Anthropic coefficient map

Fig. 4. **(continued)**

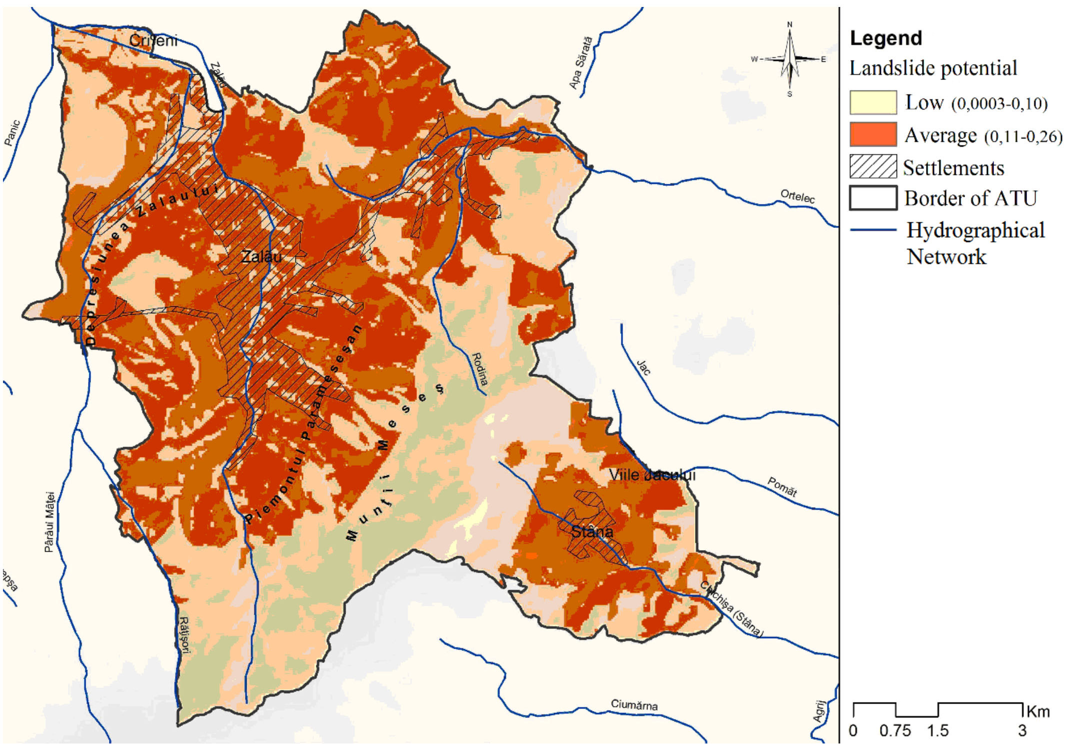


Fig. 5. **Probability of landslide occurrence**

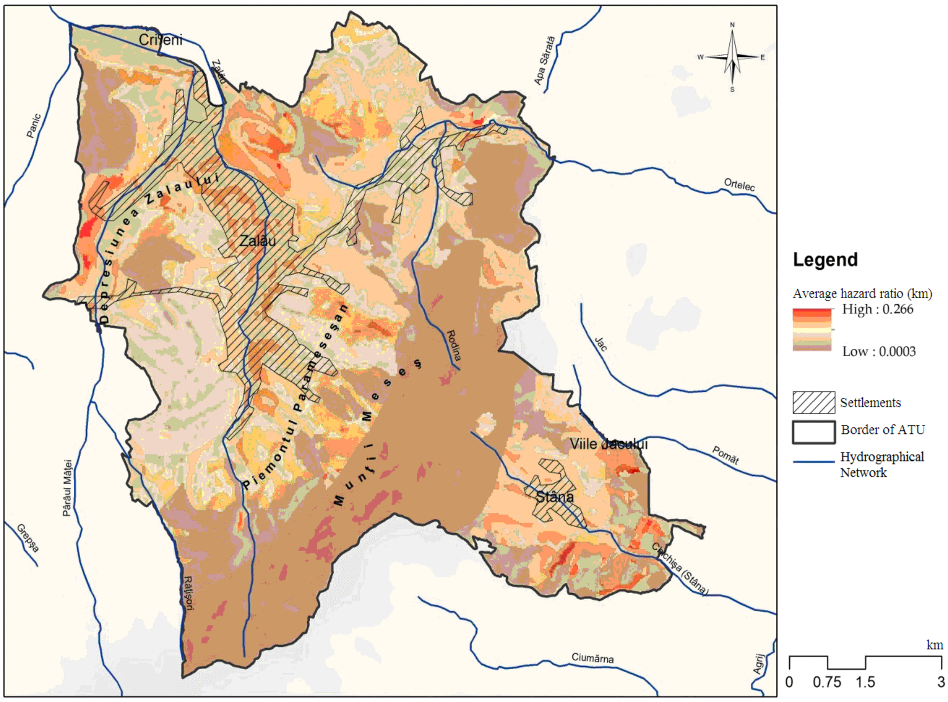


Fig. 6. **Map of average hazard coefficient**

3.3 Validation rate

After applying the landslide susceptibility model described in the legislative methodology H.G. 447/2003, an average value of the hazard coefficient was determined, ranging between a minimum of 0.0003 and a maximum of 0.260.

The territory characterised by a very low probability of landslide occurrence represents the largest percentage in the study area, 40% or 36 km^2. The medium probability characterises 37.08% of the area, which represents 33.1 km^2, while the smallest surface (23.19%) is characterised by low probability and is represented by 20.8 km^2 (Table 1).

In order to determine the success rate of the landslide susceptibility model, according to the H.G. 447/2003 methodology, the total area of landslides was compared for each probability class (Fig. 7). Thus, the medium susceptibility class is validated by 79.09% of the mapped landslides, while only 22% are located in the low susceptibility class. The susceptibility analysis is considered to be successful as less than 25% of the landslide area is located outside the class of highest susceptibility, according to the recommendations of Carrara (1995).

Table 1. **Spatial extension of probability classes**

Probability	**Class area**		**Landslide area**	
	Km^2	**%**	**m^2**	**%**
Very low	36.006	40	0	0
Low	20.875	23.19	15571	22
Medium	33.133	37.08	51537	79.09

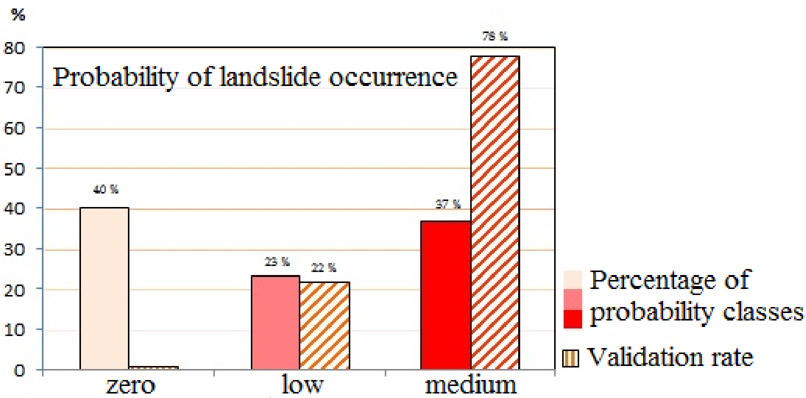


Fig. 7. **Percentage of each landslide susceptibility class and of the mapped landslides (1-zero, 2-low, 3-medium)**

As a result, the model and the factors included in the analysis successfully illustrate the situation from the field, as most of the mapped landslides are located in the areas with the highest susceptibility.

The areas with *active landslides* from Zalău Municipality, which are associated with geomorphologic risk situations, include: the right slope of the Meseş Valley in the neighbourhoods Brădet and Stadion, Gheorghe Lazăr Street, the Central Park, the cemetery, the Courthouse; the right slope of the Zalău Valley in the Ortelec neighbourhood (water tanks, clay quarry), the People's Park, Traian-Vişinilor area, Dumbrava II area. All these territories are included in the medium susceptibility area (Fig. 8).

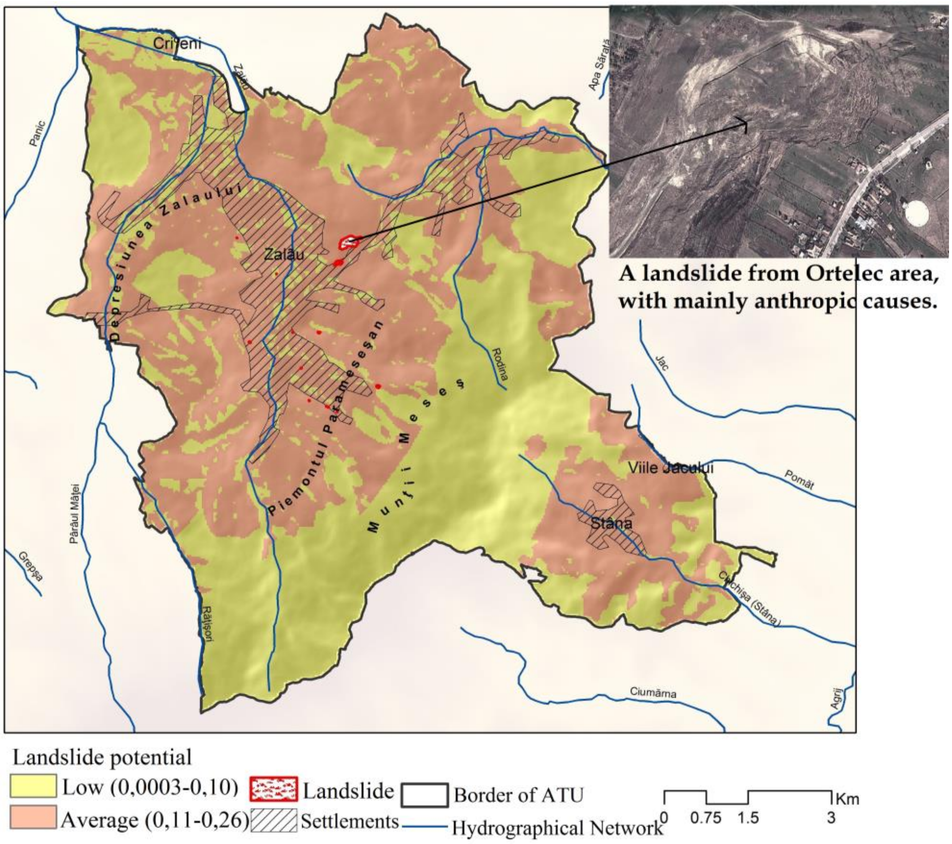


Fig. 8. **Map of active landslides, classified on landslide susceptibility intervals**

The landslides in Ortelec neighbourhood have visible effects in Zalău (Fig.8), mainly affecting the road infrastructure and the built-up area. Covering approximately 10 hectares, these landslides and have also affected agricultural terrains, water tanks, as well as the connecting road DJ 191C (Porolissum Street). Landslides of similar intensity affected also the Brădet and Stadion neighbourhoods, from the Meseş foothills.

4. Conclusions

Applying the semi-quantitative methodology, the landslide susceptibility in the Zalău built-up area has been determined and confirmed by previously mapped landslides. The medium probability of landslide occurrence was validated by 79.09% of the landslides mapped in the field, while the areas with low probability include only 22% of them, thus the model has a good success rate. In the low and medium susceptibility classes the average hazard coefficient ranges between 0.003 and 0.026 in the north-eastern part of the city (Dealul Malu, Dâmbul Ciobanului), in the western part (Zalău west), as well as in the south-eastern part of Zalău.

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