THE INFLUENCE OF URBAN EXPANSION ON LANDSLIDE EVOLUTION. A CASE STUDY IN CLUJ-NAPOCA MUNICIPALITY

A.H. KEREKES[1], *Sz. POSZET*[2]

ABSTRACT. – The influence of urban expansion on landslide evolution. A case study in Cluj-Napoca Municipality. In the case of Cluj-Napoca Municipality, the analysis of the landslides is a frequently discussed topic due to its complex geology and urban expansion tendency. In this study, we chose the Gruia Neighbourhood in order to map the landslide evolution and land-use/land-cover (LULC) changes which occured between 2003 and 2021. In order to use the post-classification Change Detection method, we applied the supervised classification technique on three satellite imageries (2003, 2009, 2021), which were validated by high Kappa coefficient values, as it follows: 0,892, 0,879 and 0,931. Comparing the three classified imageries, we could conclude that a transition between agricultural land to urban areas is visible, with a total decrease of the agricultural land by 40,69% and a total increase of the urban area by 24,47%. In the evaluation process of the influence of the LULC change on the landslide evolution, we could observe that the increase of the urban areas led to the increase of the surface of the landslides, moreover, the slided territories on urban areas have increased by 200%.

Keywords: landslide, Change Detection, Remote Sensing, GIS, Cluj-Napoca

1. INTRODUCTION

Recent studies have shown that in populated regions, where the human impact on the environment contributes to important land-use/land-cover (LULC) change, slope stability became compromised and landslides have been reactivated (Reichenbach et al., 2014). Usually, on areas with a complex geology and geomorphology affected by urbanization processes, the anthropogenic activities (excavation works, infrastructure and building construction, vibration caused by increased traffic etc.) often represent the most important landslide triggering factor (Crozier, 2013).

In the case of Cluj-Napoca, mass displacement analysis and evaluation is a frequently researched topic due to its geological, geomorphological characteristics

---

[1] Babeș-Bolyai University, Faculty of Environmental Sciences and Engineering, 400294, St. Fântânele, No. 30, Cluj-Napoca, Romania; e-mail: anna.kerekes@ubbcluj.ro

[2] Sapientia Hungarian University of Transylvania, Faculty of Science and Arts, Department of Environmental Sciences, 400193, Calea Turzii, No.4, Cluj-Napoca, Romania; e-mail: poszet@yahoo.com

and anthropical activities, which triggered a series of landslide events (Buzilă et al., 2001; Roșian et al., 2016; Poszet, 2017; Kerekes et al., 2018; Sestraș et al., 2019). Most of the buildings in Cluj-Napoca, which were built until the 20th century, are located on the most stable areas of the city (Someșul Mic floodplain), but, starting from 2008-2009, the city has expanded on steeper slopes due to the rapidly increasing population and lack of territories with low geodeclivity (Poszet, 2017; Kerekes et al., 2018).

In this research, we have chosen the Gruia Neighbourhood (Fig.1) as study area, because it is a classical example of the built-up area expansion on steeper slopes. In this area we can find many examples of landsliding, like Tăietura Turcului and Cetățuia, where the continous vibrations caused by road traffic and excavations works reactivated landslides (Kerekes et al., 2020).

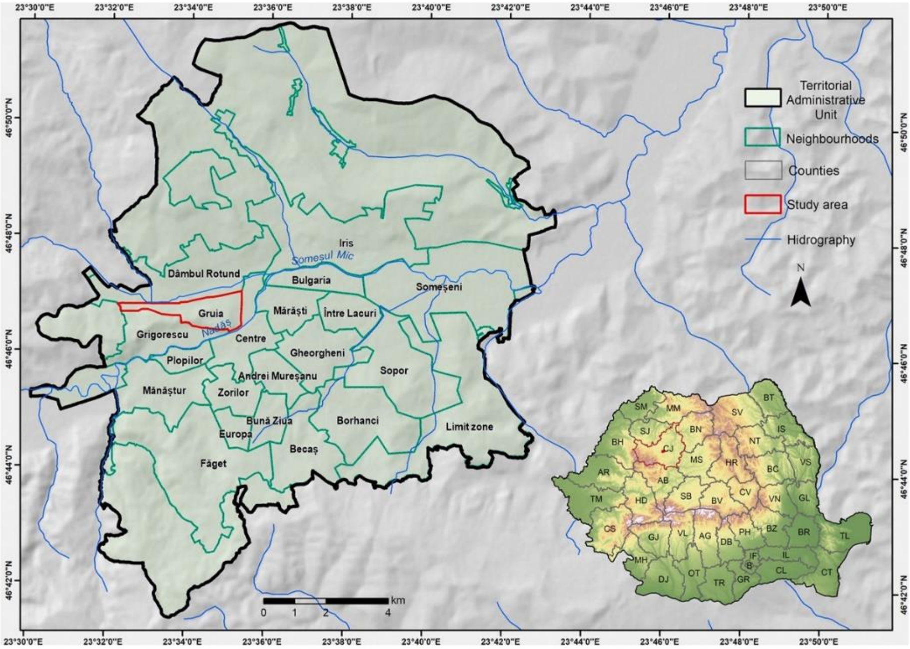

Fig. 1. The geographical position of the study area

The study area is characterized by monocline structure and steep slopes, with a >25° slope angle (Fig.2). From a geological point of view, the study area is incorporating Oligocene (Gruia Sandstone, Brebi Marl Fm, Moigrad and Dâncu Fm, Hoia Limestone and Mera Fm), Miocene (Iris Fm, Dej Tuff) and Eocene (Jebucu Fm) sedimentary formations (Baciu & Filipescu, 2002; Poszet, 2017) (Fig.3). The majority of these formations (aside from the Dej Tuff) consist of clays, marls, sands and sandstones, transforming the Gruia Neighbourhood prone to landslide phenomenon.

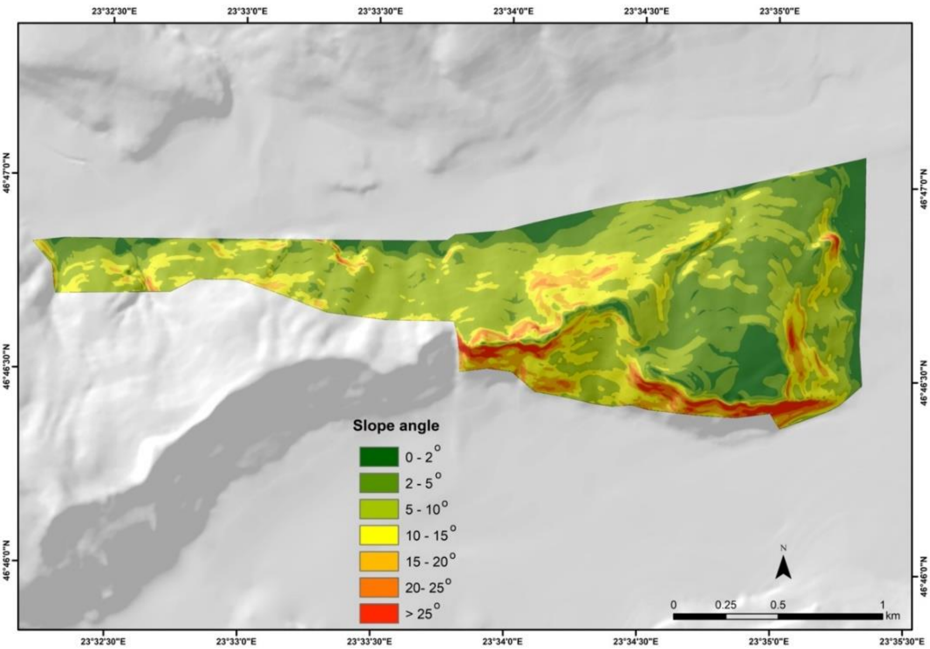

Fig.2. The geodeclivity of the study area

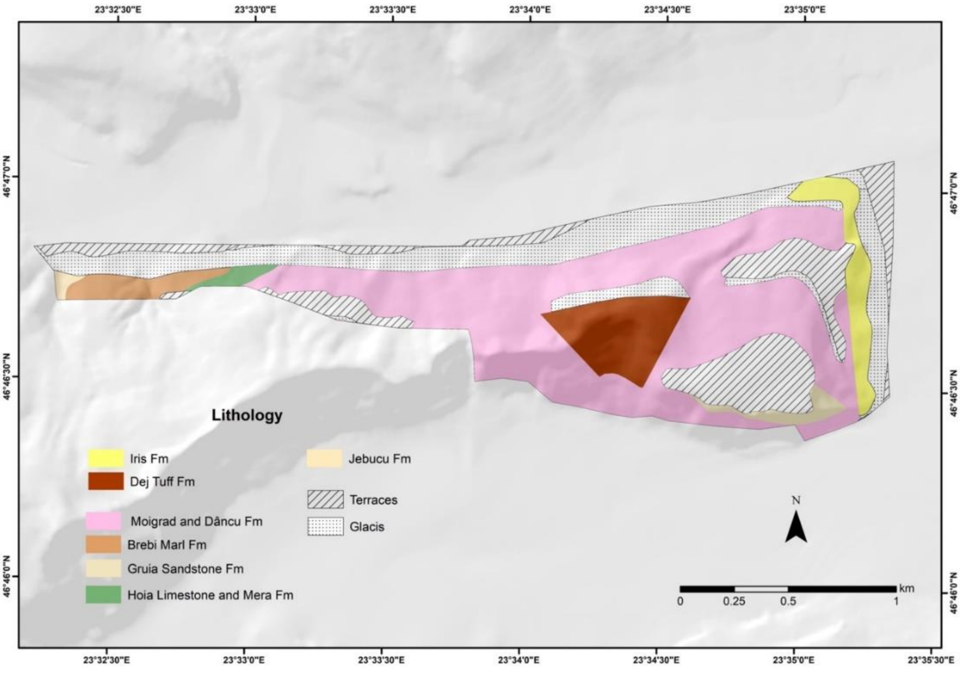

Fig.3. The lithological structure of the study area (after Poszet, 2017)

The aim of this study is to map the landslides and land-use/land-cover in Gruia Neighbourhood, between 2003-2021, using GIS and Remote Sensing methods. By this, we can analyze the effects of urban expansion on landslide evolution and this study can represent a valuable resource for improving the city's urban planning strategies and hazard mitigation works.

2. DATABASE AND METHODS

In order to correlate the landslide evolution with the urban expansion, we created a multi-temporal landslide and LULC inventory, using satellite imagery. Change Detection analysis was applied in order to detect the LULC change.

Accurate and appropriate spatial data must be used in order to accomplish precise GIS and Remote Sensing analysis (Kerekes et al., 2019). In this study, we used and created a spatial database which contains cloud-free satellite imageries and shapefiles (Table 1).

The landslide inventory was derived from the 2003, 2009 and 2021 Google Earth Satellite imagery and was processed in ArcMap 10.4. We chose these periods because they are representative for the urban expansion of the city; the 2003 and 2009 imagery represents the earliest high resolution data available on Google Earth; 2002-2003 and 2008-2009 represents the beginning of the real-estate boom of the city. Unfortunately, this phenomenon persists until the present day.

For the Change Detection Analysis, we chose cloud-free Landsat 7 ETM+ (from 2003 and 2009) and Landsat 8 OLI/TIRS (from 2021) multi-temporal imageries. Change Detection is a very popular and advantageous method which, in the recent years, was used to analyze the evolution of certain territories or phenomena. This method plays a very important role in understanding the consequences of environmental changes (Jensen & Im, 2007; Shalaby and Tateishi, 2007).

Table nr.1. The spatial database of the studied area

Name	Date	Type	Source
Landsat 7 ETM+	2003/05/27; 2009/05/27	Raster and vectorized after classification	USGS (open-source)
Landsat 8 OLI/TIRS	2021/06/30	Raster and vectorized after classification	USGS (open-source)
Landslide inventory	2003/03, 2009/09, 2021/10	Vector	Google Earth (open-source)

In order to achieve accurate results, the Landsat imageries were pre-and post-processed using SNAP 7.0 and ArcGIS 10.4. We applied image enhancement techniques and geometric corrections (Kerekes et al., 2019) using SNAP 7.0. The scan-line error from the Landsat 7 imagery was removed using QGIS, with the Fill No Data tool. Using the Pansharpening function from ArcGIS 10.4., we managed to create 15 m resolution imageries from the initial 30 m resolution Landsat 7 & 8 imageries using the panchromatic band.

After this step, we used the maximum likelihood supervised classification method using ArcGIS 10.4 and adjusted the results based on field observations and Google Earth imagery. This method can be considered as a semi-automatic classification technique and its purpose is to automatically categorize, based on training samples, the satellite imagery into land-use categories (Shalaby and Tateishi, 2007). The following land-use classes were identified: agricultural land, urban area, broad-leaved forest and urban green area.

In order to validate our classification, the Kappa coefficient (Cohen, 1960; Congalton, 1991) was calculated for each classified imagery.

After this step, in order to realize the Change Detection analysis between 2003-2009 and 2009-2021, we applied the widely used post-classification method (Dewan and Yamaguchi, 2009). With the help of this method, we could identify a "from-to" change of the land-use area (Yuan et al., 2005) between the 2003-2021 period, using the Tabulate Area tool in ArcGIS 10.4 (Kerekes et al., 2019).

After the vectorization of the classified satellite imageries, we used the Intersect tool from ArcGIS 10.4 in order to determine the landslide distribution correlated with each land-use type.

3. RESULTS

Regarding the multi-temporal landslide inventory (Fig.4.), we could observe the continuous increase of the surface of the landslide areas between 2003 and 2021 in the Gruia Neighbourhood: in 2003, the total landslide area was 0.31 km^2; in 2009 and 2021, the slipped area was 0,33 km^2 (6,45% increase compared to 2003) and 0,46 km^2 (48,38% increase compared to 2003), respectively. Both rotational and translational landslides were identified.

Concerning the Change Detection analysis, the classified imageries were validated using the Kappa coefficient. In the validation process, we obtained the following results for the 2003, 2009 and 2021 imagery: 0,892; 0,879; 0,931, respectively. According to Congalton, 1991, Kappa values higher than 0.80 represent a strong reliability of the classified data. Therefore, we could use the classified imageries for further calculations.

Comparing the 2003 and 2009 classified imageries (Fig.4), we could observe the fact that the urban area has increased by 14,68% on the detriment of the agricultural land, which decreased by 24,41%. The green urban area and broad-leaved forest area remained unchanged. The same phenomenon can be observed for the 2009-2021 period (Fig.4): the urban area has increased by 8,53%, the agricultural land decreased by 21,53% and the green areas remained unchanged. Therefore, a transition between agricultural land to built-up area can be observed, with a total increase of the urban area of 24,47% and a total decrease of the agricultural land by 40,69% between 2003-2021.

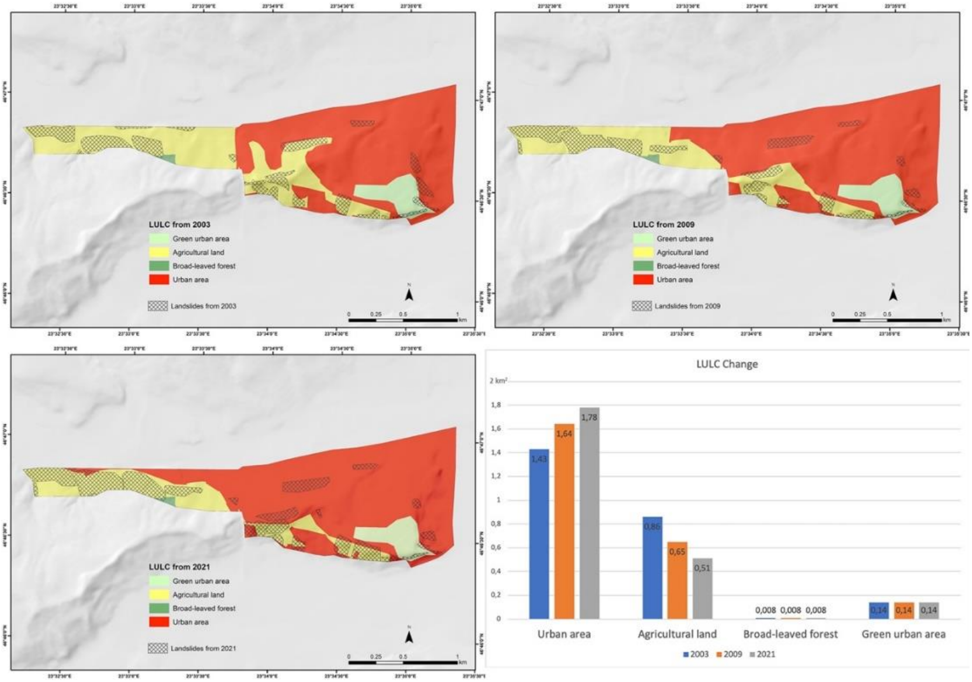

Fig.4. The LULC change and landslide evolution between 2003-2021

In order to evaluate the influence of the LULC change on the landslides, we calculated the landslide distribution for each year on every land-use category. For 2021, we obtained the following: on green urban areas we could find 0,0062 km^2 slided areas; on urban areas, agricultural lands and broad-leaved forest there were 0,15 km^2, 0,30 km^2 and 0,0017 km^2, respectively, slided surfaces. Similarly, for 2009 and 2003: on green urban areas we could observe 0,0069 km^2 and 0,011 km^2, respectively, slipped areas; on urban areas there were 0,08 km^2 and 0,05 km^2, respectively, slipped surfaces; on agricultural lands there were, in both cases, 0,24 km^2 slided areas; on broad-leaved forest areas were 0,0031 km^2 and 0,009 km^2, respectively, slipped areas. We can clearly observe the fact that due to the increase of built-up areas on the detriment of agricultural lands, the surface of the landslides in these areas have increased, too (Table 2). The landslides which can be found on the green urban and broad-leaved forest areas show a decreasing tendency, which means that they have been stabilized.

Table nr.2. Landslide distribution on LULC categories

LULC	Landslide area 2021 (km^2)	Landslide area 2009 (km^2)	Landslide area 2003 (km^2)	Total increase/ decrease
Green urban area	0,0062	0,0069	0,011	-43,63%
Urban area	0,15	0,08	0,05	+200%
Agricultural land	0,30	0,24	0,24	+25%
Broad-leaved forest	0,0017	0,0031	0,009	-81,11%

Therefore, we can observe the tendency of urban expansion towards the agricultural lands which lies on steeper slopes, and by transforming these areas in sparsely vegetated ones, they become more prone to further landsliding.

4. CONCLUSIONS

Landslides are a frequently studied phenomenon in Cluj-Napoca due to its specific natural and anthropogenic characteristics. In this study, we wanted to highlight certain problems from Gruia Neighbourhood and their possible consequences in the future.

Generating a multi-temporal landslide and LULC inventory becomes important in order to understand the anthropic influence in correlation with landslide evolution. In this study, Change Detection method was succesfully used in order to compare the 2003, 2009 and 2021 classified imageries. Therefore, a transition between agricultural land to built-up area can be observed, with a total increase of the urban area by 24,47% and a total decrease of the agricultural land by 40,69% between 2003-2021. Moreover, analyzing the landslide distribution on the LULC classes, the slided territories on urban areas have increased by 200%.

The results confirm the fact that Gruia Neighbourhood becomes more prone to landslides due to the transformation of agricultural lands in built-up areas: the steeper slopes become rarely vegetated, thus the lack of soil reinforcement is increasing the denudation processes; certain anthropic activities, like excavation works and vibration caused by traffic can reactivate landslides.

It becomes necesarry to conduct further Remote Sensing and GIS analysis on the territory of Cluj-Napoca in order to analyze the landslide triggering factors more profoundly; thus we can build more complex spatial models that can be used in urban planning, geomorphological hazard mitigation works and slope stability management.

Acknowledgement

The present work has received financial support through the project: Entrepreneurship for innovation through doctoral and postdoctoral research, POCU/380/6/13/123886 co-financed by the European Social Fund, through the Operational Program for Human Capital 2014-2020.

REFERENCES

1. Baciu, C., Filipescu, S. (2002) *Structura geologică.* In: Cristea, V., Baciu, C., Gafta, D. (eds.) *Municipiul Cluj-Napoca și zona periurbană. Studii ambientale.* Editura Accent, Cluj-Napoca, pp. 25-35.
2. Buzilă, L., Perșoiu, A., Surdeanu, V. (2001) *Dinamica alunecării de teren de pe strada Dragalina* (Dl. Cetățuia - Cluj-Napoca). Revista de geomorfologie, 3, pp. 119-123.
3. Cohen, J. (1960) *A coefficient of agreement for normal scale*. Educ Psychol Meas. 20, pp. 37-46.
4. Congalton, R.G. (1991). *A review of assessing the accuracy of classifications of remotely sensed data*. Remote Sensing of Environment. 37, pp. 35–46.
5. Crozier, M. (2013) *Mass-movement hazards and risks*. în: Shroder, J., Marston, R.A., Stoffel, M. (Eds.) *Treatise on Geomorphology*. Academic Press, San Diego, CA, vol. 7, Mountain and Hillslope Geomorphology, 249–258.
6. Dewan, A.M., Yamaguchi, Y. (2009). *Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization*. Applied Geography, 29(3), pp. 390-401.
7. Jensen, J.R., Im, J. (2007) *Remote Sensing Change Detection in Urban Environments*. În: Jensen, R.R., Gatrell, J.D., McLean, D. (Eds.*) Geo-Spatial Technologies in Urban Environments*. Springer, Berlin, Heidelberg.
8. Kerekes, A.H., Poszet, Sz.L, Gál, A. (2018) *Landslide susceptibility assessment using the maximum entropy model in a sector of Cluj-Napoca Municipality, Romania*. Revista de Geomorfologie, 20, pp. 130-146.
9. Kerekes, A.H., Alexe, M. (2019) *Evaluating urban sprawl and land-use change using remote sensing, GIS techniques and historical maps. Case study: the city of Dej, Romania*. Analele Universității Oradea, Seria Geografie, XXIX, 2, pp. 52-63.
10. Kerekes, A.H., Poszet, Sz.L., Baciu, C. (2020) *Investigating land surface deformation using InSAR and GIS techniques in Cluj-Napoca city's most affected sector by urban sprawl (Romania)*. Revista de Geomorfologie, 22, pp 43-59.

11. Poszet, Sz.L. (2017) *Studiu de geomorfologie aplicată în zona urbană Cluj-Napoca*. Editura Scientia, Cluj-Napoca.
12. Reichenbach, P., Busca, C., Mondini, A.C., Rossi, M. (2014) *The Influence of Land Use Change on Landslide Susceptibility Zonation: The Briga Catchment Test Site (Messina, Italy)*. Environmental Management, 54, pp. 1372-1384.
13. Roșian, Gh., Maloş, C., Muntean, L., Mihăiescu, R., Dobrei, G. (2016) *Geomorphological constraints in the urban development of the Gruia district in Cluj-Napoca*. Studia Ambientum, LXI, 1-2, pp. 119-127.
14. Sestraş, P., Bilașco, Ş., Roșca, S., Naş, S., Bondrea, M.V., Gâlgău, R., Vereș, I., Sălăgean, T., Spalević, V., Cîmpeanu, S.M. (2019) *Landslides Susceptibility Assessment Based on GIS Statistical Bivariate Analysis in the Hills Surrounding a Metropolitan Area*. Sustainability, 11(5):1362.
15. Shalaby, A., Tateishi, R. (2007). *Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt*. Applied Geography, 27(1), pp. 28-41.
16. Yuan, F., Sawaya, K.E., Loeffelholz, B.C., Bauer, M.E. (2005) *Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing*. Remote sensing of Environment, 98(2-3), pp. 317-328.