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AIRBORNE LIDAR DATA AND GIS TECHNIQUE OUTPUTS OVER ROMANIAN DANUBE PLAIN WITH A SPECIAL ATTENTION ON GEOMORPHOLOGY

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Abstract: Airborne LIDAR technique by its specifications and characteristics in terms of precision of the numerical terrain model and the use of the GIS technique can be used in geomorphology. REELD campaign (elaboration of a precise numerical model of the terrain over the whole Romanian Danube Plain with more than 600,000 ha distributed along 1,000 km and variable widths from 1 to 80 km large were scan from 600 m altitude) represented an opportunity for the analyse of actual geomorphology processes. After a brief introduction about airborne LIDAR technique and a short description of parameters and methodology used in the field campaign, this paper consider the application of the airborne LIDAR technique to the provision of elevation data at accuracies and spatial densities suitable to use with the current generation of high-resolution hydraulic models. Finally, the scientific challenges to describe geomorphologic processes and map the soil loss, due to erosion, using the combination of airborne LIDAR data and GIS technology for a rapid production of cartographic representations of floodplain environments is particularly pointed out.

Keywords: digital surface modelling, Gruia village, gis, gullies, erosion mapping.

1. INTRODUCTION

Recently, an airborne LIDAR system, which integrates a laser scanner, a Global Positioning System (GPS) and an Inertial Measuring Unit (IMU), has become a reliable technique for collecting data of the earth surface (Zhilin Li et al., 2004). Using airborne LIDAR technology, a dense (3-4 points per square meter horizontal) and accurate (5-10 cm vertical) DSM (Digital Surface Model) can be obtained. As Akel et al., (2003) show, the accuracy and resolution of the DTM depend on the flight (speed and altitude) and sensor characteristics (scan angle and emission rate). Airborne LIDAR is a novel technology that successfully assists the traditional field surveying and photogrammetric approaches, but its capability of mapping topography and 2.5 D models of civil objects is uncommon to any other remote sensing technologies, (Akel et al., 2003); Gamba & Houshmand, 2000; Koch & Heipke, 2006; Wehr & Lohr, 1999).

"Ecological and Economical Reconstruction of the Danube Floodplain (R.E.E.L.D.)" is a Romanian Government financed project started in 2006 and aimed to elaborate a new and improved strategy for flood risk management in the Danube Plain (Fig. 1.a.). In the period April-May 2006, Romanian floods set Danube's debit record, 16,000 m^3/s endangering social and economical life in the Danube Plain region. Part of this project, a high resolution DSM was generated with airborne LIDAR and the GIS technique. This approach to generate high resolution DSM's was applied for the first time in Romanian mapping projects. The high resolution DSM of Danube plain serves as a valuable input for geological hazard simulations and flood risk assessment, (Covasnianu et al., 2007).
Beside the above-mentioned application, geomorphological processes (e.g. gullies erosion) can be recognized and characterized using data obtained from airborne LIDAR high resolution data (Digital Surface Model) and the GIS technique.

Gullies erosion are a major cause of sediment movement to water courses and can cause significant environmental problems such as soil fertility loss, sediment and nutrient discharge and deterioration of water quality within a catchment, (Perroy et al., 2010). Also, they are one of the most destructive forms of erosion, undermining infrastructure, damaging agricultural fields, altering transportation corridors, and lowering water tables (Valentin et al., 2005). Worldwide, only few research groups studied the gully erosion by specifically applying LIDAR technology. Using ground-based LIDAR systems, Hancock et al., (2008) examined gully formation on mine spoils, (Collins et al., 2008, 2009, Collins & Kayen, 2006) mapped gully thalwegs and geomorphic changes associated with sensitive archeological sites. Using airborne LIDAR data, James et al., (2007) tried to map gullies and headwater streams under dense forest canopy and Eustace et al., (2009) was using a semi-automated object oriented classification method to detect and map gully extent and volume. By combining ground-based and airborne LIDAR systems to collect data, Perroy et al., (2010) compared gully volume estimates, with the goal of assessing the utility of the two systems for measuring gully volumes at a landscape scale.

In this study, we compared a 2.5-D digital model produced by airborne LIDAR systems with ground-based geomorphic and geodetic survey data (available since 1932) for a particular area over Danube Plain, namely in south-western part of Romania - Mehedinti County, inhabited area from Gruia and Garla Mare villages. Specific geomorphological processes parameters are calculated and interpreted. The derived results are used to draw a soil erosion susceptibility map.

2. METHODOLOGY

The hydrological risk assessment is primarily based on the elaboration of a precise Digital Surface Model (DSM) and on the analysing of terrain configuration, (O'Callaghan & Mark, 1984). An accurate and precise methodology for spatial data acquisition was required (Table 1) for hydraulically simulations and for geomorphological studies.

During the REELD campaign, about 600.000 ha distributed along 1000 km and with variable widths from 1 km to 80 km large were scanned from 600 m altitude using the airborne LIDAR.

The collected data (more than 3-4 points per square meter horizontal with 5-10 cm vertical accuracy) are useful for the DSM output, for hydrologic applications and the potential application of Romanian Danube Flood Plain assessment strategy, (Peckham & Gyozo, 2007). Complementary visible and infrared observations of the scanned area were taken from 5.000 m resulting in a 20 cm horizontal resolution, (Gamba & Houshmand 2000). For precise measurements a real-time update of the local geodetic network using GPS technique (in this case, an on-board GPS) was required.

Table 1. DSM-LIDAR flight parameters of REELD campaign.

DSM – LIDAR flight parameters	Value
Flight altitudes	450 m
Speed flight	45 m/s
Bandwidth	500 m
Lateral coverage bands	20%
Distance between bands	415 m
Laser emission frequency	65 kHz
Scanning angle	60 degree (+/- 10)
Scanning frequency	75 Hz
Total planimetric precision of the measured laser points	20 cm
Medium density of laser points	2 - 4 points/m^2
Medium distance between laser points (flight direction and perpendicular)	0.6 m
Spatial precision (Z value)	5 cm

The inertial measurement unit (IMU) recorded the elevation of the sensor and the aircraft altitude. A second GPS located at a determined ground position, receives data at the same time as the over flight for later differential correction of the on-board GPS data (DGPS). Working in the L-band frequency, the GPS instruments used at the ground level are four GPS surveying Stratus Sokkia which consist of an integrated GPS system combining a 12-channels, L1 at 1575.42 MHz as standard position code (SPS), a GPS receiver and one antenna (operating range is 20 km), 2 GPS Leica L1 (1575,42 MHz), L2 (1227.60 MHz as the precision positioning code - operating range is 40 km wide) and 2 GPS Topcon L1 and L2 (operating range is 40 km wide) (Gamba & Houshmand 2000; Raymond, 1992; Wilson & Gallant, 2000). Reference stations were positioned in geo-rectified points and determined by triangulation method (Sarkozy, 1998; Shekhar & Xiong, 2008), thus allowing aircraft flight instrumentation to permanently be at less than 20 km from a station and at about 30 km from another one. For every flight episode, at least three stations are installed for good management of the network and better precision. GPS data allowed determining the accurate position of airborne LIDAR system in XYZ coordinates (latitude, longitude and elevation) projected in international coordinate system WGS84.

The trajectory calculated based on GPS was combined with inertial measurement unit (IMU) in order to improve the density of the aircraft's positions and to calculate space orientation of LIDAR system. Consequently, a trajectory with 200 positions and orientations per second (200 Hz) equivalent to spatial resolution of 23 cm was obtained. The redundancy of the GPS receivers and calculating procedure allowed control over the trajectory precision. Several parameters have to be precisely known to determine the geographical position of each backscattering laser pulse but also the distance to LIDAR system, namely: position of the sensor, angle of laser pulse, atmospheric effects on speed of light.

In the REELD campaign, the flight was maintained at a height of about 600 m (using IMU), which allowed a relative altimetry precision of 5 cm and an angle of measurement varying between 60 and 70 degrees. The total scanning area and the spacing between measurement points depends on the scan angle of the laser ranging system and the airplane flight altitude.

The overlapping coverage varies from 10 % up to 50 %. These measurement parameters enabled a density of points from 2 to 4 points per square meter. The lateral coverage of 20 % lowered the risk of gaps between bands while the raw density of laser points of 4-5 points per square meter allowed with no ambiguity the identification and a good representation of civil buildings, dams and channels.

In order to process and interpret the data recorded a series of steps where needed: starting with the acquisition of topographical data, next the transformation of the raw data into xyz files (ASCII files containing values of latitude, longitude and elevation) in WGS 84 coordinate system and finally resulting a 3D point cloud for the generation of a Digital Surface Model. Furthermore by filtering the data in the GIS technique, a Digital Elevation Model was created.

During the campaign, a daily validation of data (graphic-trajectory at ground level validation) was performed. If scanning error occurred, the flights were re-scheduled or the LIDAR system was inspected or maintained. Based on 3D view representation processed from a high-resolution numerical terrain model high GIS platform hydrological forecasts can be emitted. Due to technical characteristics required by hydraulically model of DELFT Hydraulics software (courtesy of Delft Software Sales, The Netherlands) a series of parameters needed to be fulfilled: tri-dimensional digital surface model for the whole flow of Danube needed to be 1075 km long; the bands width should vary from 1 km to a maximum of 80 km; the area is full of channels and dams, in this matter bands for every 50 meters where needed with points at every inflexion of the terrain – at a dam with road territory at about 20 meters high – at least 9 points (2 points for base of slope, 4 points for dam berm and 3 points per dam). This implies that for a cross section of a dam were needed 4 points per square meter; the Z precision (elevation) must be maxim of 5 cm. The LIDAR data set allows planners and hydrologists to predict flood extends and plan remedial strategies. Therefore, this rapid technique is highly valued in the hydrological management of the Danube River. The precise digital terrain model can be considered the fundamental base for flood risk management. With an accurate numerical model of the terrain and by correlating with series of hydrological data (daily values of levels and flows) collected from hydrometrical stations, flood scenarios in specific areas can be predicted. To characterize the accuracy of the LIDAR outputs in GIS, some comparison were performed.

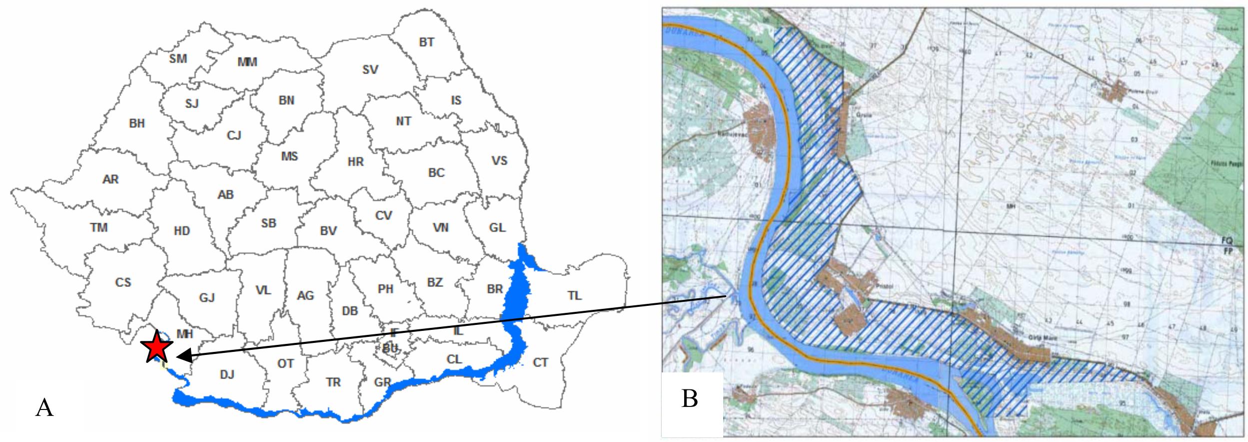
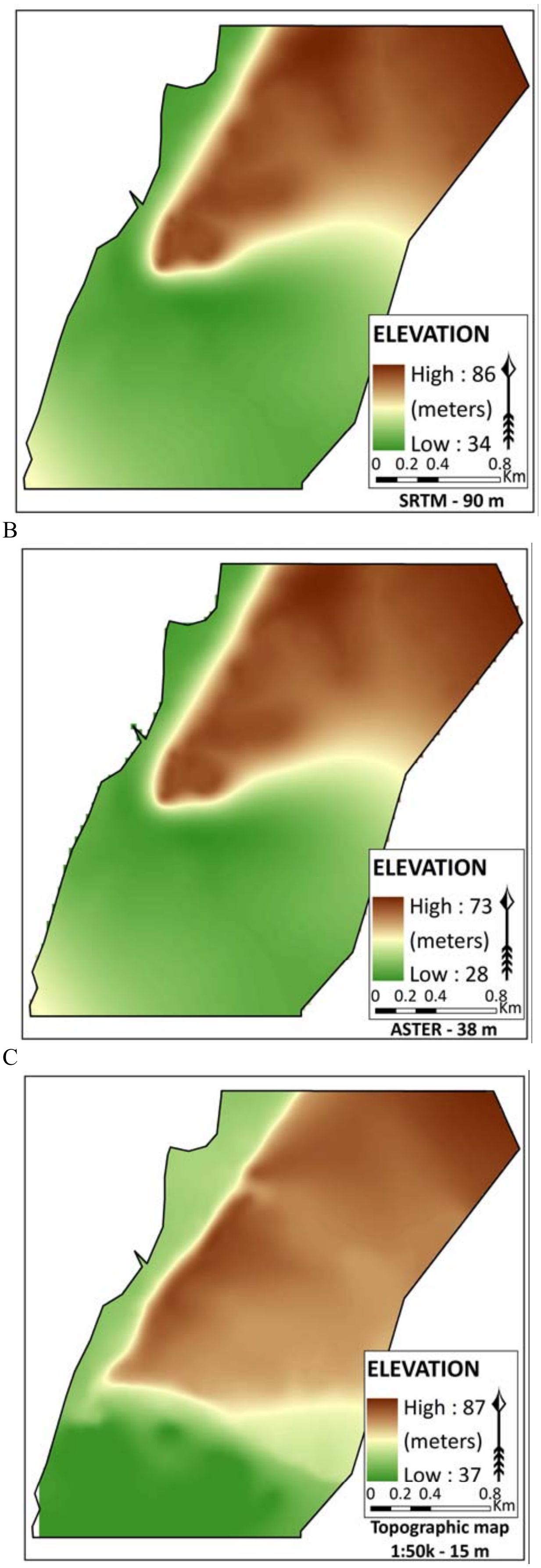


Figure 1. (a) Area of interest over Danube Plain-Romanian sector; (b) Location of the Gruia-Garla Mare Area.

A

B

C



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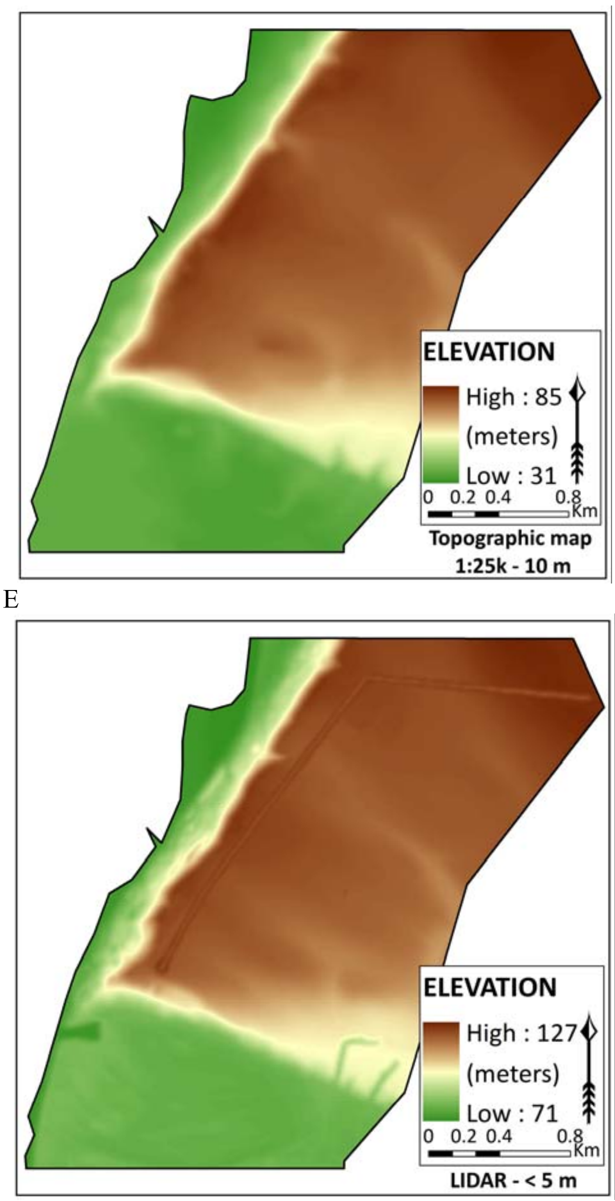

Figure 2. Comparison between different types of Digital Surface Models – Gruia Area.

Using additional processes in GIS technique (an interpolation method based on ANUDEM algorithm developed by CRES - Centre for Resource and Environmental Studies of National University from Australia), the Digital Surface Model was elaborated. The ANUDEM algorithm, implemented in GIS software, is based on Hutchinson algorithm and has been included in Topo2Raster tool from ESRI ArcView (Hutchinson 1993). This method is an optimized interpolation for local surface calculations having as an advantage non-continuity loss as provided by the global methods. It is designed for numerical models of the latitude for hydrological modelling. Some particular processes were customized, such as drainage enforcement (removal of false sink points), cell size and color ramp (Goodchild & Mark, 1987).

Depicted in figure 2, the accuracy of the terrain varies from a very loose representation (due to the resolution of SRTM with a 90 m precision and ASTER mission with less than 38 m precision) to a relatively precise reproduction of terrain's characteristics seen in digital terrain model from topographical maps at 1:50.000 and 1:25.000 scales. Although LIDAR data represents Digital Surface Model (including also Digital Terrain Model with natural and artificial elements above the terrain) the precision of the representation permits to observe the river courses and the dam.

3. RESULTS AND DISCUSSIONS

Using the LIDAR data processing procedure detailed above, a series of cartographic representation were developed. Although the primary goal of the Danube plain mapping with high-resolution LIDAR was to support the flood risk management, this paper will use some of the data collected to perform gullies erosion analysis. The results will particularly point out the landforms dynamics from a historical perspective with a detail upon the airborne campaign from 2007. The area under discussion (Fig. 1.b.) is located in South-West of Romania, in the Mehedinti County.

The collection of data from the airborne campaign between the cities of Drobeta Turnu Severin and Calafat was elaborated in September-October 2007. The case study is focused on 2 villages, namely Gruia and Gârla Mare, located 52 kilometers south from Drobeta Turnu Severin and 63 kilometers north from Calafat city. The general research area covers a total surface of more than 2.874 hectares. They were primarily chosen because their area is known to be affected by important actual geomorphological processes. The Digital Surface Model features 1.152.875 points, yielding a density of 401 points/ha. Using interpolation methods and the GIS technique, Danube Plain map was represented.

In figure 3, the Digital Surface Model depicts the bank river by the lower values area (green colour starting with altitude of 69 m) and the superior terrace of the Danube plain by the higher ones (maximum of 152 m).

Additionally, valuable geomorphological parameters were represented. For instance, analyzing the slope map (Fig. 4), the highest slope areas (close to Gruia and Gârla Mare villages) of the Danube Plain are easily observable. Some areas indicate slopes with value higher than 20 degrees. Although these values of declivity represent only 7.39 % of the total area, it represents a good start to analyze further the actual geomorphological processes.

Further on, analysing the fragmentation depth parameter (Fig. 5), in the interest area, the maximum difference of elevation is more than 20 meters.

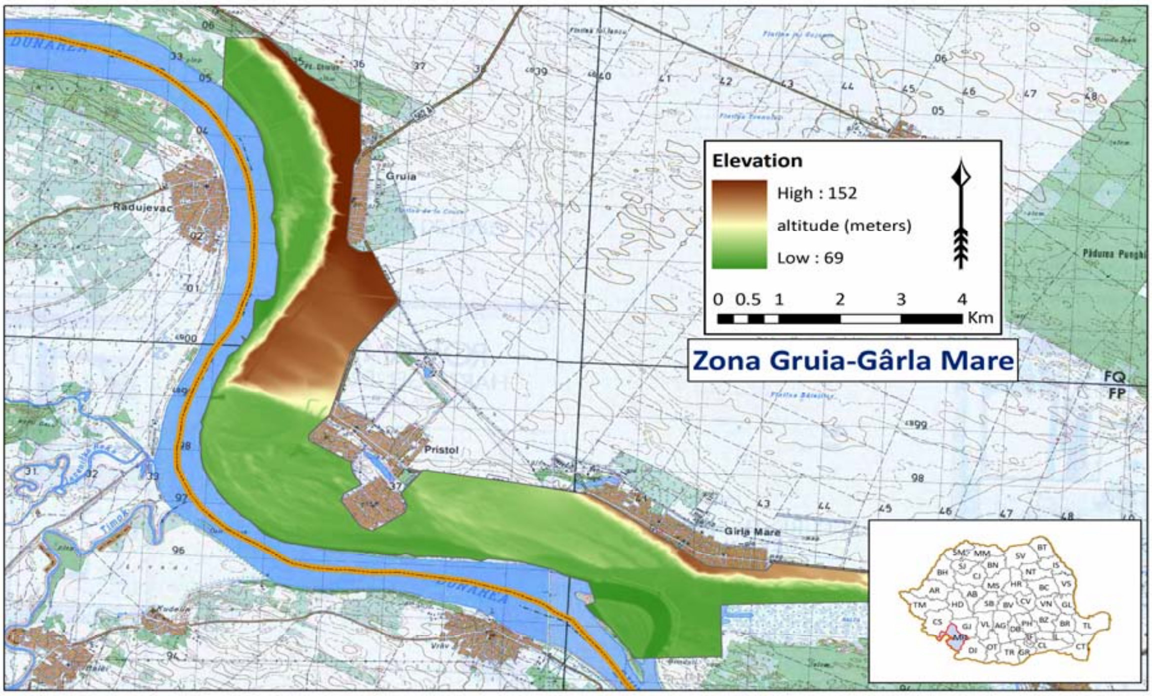

Figure 3. Digital Surface Model over Danube River (Mehedinti sector).

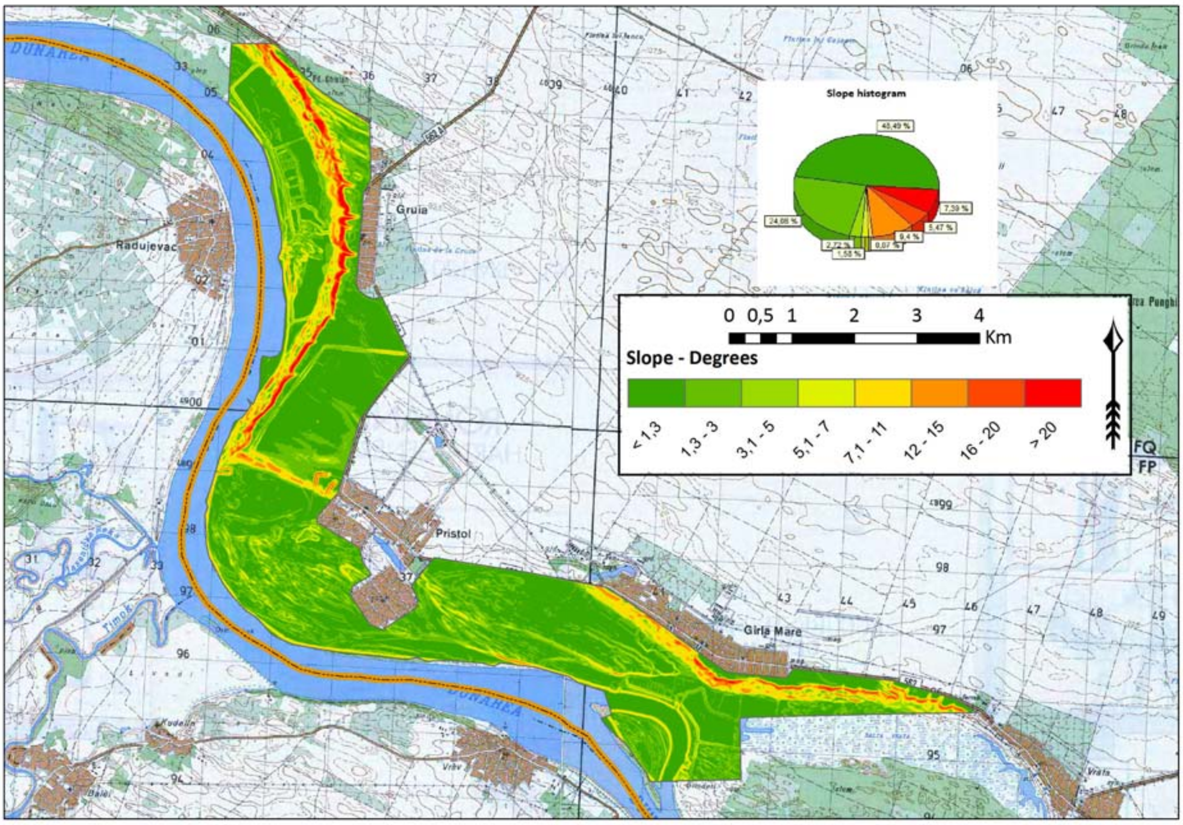

Figure 4. Slope map over Gruia and Garla Mare villages.

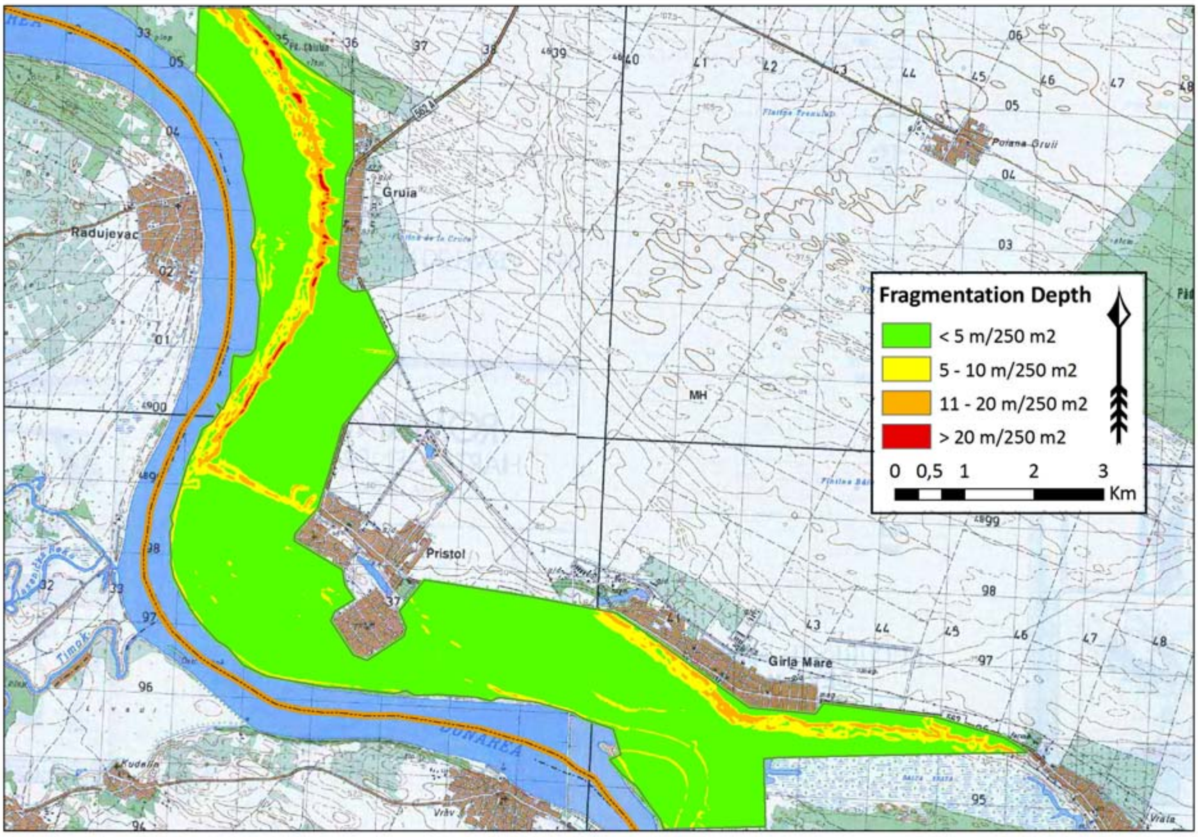

Figure 5. Fragmentation depth over Gruia and Garla Mare villages.

In order to emphasise the current analyse, the geology was taken into account. The geological deposits are from Pleistocene and Holocene Period and contain wind deposits, sands, gravel and also loess deposits.

In addition, the LIDAR technique permits to analyse the evolution and the dynamic of landforms. In order to analyse the impact of gullies near the human settlements, the research focused on the landforms dynamics around the Gruia village. The reason for which this geomorphology process was selected is related to its dynamics and negative effect on agriculture, housing and infrastructure. The research area covers more than 669.6 hectares and is focused on the phenomena of terrain dynamics.

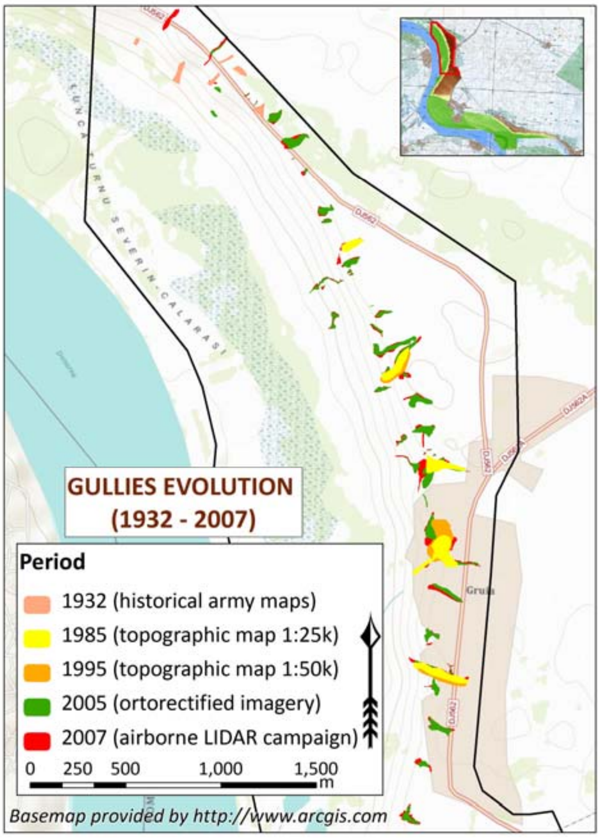

Figure 6. Gullies evolution over Gruia village.

As depicted in figure 6, the gullies are located on an exposed side (the left shore of Danube River, the first terrace of the river) affecting the inhabited area of Gruia village. The diachronic analysis covers a period of 75 years, starting with 1932, when some particular areas with gullies are located in the northern part of the village. In the following years, the gullies expanded and reached the village of Gruia, threatening the houses and local infrastructure. The landscape changed over the years, at a higher rate in the later period as indicated by the consequences of Law no. 18/1991 (also known as the *Law of Land Fund*). Slope processes evolved rapidly from 1985 to 2007 in terms of surface and depth. The most dynamic area is in the vicinity of the Gruia village, in the north, centre and south part of the inhabited places, where the gullies expanded in principal due to anthropogenic effects and secondary the landform and geology.

Analysing figure 7, it can be observed that the total area covered by gullies increased slowly from a small value of 1.08 hectares recorded in 1932 to a 6.9 hectares in 1985. This increase can be misleading, due to the fact that in 1932 the geomorphology processes weren't recorded properly. Nonetheless, this value permits us to estimate that this soil loss process was present in that period of time. Gully erosion evolved to 7.03 hectares in 1995, reached a total surface of 8.34 hectares in the period of 2003-2005. From that last recorded time till airborne LIDAR campaign the gullies expanded to near doubled value of 14.38 hectares in 2007.

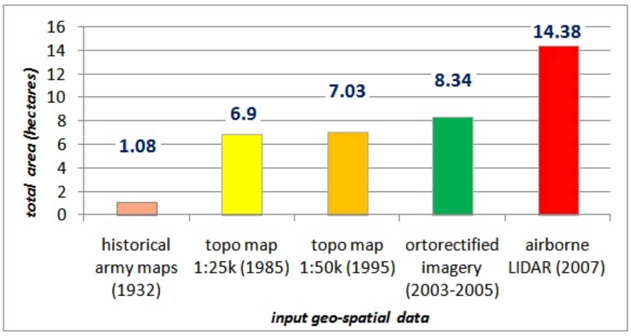

Figure 7. Surface evolution of the gullies since 1932 to 2007

This densely area with gullies near Gruia village that highly increased (in term of surfaces affected by depth erosion) is a consequence of complex factors. In the '90, after the change of the political regime, the government left loose (by lack of interest) and didn't finance properly the state policy of ensuring the protection of land against landslides and gully erosion. Moreover, boosted by the Land Reform (Law no. 18/1991), which returned the property of the lands to the former owners (especially to the peasants), those terrains were "free" of measures to prevent land degradation and soil loss, which could slow actual geomorphology processes. Additionally, the Law of Land Fund fragmented the parcels in order to put in possession of land. Allotment was made against measures of land degradation, by a "hill to valley" direction.

The high resolution LIDAR technique determined the deepness of gullies. Over a length of 2.2 kilometres (a cross-section for a general North-South direction) the depth varies from 9 meters to the highest value of 18 meters (Fig. 8).

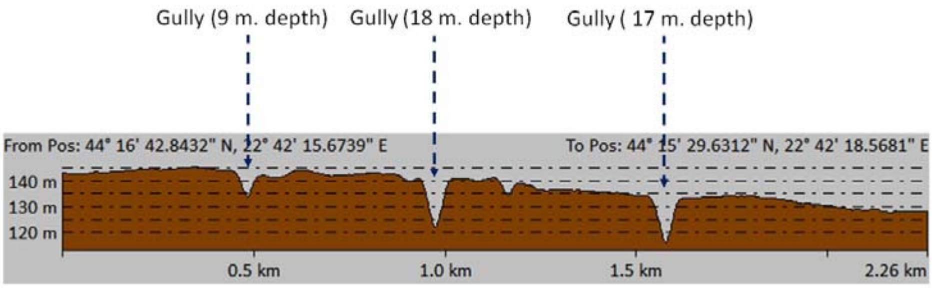

Figure 8. Cross-section over Digital Terrain Model (North to south direction).

These actual geomorphology processes mixed with landslides threaten the inhabited area of Gruia village (Fig. 9), affecting the houses, local agriculture and changing the path of a local road.

In order to express the impact in the near future of the erosion processes, a detailed analysis was implemented.

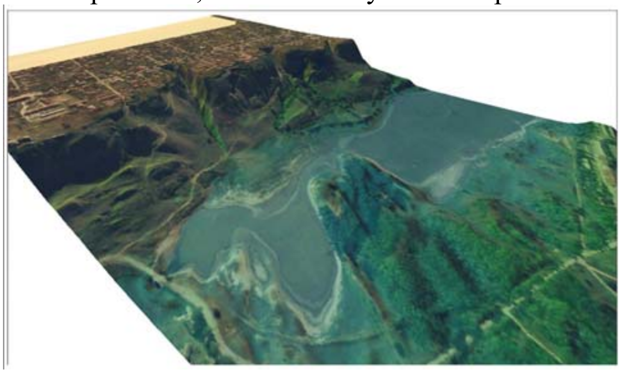
Figure 9. Landslides near inhabited area.

The current analyse was based on *Revised Universal Soil Loss Equation* (Patriche et al., 2006, Wischmeier, Smith, 1978).

This algorithm estimates the quantity of soil loss by 5 factors, according to the formula:

A = R * K * L * S * C (Fig. 10), where:

A is the average soil loss factor, **R** is the rainfall intensity factor, **K** is the soil erosion factor, **L** is the slope length factor, **S** is the steepness factor, **C** is the surface cover. These parameters were adapted to the specifications of the area.

As seen in figure 10, the detailed schematics, the indices used are:

- value of *R factor* was obtained from zoning map of rainfall erosivity for Romania (Moțoc et al., 1975);

- *K factor* was derived from soil map (use of soil and texture type) and reclassified according to ICPA [ICPA, 1975];

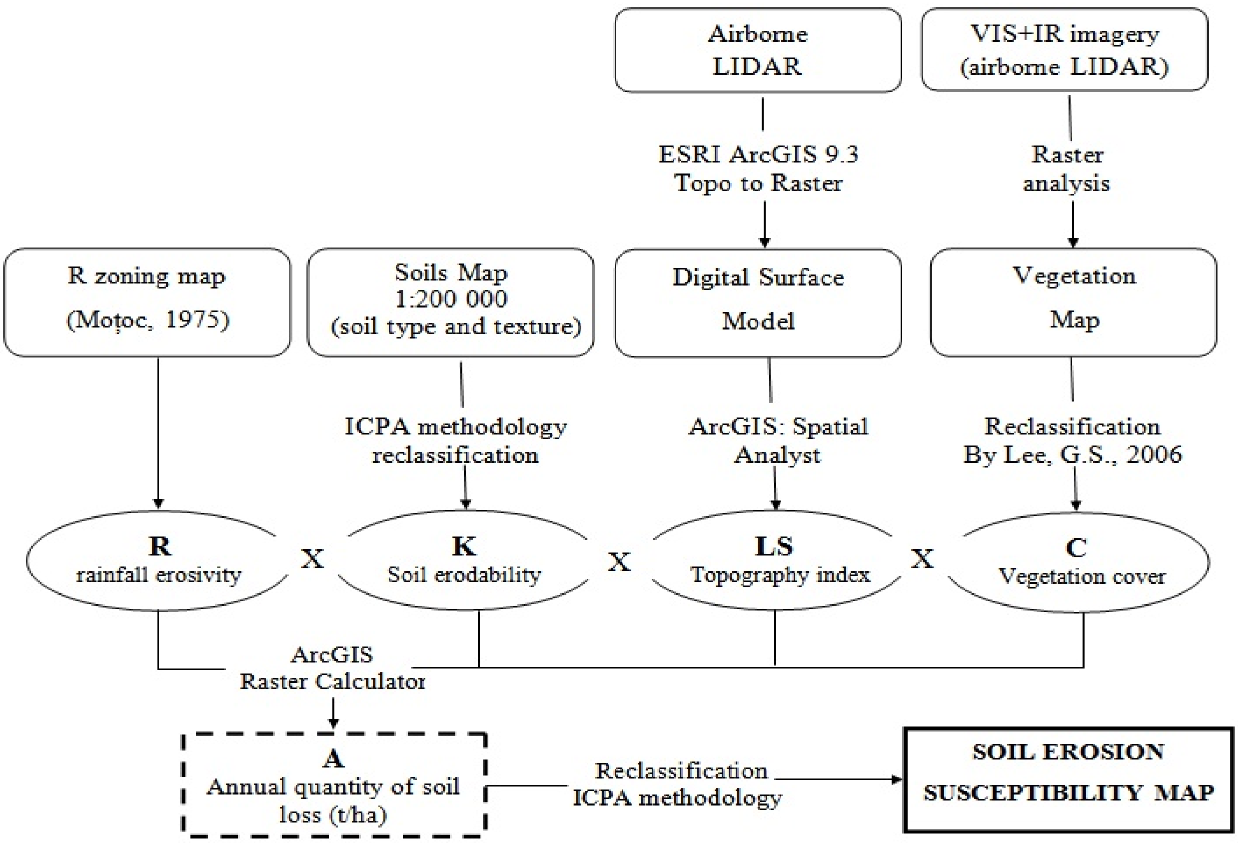

Figure 10. Schematics of applying RUSLE algorithm. *(Adaptation by Lee, G. S. & Lee, K. H., 2006)*

- *L* and *S factors* were determined from Digital Surface Model Airborne LIDAR, by the help of Spatial Analyst with calculation upon flow accumulation;

- *C factor,* based on raster interpretation of visible and infrared imagery from airborne LIDAR campaign within a reclassification according to Lee, G.S. & Lee, K.H., 2006.

By multiplying the parameters and use of the Raster Calculator within ESRI ArcGIS, the quantity of soil loss, in tons per year, was computed. Finally, ICPA converted the values and estimated the soil loss from a scale starting with no soil loss to very high areas with soil loss.

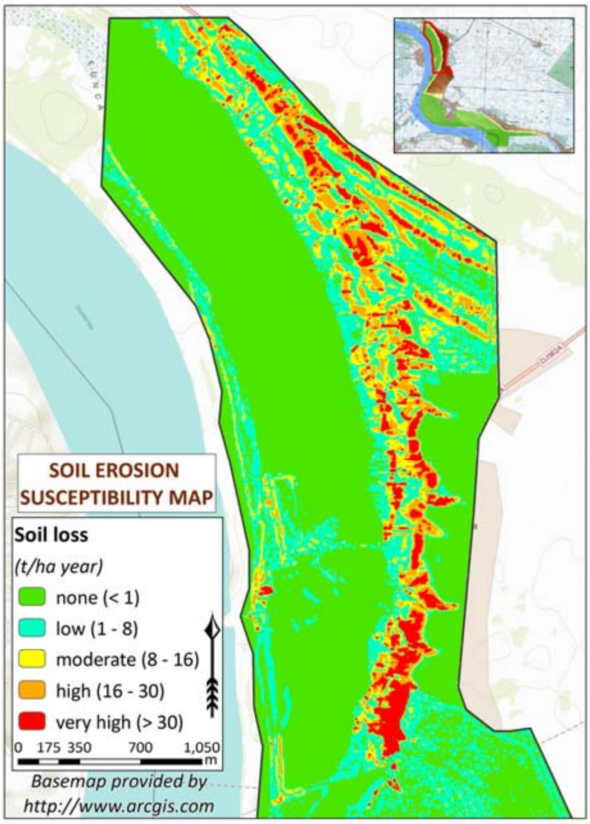

Figure 11. Soil erosion susceptibility map.

According to figure 11, there are areas with no soil loss, especially where are present water surfaces (western part of the area) and inter-flows (eastern part of Gruia village). Some important areas with high and very high values of soil loss (in excess of 16 tons/ha year) are identified at locations where the slopes are higher, the terrain is steeper and the actual geomorphology processes (gullies, landforms) are present. Even more important, the model applied to this specific region from the Danube Plains indicates that the soil erosion threatens in the near future the inhabited area and the local infrastructure.

The cartographic representation is very useful for the future development of the housing, practice of the agriculture and developing the public utilities in terms of sustainable development and urban planning.

4. CONCLUSIONS

As a consequence of hydro-morphological dynamics of the Danube's channel, using data resulted from airborne LIDAR technique; the resulted Digital Surface Model is a basis of modelling and hydrological simulation. DSM allows a dual functionality: first it collects information regarding the terrain features showing the particular characteristics and second observes the changes resulted from natural and artificial processes and phenomena.

Additionally, along with the main destination of the campaign (flood risk management), this contribution is focused on a particular research direction upon expressing the landforms dynamics. By demonstrating the importance of the accuracy of the Digital Surface Model in terms of resolution, the results permitted to emphasize the nature of the gullies and they are consequences. More than that, by the use of the precise resolution of the numerical terrain model, the gullies effects in time can be studied.

In conclusion, the results of the campaign should "pull an alarm signal" for the authorities in order to reestablish the natural areas where the river should flood and to be aware of the landforms dynamics, due to the fact that the inhabited area is close to the landslides and gullies.

Moreover, considering that the main activities of the rural population from Gruia village are livestock and agriculture, the soil loss mapping due to erosion (gullies and landslides) should determine the local administration and community to combat the negative effects of these geomorphological processes presented in the analysed area.

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