GIS APPLICATIONS FOR GEOMORPHOLOGICAL CONSTRAINTS ASSESSMENT WITHIN NEW RESIDENTIAL AREAS OF CLUJ-NAPOCA MUNICIPALITY

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***Abstract**: This paper proposes a quantitative method to assess the geomorphological constraints in new residential spaces of Cluj-Napoca Municipality. Our method encompasses GIS applications to evaluate the relations amongst slope declivity, buildings types and geomorphologic processes. We tried to detect the situations where, in the process of constructions, topographical parameters have been taken into account, and the cases were not. Some of slopes categories classifications from scientific literature were utilized to compare and highlight the situations described above. On this basis, a detailed mapping of the slopes facets has been realized at the micro scalar level. Thus, the implications for geomorphological practice in urban residential spaces are very important within this context. The main output of assessment is a thematic map which can be used in urban planning.*

***Keywords:** GIS assessment, residential areas, geomorphological constraints, Cluj-Napoca.*

1. Introduction

The rapid spread of urban space and its environmental challenges require precise mapping techniques to represent complex earth surface features more accurately. Some mapping approaches (GIS processing) can be used to assess urban land use and urban sprawl (Thapa, Murayama, 2009).

Urban sprawl is commonly used to describe physically expanding urban areas. The European Environment Agency has described sprawl as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas. Sprawl is the leading edge of urban growth and implies little planning control of land subdivision. Development is patchy and scattered with a tendency for discontinuity. It spread over areas, leaving agricultural or forested enclaves. (EEA, 2006).

The sprawling problem of Romania’s cities is critically in the last two decades and it is important because of the major impacts that are evident in increased energy and land consumption. Thus, urban sprawl produces many adverse impacts that have direct effects on the quality of life for people living in urban area.

We decide to assess the relationship between urban sprawl, new residential areas and geomorphological constraints in Cluj-Napoca city. Cluj-Napoca city, located in the central part of Transylvania, has a surface area of 179.5 square kilometres. The city sprawls over the Someşul Mic and Nadăş valleys and to some extent over the secondary valleys of the Popeşti, Chintău, Borhanci and Popii rivers.

The study site is a new residential space of the Cluj-Napoca city (Colonia Făget and Sf. Ioan Valley) situated in the south-western part of urban area (Figure 1). The study area covers about 1159.705 ha of land, with a perimeter of 16768.67 meters. The coverage has relatively heterogeneous (i.e. residential, green spaces, etc) landscapes.

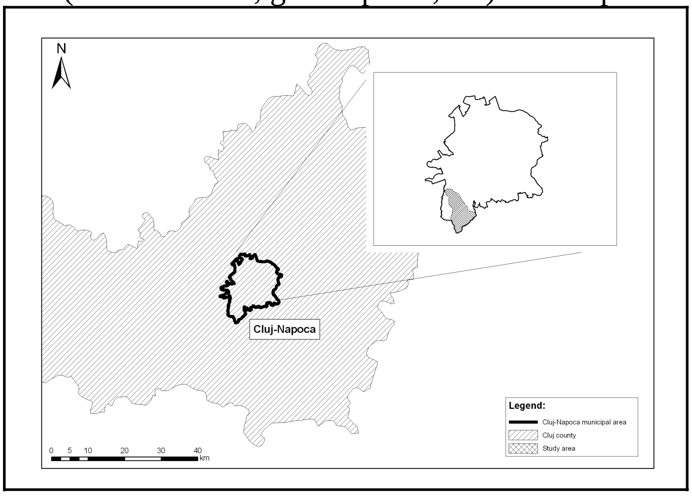

Fig. 1. Location map of study area

The population in the urban core of Cluj-Napoca city and its vicinity is growing, with a density of 1707.0 persons per square kilometre as of 2009. New residential and commercial zones (i.e. Europa, Mănăştur Nord, Făget, Becaş, Tempus, Borhanci) are being built in a very rapid manner and, as a consequence, some rapid changes in landscape can be observed, even at a monthly or annually basis (i.e. in the western and eastern part of the city). Problems appear from the competing land uses within these zones and the constant pressure for new development, even in areas that have green belt status or other forms of protection (i.e. Făget Forest).

According to CLC 2000, land use in our study area is dominated by forests, with some small areas covered with shrubs and natural grasslands. This situation has changed into the last ten years and now we can see that the residential area has increased in size and should be taken into consideration. By analyzing some aerial photogram we can conclude that the residential area has increased on the expense of the natural grasslands.

Table 1. Land use in the study area (according with CLC 2000)

No.	Land Use	Area (hectares)	Percent (% from total area)
1	Broad-leaved forest	1018.23	87.80
2	Natural grassland	50.87	4.39
3	Transitional woodland-shrubs	90.60	7.81

2. Geological and geomorphological settings

Geomorphological constraints can lead to continual damage and destruction of buildings, roads, waterworks and sewerage infrastructure. They fall far below the topographic threshold envelope, a relationship of slopes at the head of the slide and the surface area drained into it, indicating anthropomorphic triggering. The superficial landslides still reactivate occasionally (Trefois et al., 2007). Deforestation and rural-urban fringe, followed by a moderate increase in the population, has been indirect causes of the reactivated mass wasting processes. On the steep slopes in the many parts of the study area the density of newly built houses has led to reduced water infiltration and enhanced runoff, causing landslides and creeping.

The study area is related to Sf. Ioan river catchment, a tributary on the right side of Gârbău River, the last one being also tributary of the Someşul Mic River with the confluence in Cluj-Napoca city. Our river catchment area is localized on the north-western part of Feleac Massif and it has landforms specific to this unit. At the basement of the Feleac Massif rocks of crystalline shales are present these rocks which emerging at the surface only on the summit of Măgura Sălicii (Meszaros 1976), being covered with Eocene, Oligocene and Miocene formations. This will lead to a differentiation between the upper and the lower part of the catchments area. The values for fragmentation depth of the morphology in the upper part of the catchments are not so high compared with the lower part where, taking into consideration also the thickness of the sediments the fragmentation generated by the river is influencing the parameter resulting in higher values. Because of the low level of Someşul Mic River, the main collector in our study is deepening with 110 – 130 m just after 5 km, this situation being influenced by the presence of sedimentary rocks. If we consider these values and add also the fact that between the highest point (Vf. Peana 832 m altitude) and the most lower one (Gârbău River confluence at 370 m altitude), it is clear the potential for geomorphologic processes.

The main process affecting our study area is represented by landslides. These have been very well documented by field research and on aerial photographs. From a total surface area of 1159.7 ha, the total area affected by landsliding processes is 191.7 ha. These landslides are considered to be old, deep and currently stable. From the point of total surface and regarding the residential area, the most important landslide is situated in the upper part of the basin. They are presenting areas covered with specific vegetation represented by a number of hygrophilous species. With a more reduced size are the landslides from the right slope of the river which cover a total area of 17.3 ha. The left slope is more stable, being characterized by the presence of a single massive landslide (44.7 ha) localised near the confluence of Sf. Ioan River with Gârbău River. The sliding body of this landslide has reached the valley floor forcing the water to cut through the debris. The sliding mass acted as a local and temporary base level which interrupted the connection between the elevations of Sf. Ioan river catchment. Thus, Gârbăului River catchment determines a high deposition in the upper landslide sector. So, the river bed has been lifted, thus reducing the potential energy of the tributary valleys. In the sliding mass the water carved a small gorge. Despite the fact that these landslides are considered to be stable, there is the possibility that by building and adding more weight on the slopes the old landslides may become active again or maybe new landslides will be generated.

3. New residential spaces in Cluj-Napoca urban area

Cluj-Napoca city flows perceptibly across municipal boundaries and this process is at different stages of development in different new residential areas. Thus, the responsibility for land use management remains divided between local administration and this fragmentation of urban management, frequently exacerbated by the political tensions, may lead to incoherent land use planning. In our context, the mix of forces include socio-economic trends such as the means of individual housing preferences, transportation, the price of land, demographic trends, cultural traditions and environmental constraints, the attractiveness of existing "green areas", and the application of land use planning policies at local scale.

The process of urbanization in Cluj-Napoca city has evolved as a cycle of changes during the post-war period from urbanization to suburbanization and, most recently, to re-urbanization. Historically, the growth of city was fundamentally linked to increasing population during the communist and post-communist period. Local urban sprawl is a more recent phenomenon and is no longer tied to population growth as we above mentioned. Rather a variety of other powerful factors drive the development of this modern Romanian city, including individual housing preferences, increased mobility, commercial investment decisions, and the coherence and effectiveness of land use policies at local level.

The compact urban form and high densities mainly reflect the strong centralized planning regimes and substantial reliance on public transport that prevailed during the communist era. Today, Cluj-Napoca city is facing the same threats of rapid urban sprawl because of the land market is liberated, housing preferences evolve, improving economic pressures for low density urban expansion, and less restrictive planning controls prevail.

In last decade, however, urban sprawl has started to develop at unprecedented rates and it is most probable that unless land use planning and zoning restrictions are more rigorously applied (based on the General Urban Plan and Urban Regulations). Thus, during the twenty year period (from 1990 to 2010) the growth of urban areas and associated infrastructure throughout Cluj-Napoca city consumed more than 20 km^2. These changes may seem small but urban sprawl is now concentrated in particular areas which tend to be where the rate of urban growth was already high during the 1980s and 1990s. A major consequence of this trend is that Cluj-Napoca city has become much less compact. The dense enclosed communist quarters of the compact city have been replaced by free standing apartment blocks, semi-detached and detached individual houses (i.e. Colonia Făget).

The new developments predominantly take the form of diffuse sprawl (i.e. Colonia Făget as a new residential area), and most new services, other than commercial, and recreation activities are developed outside the centre of the city. City centre is perceived by many as more polluted, noisy and unsafe than the suburbs and the built-up environment is also considered unattractive because of poor urban planning, with areas lacking green open space and sports facilities.

All new residential areas (known as "new urbanism") and old residential areas ("old urbanism") are very interlinked in the Cluj-Napoca urban area. In addition, we mention the existence of "green urbanism" based on the green discontinued corridors (i.e. Someşul Mic Valley, Nadăş Valley), green urban spaces (i.e. Central Park) and protected areas (i.e. Făget Forest). A territorial melting-pot of buildings density, architectural diversity and mixed land uses are main features of these new residential areas.

Urban development has impacts far beyond the land consumed directly by construction and infrastructure and its immediate surroundings (EEA, 2006). Some of the most direct and visible impacts, evident in local urban sprawl, are apparent in Cluj-Napoca area which is a metropolitan region with rapid economic growth in the last decade. In half of the urban areas studied in the Cluj-Napoca urban area, more than 75% of all residential areas built after the mid-1990s were low densities or natural areas, with less than 50% of the land surface covered by buildings, roads and other structures.

In Cluj Napoca, the residential function of the city, directly related to the enhancement of the industrial and business functions, led to the perpetual development of the settlement situated alongside the riverbank of Someşul Mic River. For a long time the residential function was fulfilled by the present central area, gradually expanding with new building areas. The year 1895 marks the integration of the settlement called Mănăştur into Cluj-Napoca area, followed by a certain development of the other neighbourhoods during the interbelic period: Andrei Mureşanu, Grigorescu, Gruia, Dâmbu Rotund, Iris etc, and after World War II Someşeni village was added. The two settlements which have been engulfed by the city are presently neighbourhoods belonging to Cluj-Napoca and were submitted to some of the most significant transformations.

The most important phase in the development of the city took place between 1960 and 1990, when the major residential neighbourhoods were constructed, at first in Gheorgheni and Grigorescu, followed by Mănăştur and Zorilor, and finally Mărăşti where constructions were finished around 1990. Immediately following the year 1989, the constructions of buildings came to a halt, and gradually recovered over the next few years, at which time worth mentioning is especially the emergence of private houses in different parts of the city (Pop, 2007). After 2000, tens of real-estate projects began to develop, concerning particularly the peripheral areas of Cluj-Napoca. Thus, Cluj Napoca had 14 neighbourhoods: Dâmbul Rotund, Iris, Bulgaria, Mărăşti, Someşeni, Între Lacuri, Gruia, Centru, Gheorgheni, Andrei Mureşanu, Zorilor, Mănăştur, Grigorescu, Plopilor. Afterwards, once the real-estate investment fever started, coupled with the enhancement of the industrial and business segments, led to construction of another few neighbourhoods such as: Bună Ziua, Zorilor Sud (Europa), Becaş (Colonia Becaş), Sopor (Colonia Sopor), Borhanci (Colonia Borhanci) and Colonia Făget, and at the moment the local authorities have approved the beginning of the construction of two new neighbourhoods: Tineretului and Lombului. Based on this data, we can observe the urban development process through out Cluj-Napoca city has increasing from 14 to 22 neighbourhoods.

Between 2000 and 2009, The General Urban Plan (PUG) approved by the Local Council (Decision no. 792/1999) has suffered some modifications due to changes in the Zonal Urban Plans (PUZ) and the Detailed Urban Plans (PUD), which may sometime alter the rules imposed by the PUG. According to data from PUG, the surface of the administrative territory of Cluj-Napoca was 17952.00 ha, out of which 22.67% (4,069.68 ha) is inner urban area and 77.33% (13881.95 ha) is outer urban area. One of the changes brought to PUG of Cluj-Napoca was the introduction of a new terrain in the southern area of the city, therefore doubling the inner urban area. After the approval of PUZ – Făget, the inner urban area of the city expanded with an other 1135.00 ha (out of which 53.2% constitutes non-agricultural fields, among which forests and bushes occupy 89.7% - forest with a double function: protection and recreational). The opportunity of developing PUZ Făget rose in the context of a great necessity to protect the Făget Area from unauthorized buildings with alleged temporary recreational characteristics. Although PUZ has specified the functional areas on which new buildings may be constructed, introducing the Făget Forest area into inner urban area, has amplified the human pressure on the forest area. Thus, more and more wooded areas have been fragmented into patches and later on sold, therefore only augmenting the tendency to construct inside and around the forest area (Strategia Municipiului Cluj-Napoca, 2006). Due to the increasing attention of investors concerning the real-estate development of Făget Forest area, along with the enforcement of the Ministry Decree no. 776/05.09.2007, this area was declared a natural site an was included in Natura 2000 EU-network.

We have to add a special note for the NATURA 2000 SCI site Făgetul Clujului-Valea Morii. This covers a total area of 1639.00 hectares, including approximately 70% of our study area. At this moment the site has no management authority. The area was designated in order to protect a complex ecosystem with important plant and animal species (*Ligularia sibirica,* *Maculinea teleius, Aquila pomarina*) and habitats (code 7210 - Calcareous fens with *Cladium mariscus* and species of the Caricion davallianae, 9170 - Galio-Carpinetum oak-hornbeam forests on more clayey-loamy and intermittently dry soils and code 7230- Alkaline fens of the *Caricion davallianae* with mostly low-growing sedge and rush communities and helophilous mosses - Caricetalia davallianae -).

4. Material and method

Geodeclivity is a morphometric indicator used in slope analysis. For assessment of the interaction between slopes declivity, types of buildings and geomorphological processes was taken into account or not, we have utilized two categories of slopes classifications. Thereby, we have tried to highlights those cases where the valley-slope equilibrium was strongly affected and where the natural and human induced risks reach high values. We have compared the two types of slope declivity classification and then we have verified the acquired values in the field (Figures 2 and 3).

First classification taken into account was that elaborated by the Commission for Slopes Studies of International Geographical Union, classification based on the relationship between slope's angle, particular morphodinamic, and possibilities of agriculture utilization. According to this classification, categories of values are: category I (0^0 - 2^0) – for the horizontal land surfaces or those with a low gradient of slope; particular processes here are those pedogenetics; category II (2.1^0 - 5^0) – low inclined land surfaces affected by gravitational processes, runoff and rill erosion and solifluction; category III (5.1^0 - 15^0) – inclined land surfaces with the presence of slope processes (pluvial and nival ablation), rill and gully erosion and landslides; category IV (15.1^0 - 35^0) – very inclined land surfaces; erosion processes with high magnitude, torrents and landslides; category V (35.1^0 - 55^0) – abrupt slopes dominated by rock fall and scree mobilization; category VI (> 55^0) – very abrupt slopes with intense processes of slopes retreat, rock fall and scree dynamics.

The second classification taken into consideration similar with the first one utilized six categories of declivity, divided on the base of genetic criterion. In accordance with this criterion, the slopes values of 3^0 are considered as superior limits for land areas under the influence of fluvial activity and water accumulation. The values of 3^0 – 6^0 are specific for the contact between river bed areas and slopes or between slopes and interfluves ridges dominated by slight erosion or accumulation of deluvial, coluvial, and proluvial deposits. The category 6^0 – 17^0 is dominated by wash erosion, land collapse processes and runoff. Slope's values of 31^0 – 32^0 represent the limit for not bonded scree mobilization and the gradient of 42 is the limit for bonded scree (Ichim, Bordeianu, 1970).

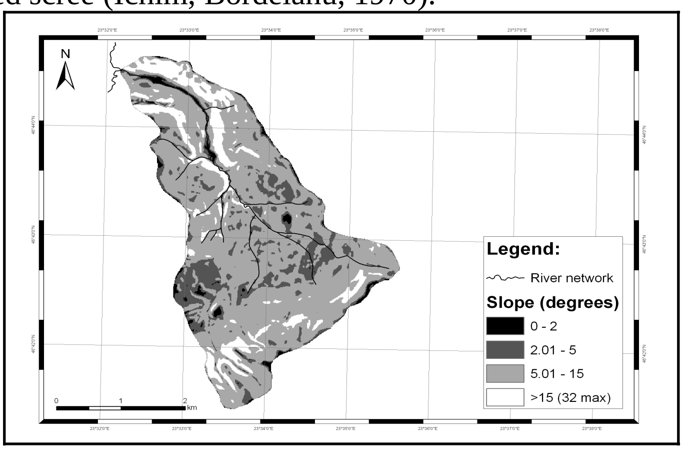

Fig. 2. Declivity map of study area (in accordance with International Geographical Union)

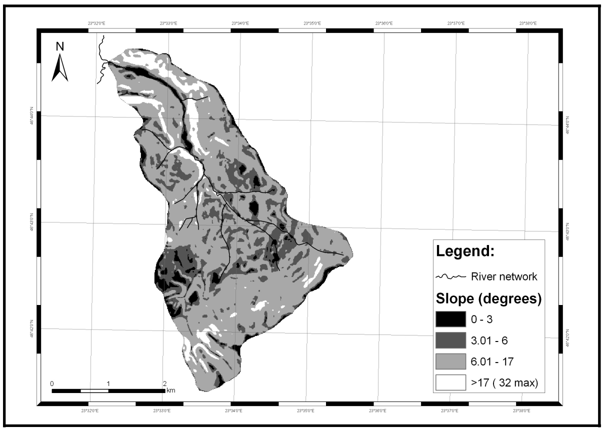

Fig. 3. Declivity map of study area (in accordance with Ichim, Bordeianu, 1970)

It can be noticed a strong resemblance between the two classifications for the intervals having low values of slopes gradient; up to the limit of 35^0, for the first classification and $31^0 – 32^0$ for the second classification, the intervals values are quite the same. Important differences are noticed for the intervals having values more then 35^0. For the present study, both classifications were used concomitant for the slopes with the high gradient values have as the superior limit 32^0. Under this limit the value differences between classifications categories do not exceed $2^0 – 3^0$.

5. Results and discussions

The geomorphological constraints derive from a combination of natural vulnerability of territory (as a result of interaction between geology, geodeclivity), occurrence of a phenomena with a certain magnitude (climatic, hydrologic, geomorphologic) and human pressure induced upon this. All these will lead to a degree of risk higher or lower. Within this context, the vulnerability is materialized through a susceptible geology to landslides and through morphometric characteristics of hydrographic basin.

By analyzing of slopes we can observe that from the total studied area the majority surfaces is included in category III ($5,1^0$ - 15^0, respectively $6,1^0$-17^0) and IV ($15,1^0$ - 35^0, respectively $17,1^0$-32^0). These are, in fact, critical intervals where the most important geomorphologic processes are developing. A study of landslides map shows that landslides are not determined by a specific slope interval, but with only one exception landslides are found on the right slope of the valley.

From the geodeclivity point of view the two slopes of the valley are symmetrical; we can even speak of a mirror image for the slope intervals with the same values. The major differences between the morphodynamic of the two are explained by some elements. The right slope has a south aspect which determines a more accentuated morphodynamic compared with the left one. On the other hand the north aspect of the left slope contributes to the fact that this slope is unattractively from a residential point of view. More, the proximity of the right slope with the build perimeter of the Cluj-Napoca urban area, determined here a high anthropogenic pressure, materialized by deforesting, development of infrastructure and households. As a consequence the left slope it maintains the natural character while the right one is suffering an intense process of human intervention.

The landslide from the upper catchment area is developed on the watershed between Sf. Ioan Valley and Căprioara Valley. It shows multiple morphological, morphometric and position similarities with Sălicea landslide which make as assume that they are of the same age. The values for the slope angles of the landslide are small (3^0 - 6^0) and as consequence the extension of the building are on the body of the landslide has been advantageous. In fact these low slopes are the result of the sliding process when the landslide has reached a new unstable equilibrium. Also, the substratum is made by clays and sands of Sarmațian age which belong to Feleac strata, rocks very susceptible to mass movements.

The evolution of the buildings in the area between 2003 and 2009 is constant. In 2003 there were 165 households and in 2009 the number increased at 261. An important detail is that all these buildings are on the right slope of the valley, phenomenon accelerated by the south aspect of the slope and proximity with Cluj-Napoca urban area.

In the calculation of the medium density of households we took into consideration only the right slope of the valley (512.83 ha), because the left slope has no building at all. The medium value for household density was 0.3 unit/ha in the year 2003 and 0.56 unit/ha in 2009. It is easy to notice an increase in the human impact which has doubled in short time interval. Unfortunately, this phenomenon is not documented by studies to show the impact on the substratum, to show what will be the response on the medium and long term, fact that could lead to disturbances in the valley-slope system (Figures 4 and 5).

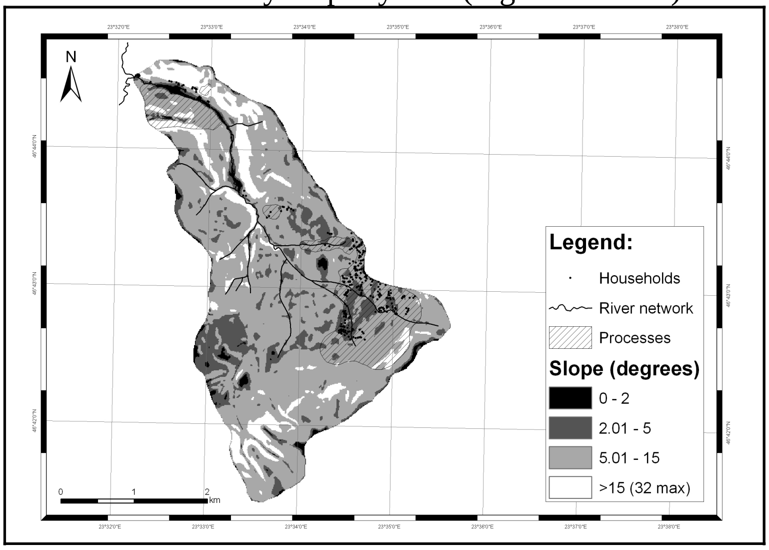

Fig. 4. Geomorphological process, slopes and households map of study area (2009)

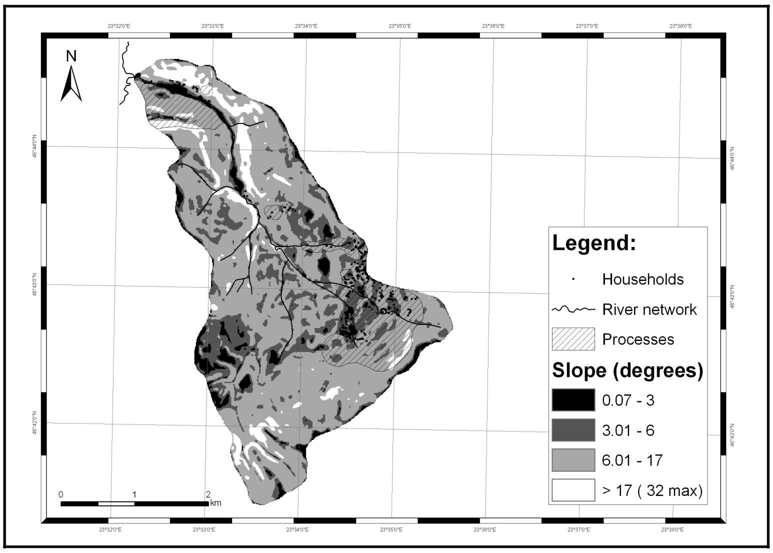

Fig. 5. Geomorphological process, slopes and households map of study area (2009)

The situation might become a lot worse because probably the increase in the number of households will continue (the area has a high recreational and landscape potential), without detailed geotechnical studies on the background, thus adding more mass on the slopes. Another interesting situation is presented by the lower area of the catchment, around Sf. Ioan Hotel. In these case the problem are households constructed or projected at the base of the right slope of the valley. In this sector the values of the slope angles are high (around 30^0) which makes the slope a lot more susceptible to landslides and gushing and torrential processes. The values correspond to a substratum made by sandy and shale rocks of Eocene superior age. In order to be able to build here, in most cases specific works at the base of the slope have been carried out which has lead to disequilibrium in the system.

Regarding the triggering moment for the landslides there are also some differences. The massive landslides, the one in the upper catchment area and the one at the confluence of Sf. Ioan River and Gârbău River, are old probably of the same age with Sălicea landslide. The more reduced landslides, on the left slope of the valley are recent, triggered in the last decades. It is probable that the triggering of these recent landslides was influenced by human intervention, because in the same conditions of slope and geology the left slope is not affected by such movements.

Based on terrain analysis, GIS technique and overlaying maps method a constraints geormorphological map was realized (Figure 6). The constraints geomorphological map can be also a digital mapping tool providing local, reliable and inter-comparable urban planning data with high-resolution maps.

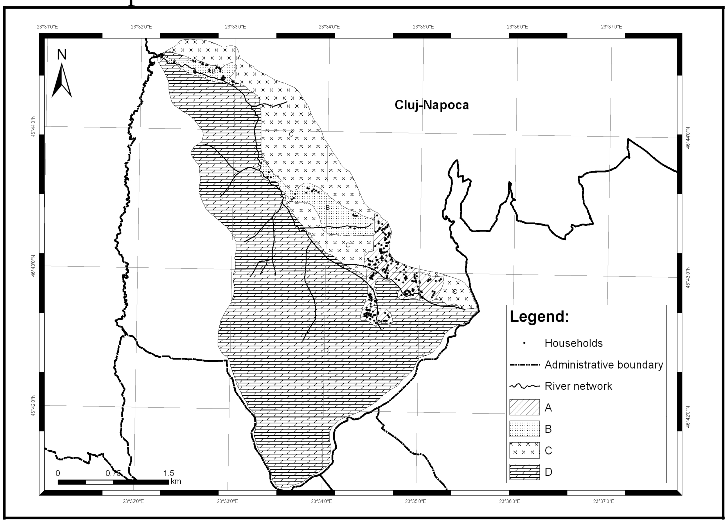

Fig. 6. Geomorphological constraints map of study area (*Note for legend: Area A - severe human-induced geomorphological constraints derived from processes-slopes relation; Area B - moderate geomorphological constraints derived from processes-slopes relation; Area C - low and natural geomorphological constraints derived from from processes-slopes relation; Area D - mixed derived from geomorphological and ecological constraints*)

6. Conclusions

This study will be developed and some problems still remain to be solved in the future. One of the challenges is the validation of the methodology and results in practice by calibrating the environmental model of whole urban area. Some new satellite images must to be used as base for geohazards map of Cluj-Napoca urban area. GIS and geomorphological analysis are very useful for urban mapping and they may help urban planners to monitor and interpret complex urban sprawl. A good understanding of the relationships between the socio-economic trends and environmental constraints that drive urban sprawl is essential to manage the uncontrolled residential areas.

In our case, all new residential areas are exposed to natural and human induced constraints (i.e. differentiated morphology, traffic, pollution, dust, demographic pressure, soil consumption). Within this context, a specific feature is geomorphological constraint that can be a really urban problem for planners, community and real estate investors. We consider that geomorphological constraints are obvious at the micro-scale level (i.e. slope facets, slope units) and they are highlighted by geotechnical problems. These areas with geomorphologic processes have direct impacts on the future territorial development of Cluj-Napoca city.

Finally, we consider that the new residential areas and their hinterlands are becoming increasingly vulnerable to geo-problems controlled or induced by geomorphological processes. The total cost of these problems to local community ranges from major hazards (i.e. floods, land subsidence, landslides, creeping) to minor hazards (i.e. local swelling or shrinking of clays in foundations).

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