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MAP ZONING OF NATURAL SLOPE STABILITY IN THE CITY OF IAŞI

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Rezumat. *Elaborarea acestei documentaţii - Harta de hazard la alunecări în Municipiul Iaşi, zona Bucium - se înscrie în efortul de sprijinire atât a autorităţii locale în domeniul amenajării teritoriului şi al urbanismului cât şi a persoanelor sau companiilor interesate de achiziţii imobiliare. Identificarea, localizarea şi delimitarea zonelor expuse la hazardul natural al alunecărilor de teren are ca obiect elaborarea hărţilor de hazard pentru aceste zone, definirea condiţiilor de producere a acestor fenomene la nivelul municipiului Iaşi, de stabilire a programului de măsuri pentru prevenirea şi atenuarea efectelor acestora precum şi de elaborare a hărţilor de risc. De asemenea, această hartă oferă o primă imagine proprietarilor de imobile asupra necesarului de măsuri a fi luate in zona proprietăţilor lor pentru a preveni şi/sau combate alunecarea terenului şi asupra ordinului de mărime a costului aferent printr-o simplă operaţie de interogare a hărţii şi determinare a coeficientului mediu de hazard la alunecare a terenului.*

Abstract. *The elaboration of this document – Hazard map for landslides in the city of Iasi, is part of the effort to support both local authorities in the field of urban planning and the persons and companies that are interested in acquiring and developing a real estate. The identification, location and delimitation of the areas exposed to the natural hazard of landslides involves the elaboration of the hazard maps for these areas, defining the conditions in which these phenomena occur in the city of Iasi, to establish the measures to prevent and reduce their effects and to determine the risk maps. Also, this map offers land lords a first glance on the necessary measures needed to be taken at their properties to prevent and/or combat landslides and on the estimated size of the subsequent costs, only by simply interrogating the map and thus determining the medium hazard coefficient for landslides.*

Keywords: slope, stability, zoning, landslide hazard, urban planning

1. Introduction

Identification, location and delimitation of the exposed zones to natural hazard of land sliding have the main objective of making the hazard maps in respect to that

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areas, identifying the triggering conditions of such phenomena in the city of Iasi, setting a management program for prevention and reduction of their effects as well as making the risk maps [1], [2].

Another very important paper objective is to induce awareness and mobilization of various national, regional and local actors in the process of preparation, making, notice and acceptance of the natural risks maps [3], [4]. The limited recommendation of the remedial works in the critical zones and the slow performance and conservation of the proposed construction works required compulsory extensive studies of slope stability analysis as well as urgent measure strategies that are enforced for the parameter rehabilitation of the existing damaged objects or for the durability of the objects proposed to be performed in these specific areas. For this reason the results of such studies are very useful for all the involved institutions that work with or manage the urban and land development maps as well as for land developers. Learning about these zones, the risk involved when deciding to build social and economical objects within the perimeters prone to land sliding, as well as the implementation of adequate structural and non-structural measures will imply the damage limitation and protection of the future investments.

2. Elaboration of the influence maps on the probability of the landslide occurrence

[1].The elaboration of the thematic maps, with establishing the values of the specific influencing factors in case of the territory for the city of Iasi, has been made according to the requirements of the appendix C to the Methodological Norms of the Law 575/2001 regarding the approval of the Urban Planning Map for the National Territory–Section V–zones of natural risk [3], [5] and the Government's Decision 477/2003 regarding the method to elaborate and the content of the landslides natural risk maps.

According to these norms, the influencing factors are:

1. Lithologic factor - K_a
2. Geomorphologic factor - K_b
3. Structural factor - K_c
4. Hydrologic and climatic factor - K_d
5. Hydro geologic factor - K_e
6. Seismic factor - K_f
7. Forestation factor - K_g
8. Anthropic factor - K_h

All the maps of the influence factors have been elaborated in vectorial format and the values related to specific coefficients have been recorded in the data base and presented in the interior of polygons with isovalues. The land surveying data base to elaborate the maps of the influence factors with the values and geographical distribution of particular hazard coefficients K_{a-h} has the source as O.J.C.P. IAŞI, ortofoto 2005, with delimitation over the zone of interest, in the inner part of the city of cu Iaşi and the Bucium zone (fig. 1) [6].

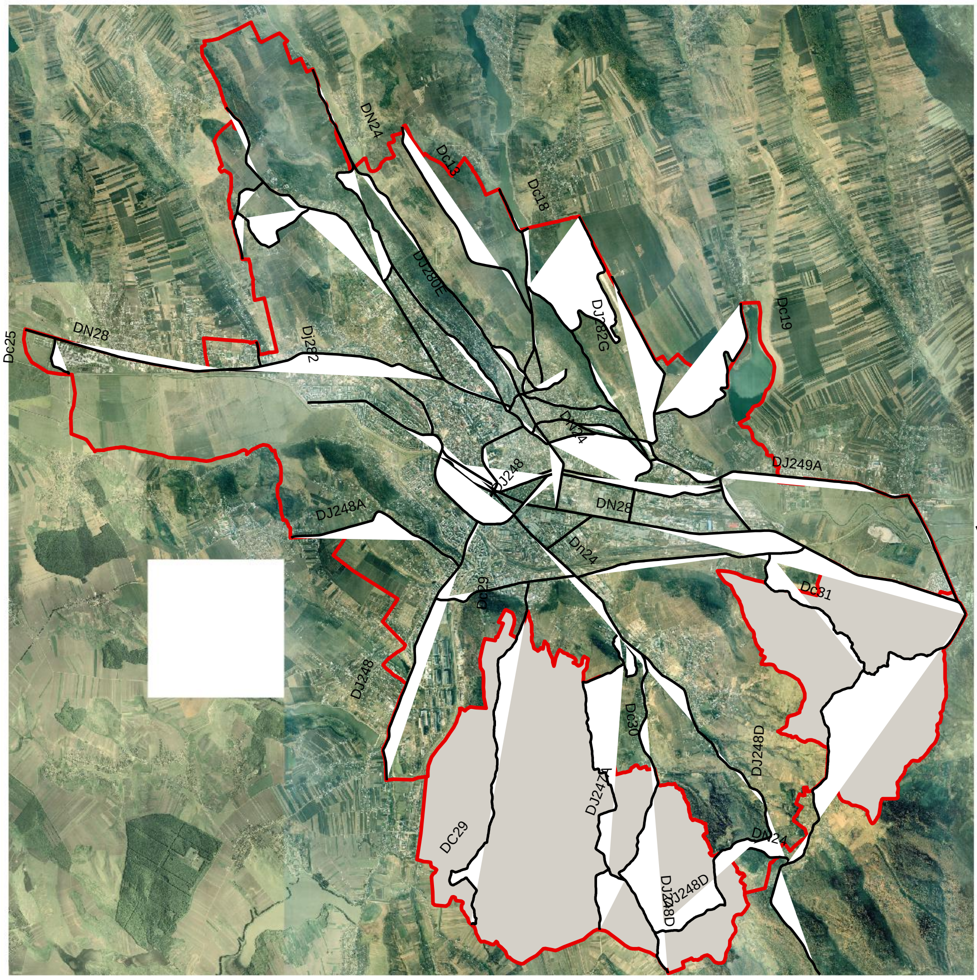


Fig. 1. Ortofotoplan of Iaşi, limits of UAT and the main roads.

Values for the $\mathbf{K_a}$ factor are given on the geological map (fig.2) scale 1:50.000-1:200.000, elaborated by IGR [7], [8], [9] based on the general framework for the entire Romanian territory defined by S.C. Prospecţiuni S.A. Sintetic.

In the present work the following lithological categories are used and evaluated as for land sliding probability: high probability (0,51-0,80) and very high probability

(>0,80) – detritus unconsolidated – uncemented sedimentary rocks (clays and fat clays, saturated, plastic soft – plastic consistent, montmorillonitic clays, strongly expansive, silts, fine to medium loose sands, submerged, salt breccia;

- **0.70** (high probability) on the extension zone of the calcareous-arenaceous flysch;
- **0.80** (very high probability, 0.81-1.0) on the day arenaceous flysch with slate breaks;
- **0.95** (very high probability, 0.81-1.0) for the unconsolidated detritus sedimentary deposits dislodged by various geodynamic processes.

The map of the geomorphologic factor K_b (fig. 3) is elaborated based on the vectorial maps with level curves (sc. 1:5000) [10] by zoning of the slope categories: 0-10^0, 10-20^0, > 20^0, on which the relative slopes have been drawn. The allotted coefficients to quantify the geomorphologic factor are ranging on the following intervals:

- **0.31-0.50** (medium to high probability) for zones with slopes <10%;
- **0.51-0.80** (high probability) for zones with slopes ranging between 10%-20%;
- **0.81-1.00** (very high probability) for zones with slopes >20%.

The value allocation of the K_b factor is made automatically by the digital slope analysis within the ArcGIS program that will mark the zone with the isoslope value in between the pre-established limits.

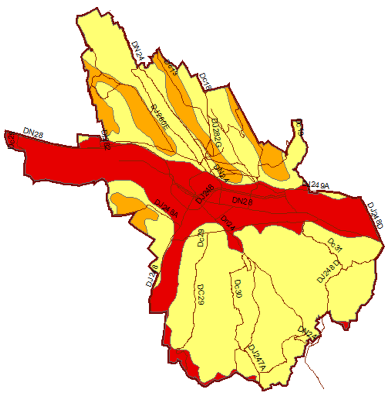


Fig. 2. The map of the lithological factor, K_a

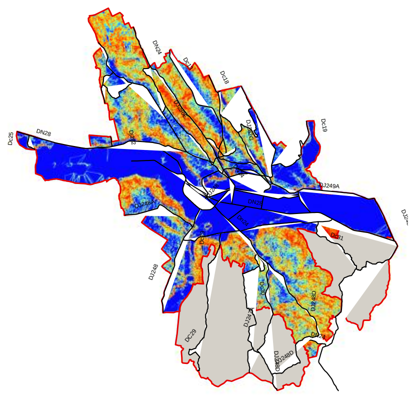


Fig. 3. The map of the geomorphological factor, K_b

For the entire city territory, the structural factor K_c (fig. 4) is evaluated at 0.30, according to the characteristic geological structures for the geosyncline areas as flysch facies, geological formations that are strongly bended and dislodged, affected by a dense mesh of cleavage, cracks and layering [11].

The map of the hydrological and climatic factor (fig. 5) is established based on the existent climatic maps and the precipitation history of the zone, the coefficient value $\mathbf{K_d}$ is evaluated at **0.50** – slow, long term precipitations with high ground infiltration possibilities, that during fast rains induce high speed water flow mixed with solid debris, predominantly developing vertical erosion processes. Information regarding ground water tables in boreholes, wells and springs will be used to elaborate the map of the hydro-geologic factor (fig. 6) [12]. Values of the hydro geologic coefficient $\mathbf{K_e}$ range in the following intervals:

- **0.05** (medium probability) for zones where aquifers develops at high depth and are not influencing natural slope stability;
- **0.40** (medium to high probability) for zones with exfiltrations.

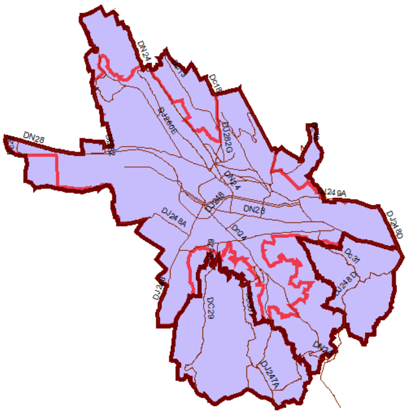


Fig. 4. The map of the structural factor, $\mathbf{K_c}$

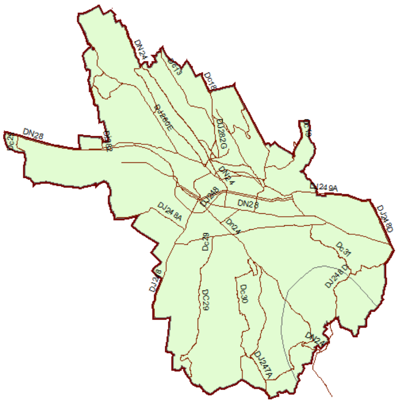


Fig. 5. The hydrologic and climatic map factor, $\mathbf{K_d}$

Standard P100-1/2004 will be used to elaborate the map of the seismic coefficient, (fig.7). The present area is located in the seismic zone C, with a corresponding value of the coefficient K_s = 0.20 (P100/1-2004), the value of Tc = 0.7s and MSK VIII degree. Consequently, the $\mathbf{K_f}$ factor is evaluated at **0.90.**

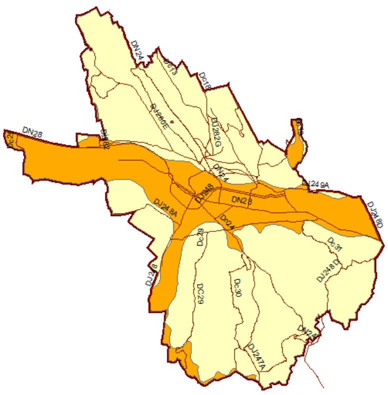


Fig. 6. The map of the hydro geologic factor, $\mathbf{K_e}$

Fig. 7. The map of the seismic factor $\mathbf{K_f}$

The map of the forestation factor $\mathbf{K_g}$ (fig.8) is elaborated based on the aerophotogram of the zone of interest, as well as on the land surveying map. The forestation zones are thus being presented as being with a supporting role for the slope stability, hygrophilous vegetation indicating zones with excessive moisture content and other vegetation types, by the following coefficients:

- forest, **0.10** (medium probability 0.10-0.30) the covering ratio with forest is higher than 80% - deciduous trees of large dimensions;
- wineyards, **0.30** (medium to high probability 0.31-0.50) with a forest ratio in between 20% and 80% - deciduous and pine trees, of various ages and dimensions;
- pasturage, **0.70** (high probability 0.51-0.80), with a forest ratio less than 20%;
- inhabited zone, **0.80** (high probability 0.51-0.80).

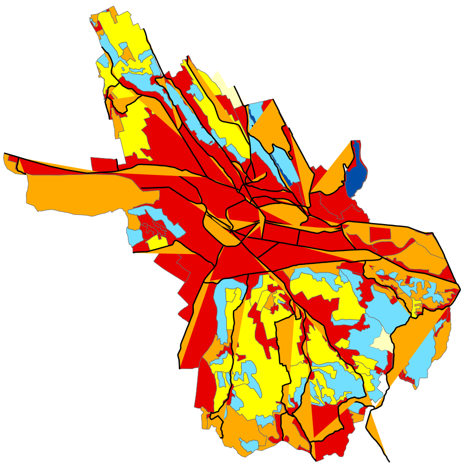


Fig. 8. The map of the forestation factor, $\mathbf{K_g}$

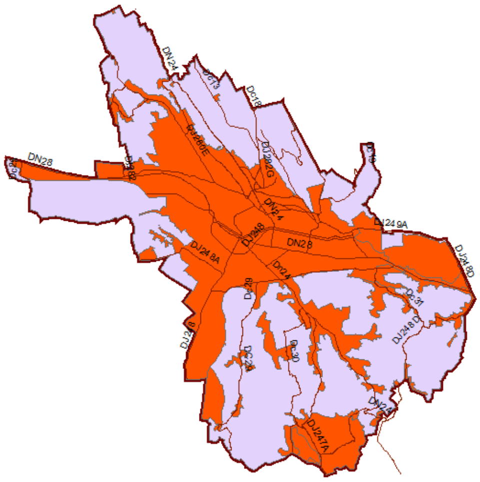


Fig. 9. The map of the antropic factor, $\mathbf{K_h}$

The map of the anthropic factor $\mathbf{K_h}$ (fig. 9) is elaborated based on the cadastral and urban planning maps available at the Regional Council. The anthropic factor ranges in the following intervals:

- uninhabited zone, **0.10** (medium probability, 0.10-0.30) for zones where no important constructions are located on the slope and water accumulations are missing;
- inhabited zone, **0.80** (high probability, 0.51-0.80), for zones where the slope consists of a dense networks of water supply and sewage, roads, railways, water channels, quarries and overloading of the

upward slope with heavy constructions; accumulation lakes that provide moisture effect at the downward part of the slope.

3. Elaboration of the map for land sliding hazard

The map of landslide hazard is elaborated based on the present legislation, the calculation of the influence coefficients, their geographical distribution and establishment of the potential degree (low, average, high) for which corresponds a particular probability of landslide occurrence [13], [14], [15], [16].

The medium hazard coefficient $K_{(m)}$ is computed based on the coefficients of the influence factors with the formula:

$$K_{(m)} = \sqrt{\frac{K(a)\times K(b)}{6}\times\left[K(c)+K(d)+K(e)+K(f)+K(g)+K(h)\right]} \quad (1)$$

The entire operation is performed by the ArcGIS software, ArcMAP version 9.3, as consequence of the interception of the surfaces corresponding to each factor/layer, resulting in the mathematical value of $\mathbf{K_{(m)}}$ from the above formula, related to each generated polygon.

Previously, every thematic map has been analyzed to eliminate the digitalizing effects (superposition of polygons, elimination of the voids between polygons and of the duplicated points).

The map with the geographical distribution of the medium hazard coefficient into the GIS system will conclude into the following zoning categories:

- 0 (probability actual 0);
- 0.00-0.10 (reduced probability);
- 0.11-0.30 (medium probability);
- 0.31-0.50 (medium to high probability);
- 0.51-0.80 (high probability);
- 0.81-1.0 (very high probability);

The mathematical procedure will proceed, after elaborating the factorial maps, by the generation of a unitary grid (for the 8 factorial maps and for the map of the medium factor, into a hypothetical grid of 10 m×10 m).

The obtained product will consist of a dense mosaic of polygons defined by their $K_{(m)}$ values, extremely different (theoretically in between 0 and 1).

The final map $K_{(m)}$ will simplify this extreme variability in concluding value strips (the same for the entire national territory), that will reduce the distribution polygons to approximately 8-12 categories.

The map of landslide hazard is presented in fig. 10 as it results from using the ArcGIS software and following the above mentioned stages, concluding from the evaluation of the landslide potential across the city of Iasi and the Bucium zone.

The hazard map uses mainly 3 out of the 6 categories: 0.11-0.30 (medium probability); 0.31-0.50 (medium to high probability); 0.51-0.80 (high probability).

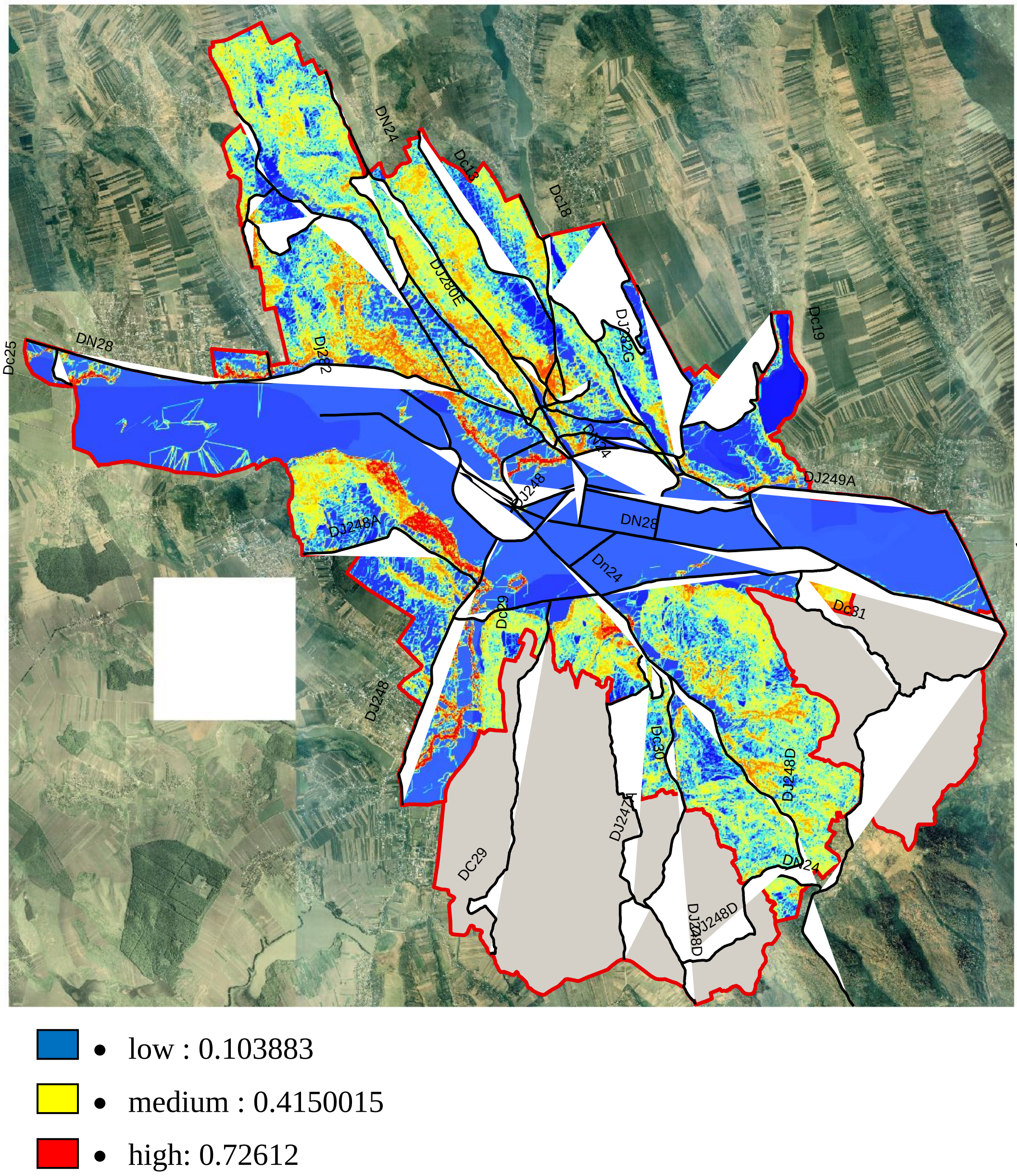
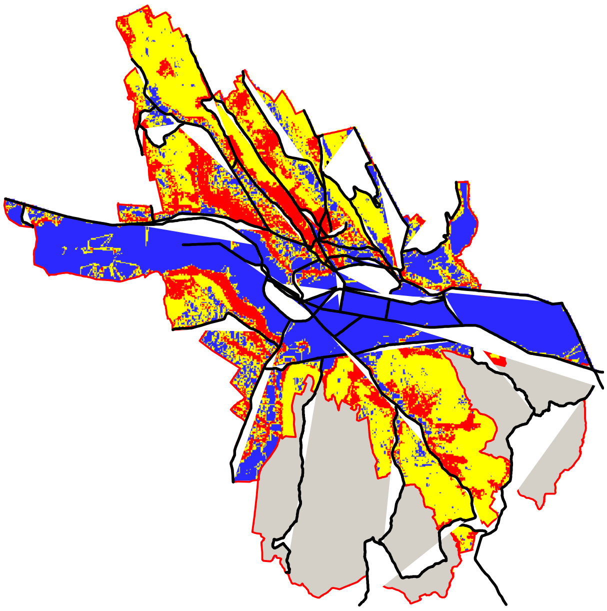


Fig. 10. The map of the **medium hazard coefficient, $K_{(m)}$.**



In this terms, **the hazard probabilities map** can be generated with only the three above mentioned categories, $\mathbf{K_{(m)3}}$:

- 0.11-0.30 (medium probability); 59809570 polygons
- 0.31-0.50 (medium to high probability); 46023647 polygons
- 0.51-0.80 (high probability); 21657947 polygons

Fig. 11. The hazard probability map, $\mathbf{K_{(m)3}}$**,** relative to the three established categories.

4. Conclusions

The medium hazard coefficient $\mathbf{K_{(m)}}$ with the corresponding polygons are the main results from the analysis of the hazard map as well as the specific characteristics for the city of Iasi related to the dynamics of the present factors. It can be easily concluded that on all geographical formations, there are medium values from the medium probability of land sliding ($\mathbf{K_m}$ = 0.10-0.30).

These values are mostly displayed along the Bahlui river bed, as a total of 47% from the area of interest. For values belonging to the reduced probability domain, $K_m \leq 0.10$, and that of very high probability domain, $K_m \geq 0.80$, there are no polygons resulted. The generated polygon surfaces for values of K_m = 0.31-0.50, present on all slopes, belong to the domain of medium to high probability.

This domain represents approximately 36% from the zone of interest. Values of the medium hazard coefficient $\mathbf{K_m}$ = 0.51-0.80, correspond to polygons of reduced area, compact enough, with large occurrence that are encountered on all geographical formations. These belong to the high probability domain representing approximately 17% from the zone of interest. Finally, based on the hazard map analysis for the city of Iasi, there is a medium probability of landslide occurrence along the Bahlui river bed and a medium to large and large probability on all the slopes within the city, the Bucium zone included.

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