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The erosion of glaciated mountains: evidence from hypsoclinometry

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ABSTRACT

Mountain glaciation involves the erosion of cirques and troughs, which increase steep slopes but also produce gentle slopes in cirque floors and trough floors. This is expected to increase the variability of slope gradients at related altitudes. Taking a whole mountain range, its distributions of altitude and slope can be analysed to establish a signal of glacial modification. Frequency distributions of altitude (hypsometry) and gradient (clinometry) alone do not seem adequate. Taking these two variables together – hypsoclinometry, plotting slope gradient against altitude – is more promising. Frequency distributions of slope gradient at different altitudes are exemplified here for mountain ranges in British Columbia and Romania, together with altitudinal variations of steep or gentle slopes.

Cirque headwalls give the clearest morphometric signature of glaciation. Steep (especially the steepest) slopes are concentrated at cirque altitudes, increasing mean, median, standard deviation (SD) and inter-quartile range (IQR) of gradients, especially above cirque floors. There is only a small increase in SD and IQR at cirque floor altitudes. Hypsometric maxima and increased proportions of gentle slopes at cirque floor altitudes are clear only in mountain ranges densely occupied by cirques. This relates to the small proportion of each cirque (about 28%) occupied by the floor. Concentrations of steep slope aspects in directions favoured by local glaciers provide further evidence of glacial modification. The most general morphometric effect of glaciation, however, is the increase in steep slopes at cirque headwall altitudes. Thus it is possible to rank mountain ranges by degree of glacial modification.

KEYWORDS

hypsometry; clinometry; British Columbia; TanDEM-X; glacial erosion; cirque

1. Introduction

There are many differences between glaciated and unglaciated mountains, but how are these differ-

ences best expressed quantitatively? One way is to define and measure the specific landforms – cirques, arêtes, troughs and closed rock depressions – that

characterize glacial erosion (Barr and Spagnolo, 2015). Their sizes and densities show the degree of glacial modification of mountain landforms. The definition of specific landforms is progressing (in efficiency and objectivity) but remains subjective (Evans and Cox, 2017). For example, in some areas it is difficult to distinguish shallow glacial cirques from deep-seated rock slope failure scars, whose deposits may have been removed by glaciation. Glacial troughs are more difficult to define: an inverted parabola (U-) shape is characteristic but alluvial valley-floors obscure the distinction from fluvial valleys and make fitting a model to the bedrock surface problematic.

Analysis of the land surface (Minár and Evans, 2016) can employ either specific or general geomorphometry, or both. Thus in seeking greater objectivity it may be interesting to check for signals of glaciation in general geomorphometry, e.g. to take a whole mountain range and measure its distributions of altitude, slope gradient, slope aspect and curvatures. To start, frequency distributions of altitude (hypsometry) and slope gradient (clinometry) have been considered. It is widely believed that that cirque erosion around glacial Equilibrium Line Altitudes (ELAs) has produced hypsometric maxima (high frequencies of altitude) (Mitchell and Montgomery, 2006; Egholm et al., 2009). This is one of the bases of the 'glacial buzz-saw' hypothesis that effective glacial erosion at such altitudes in the Late Cenozoic has worked to limit mountain altitudes (Mîndrescu and Evans, 2014). The strength of the hypsometric maximum should thus express at least one component of the glacial modification of mountains.

Hypsometric maxima, however, are somewhat fallible evidence as they may be produced in various ways (Evans et al., 2015; Robl et al., 2015, 2015a; Crest et al., 2017). It seems better to consider altitude and gradient together, rather than separately. Further evidence has thus been sought in the variation of mean or median slope gradient (slope angle) with altitude (elevation). Equilibrium models of fluvial topography predict steady increases in both channel gradient and hillslope gradient with altitude. In glaciated mountains, however, a flattening of this trend has been found at cirque floor altitudes

(at least in the Alps: Kühni and Pfiffner, 2001; Robl et al., 2015a). Yet as glaciation produces gentle and reversed slopes (cirque floors and trough floors) as well as extra steep slopes (cirque headwalls and trough sides), plotting mean or median slope against altitude is not sufficient. It is necessary to plot frequency distributions of slope gradient at different altitudes. This combination of hypsometry and clinometry is logically labelled *hypsoclinometry*, and is more promising than the separate components, as the excellent work of Robl et al. (2015a) on the Alps has shown.

This leads me to a number of specific hypotheses:

1. There are more gradients $<20^\circ$ at cirque floor altitudes;
2. There are more gradients $>35^\circ$ above cirque floors (i.e. cirque headwalls);
3. Higher standard deviations (SDs) and interquartile ranges (IQRs) of gradients occur at cirque floor altitudes (because the altitude ranges of headwalls and floors overlap: headwalls are found immediately above the lowest cirque floors).

These hypotheses are tested here for two mountain ranges in British Columbia and compared with previous results from Romania.

2. Data and Methods

An increasing number of fairly accurate Digital Elevation Models (DEMs) are now available with near-worldwide coverage. For geomorphological interpretations, forest and human constructions can cause problems, but these are almost absent in mountains above timberline. In glaciated mountains, the main problems come from shadow (both solar shadow and radar shadow), glaciers and lakes.

The hypsoclinometry of 21 mountain ranges in Romania was analysed by Niculiță and Evans (2018) from freely available SRTM data, gridded with 30 m horizontal resolution and analysed in ArcGIS.

Here I focus on data for British Columbia, extracted from TanDEM-X 1-degree tiles supplied by DLR (project DEM-METH 1517). These provide higher resolution (30 arc-second), and were gridded (by D. Milledge) at 12.5 m grid mesh. Mountain range outlines were digitised, initially for the Shulaps and Bendor Ranges on the interior side of the southern Coast Mountains, some 175 km north of

Vancouver. The data were extracted for whole mountain ranges down to the valleys and lakes on either side, and to passes separating them from other high ground. Note that below the 'defining pass' – the highest point on the range boundary – results for slope aspect become increasingly biased as contours are not closed on that side of the range. Above that pass, as each higher contour encompasses a smaller area, there is an expectation (but not an inevitability) that each contour may be shorter and that the area in each successive band (bin, class) of altitude will be less.

As the data are radar-based, return scatter over water produces false values, with differences of tens of metres between adjacent points which should be on the same level. Thus lakes had to be masked out,

using available masks for large lakes but digitising other lake outlines. Lake areas were then treated as 'missing data'. (Alternatively, with more work, each lake could be given its true altitude so that it shows up as zero gradients at the appropriate altitude). The altitude data were read into Stata as (x,y,z) trios and slope gradients and aspects were calculated with a program by N.J. Cox, based on the formulae in Evans (1979).

Available (map-based) data for each cirque floor in these ranges include lowest, modal and maximum altitudes. To exclude extreme values, the lowest 5% and highest 5% are ignored, and the 05 and 95 percentiles of Lowest altitude plus the 95 percentile of Maximum floor altitude are used to

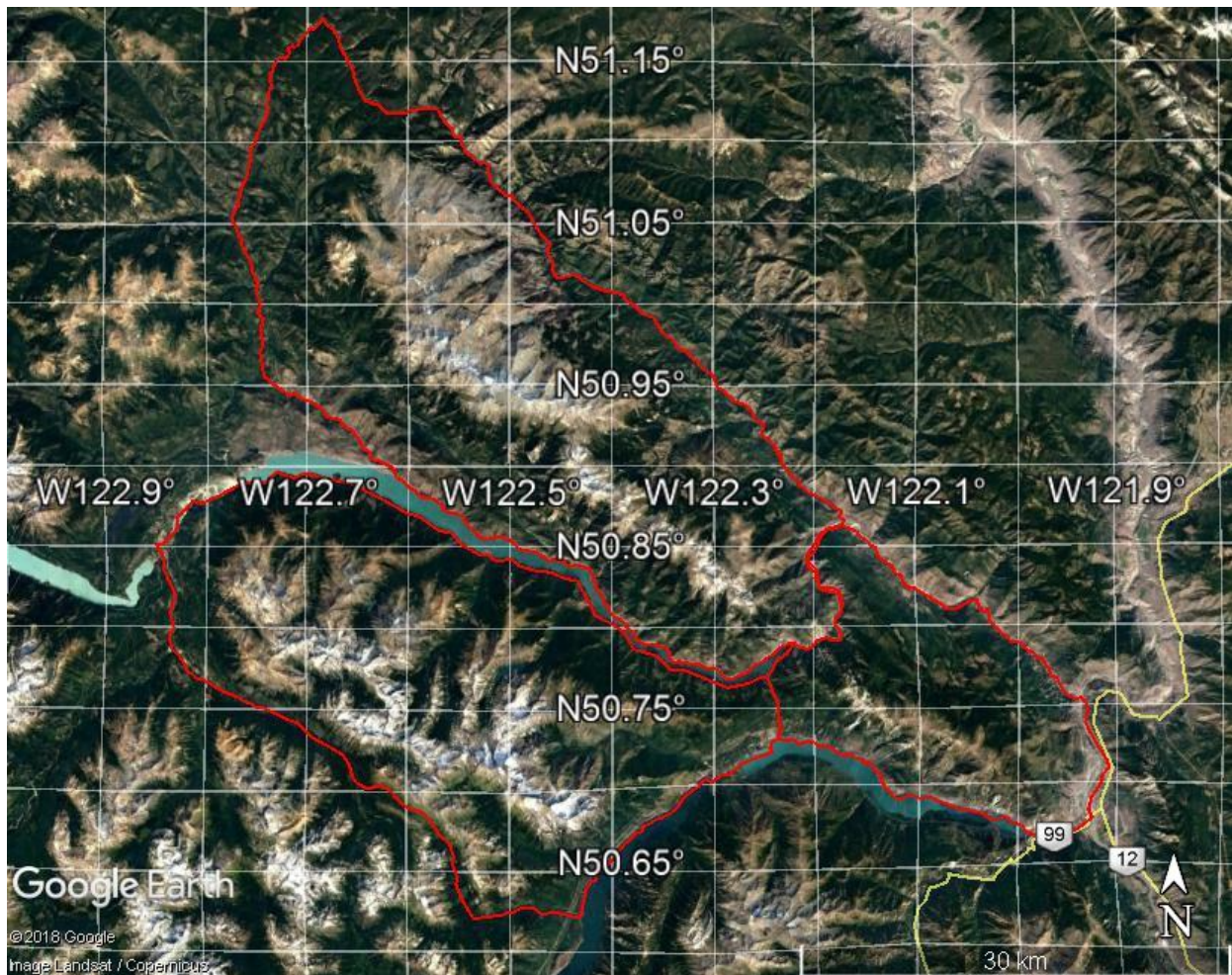


Figure 1 The Bridge River District, British Columbia. Longitude grid lines are spaced 0.1°; latitude, 0.05°. Red outlines show the Shulaps Range (top), the Bendor Range (left) and the Mission Range (right). The long central lake is Carpenter Lake (a reservoir): the north-south valley on the right is of the Fraser River

represent the altitudinal range of cirque floors. By relating results for hypsoclinometry to these previous results for cirques, available on a comparable basis for British Columbia and Romania, it becomes clear that specific geomorphometry and general geomorphometry can be complementary.

3. Results

The Bendor and Shulaps Ranges (Fig. 1) in the Bridge River District of British Columbia are on the landward side of the southern Coast Mountains, which has a much less humid climate than the seaward side. At the last glacial maximum they were submerged in the Cordilleran Ice Sheet, which flowed southward and south-westward from the Interior (Fraser) Plateau to the coast, through several passes (Evans, 1990). The Ice Sheet produced little modification of the higher ground, where it was thinner and possibly cold-based. Instead, both Ranges preserve landforms of local glaciation (cirques and troughs) which developed during the build-up of ice and in numerous previous phases of glaciation intermediate between maximum and present-day. These were mainly valley glaciers, whereas

those present today are cirque glaciers no longer than 2 km (Bendor) or 1 km (Shulaps).

3.1 Shulaps

The Shulaps Range has cirques and small glaciers mainly on its north or northeast side. Cirque lowest altitudes range from 1957 to 2456 m (05% to 95%) and the 95 percentile of Maximum floor altitude is 2610 m. Figure 2 shows the altitudinal distribution of steep and gentle slope gradients. The results for low gradients are disappointing in that there is no maximum at cirque floor altitudes. This is partly because cirque floors are on average only c. 28% of cirque areas (in Romania: Mîndrescu and Evans, 2014, 2017), and partly because there is an extensive area of low-gradient bench or piedmont just below cirque altitudes, on the northeast (Yalakom) slope. Hence there is also no clear increase in SD or in IQR (Fig. 2).

Headwalls, however, give a clear 'glacial' signal – mainly above 2456 m. At 1530–1957 m, below cirque floors, only 1.5% of gradients are $>45^\circ$: at 1957–2456 m the percentage rises to 2.5, at 2456–

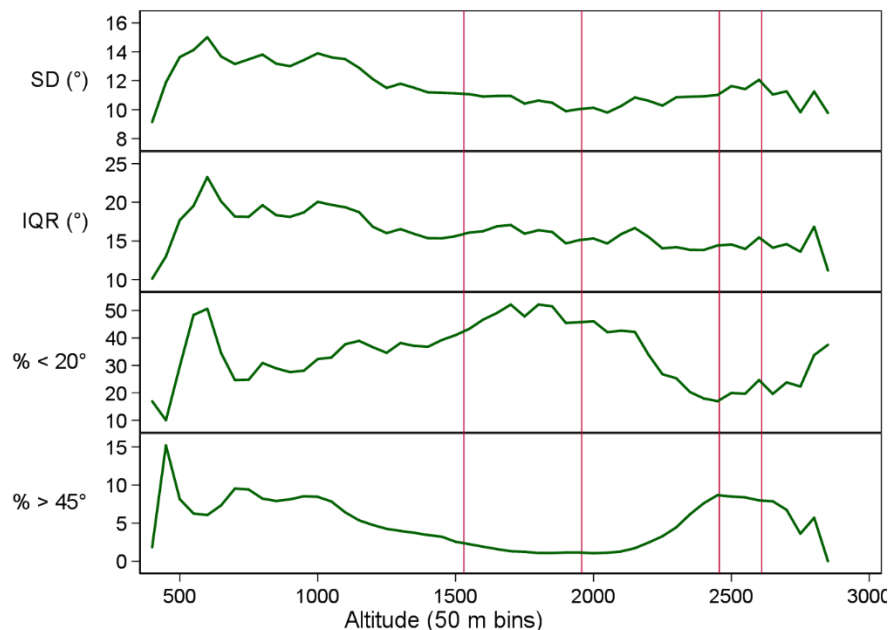


Figure 2 Shulaps Range gradient statistics by altitude: dispersion measured by Standard Deviation (SD) and Inter-quartile Range (IQR), and percentages (in each 50 m altitude bin) of gentle and steep slopes. The left red line is the defining pass; the two central lines at 1957 and 2456 m are the 05 and 95 percentiles of cirque floor *Lowest altitude*, and the right line at 2610 m is the 95 percentile of *Maximum floor altitude* per cirque

2610 m it is 8.5 and above 2610 m it is 7.5 (Fig. 2). This is a clear representation of steep cirque headwalls. Figure 3 shows the density (frequency in relation to total) of slope gradients $>45^\circ$: the strong secondary mode above 2100 m altitude shows cirque headwalls even more clearly.

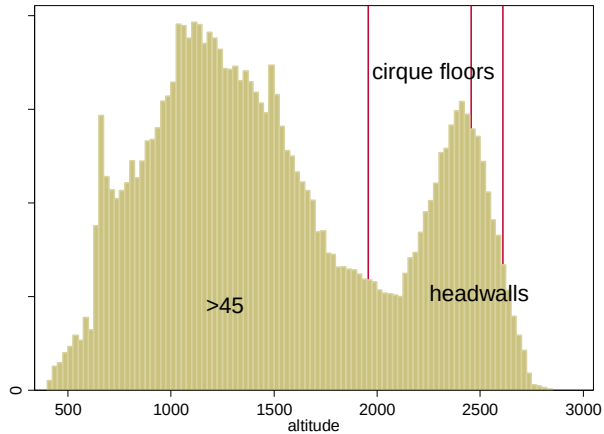


Figure 3 Density of steep gradients ($>45^\circ$) in the Shulaps Range by altitude (50 m bins)

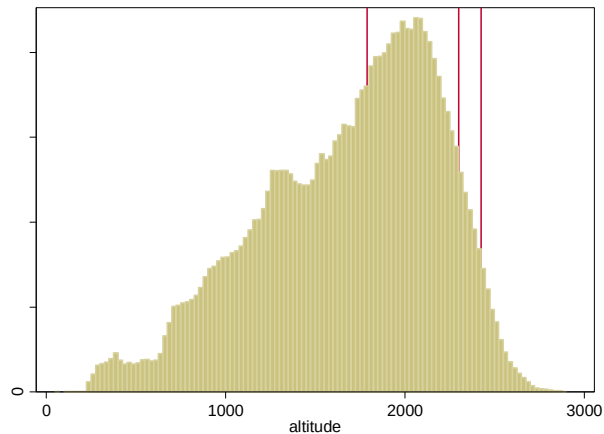


Figure 4 Density of altitude in the Bendor Range (25 m bins). The red lines at 1790, 2300 and 2425 m show the extent of cirque floors, covering the hypsometric maximum

Vector analyses of aspects of steep slopes provide further evidence of glacial modification of the Shulaps Range. Using the same altitude classes as above, but subdividing the large 1957–2456 m class, vector means are consistently northward ($351\text{--}001^\circ$) above 2200 m (Table 1). This compares with a mean of 007° for cirques. Vector strength increases, to over 0.24, only above 2456 m, where headwalls are

dominant. Below 2150 m various mean directions occur.

3.2 Bendor

The Bendor Range is well glaciated, with glacial troughs and 222 cirques (Evans and Cox, 2017). Cirque floors average 150 m lower than in Shulaps. Bendor has a ‘glacial’ hypsometric maximum at cirque floor altitudes (Fig. 4). This contrasts with the ‘fluvial’ trend of area increasing linearly downward, at least to the ‘defining pass’ (at 1865 m).

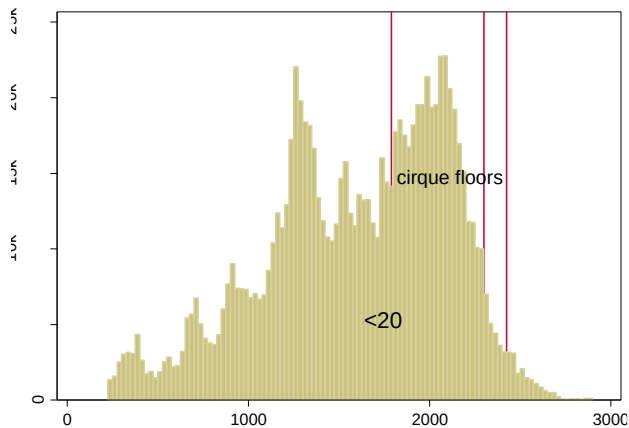
Overall, Bendor gradients peak sharply at 35° . Coinciding with the 05 and 95 percentiles of cirque floor Lowest altitudes at 1790 to 2300 m there is a strong maximum of low gradients, from the extensive cirque floors (Fig. 5). This is complemented by a strong maximum of steep gradients at the same altitudes (Fig. 6). Subdivision (not shown) of steep gradients reveals that for increasingly steep slopes the maximum shifts upwards, peaking around 2300 m – above the mid-altitude of cirque floors – for both $55\text{--}65^\circ$ and $>65^\circ$. Slopes steeper than 55° are infrequent below 1700 m. Gradients below 20° become more important especially below 1400 m, where there are benches above Cadwallader Creek.

Statistics in Figure 7 show the greater proportions of gradients $<20^\circ$ between 1790 and 2300 m (more noteworthy considering the trend of the proportion reducing with increasing altitude), and of those $>45^\circ$ above 2080 and especially above 2300 m, reflecting floors and headwalls respectively. This is supported by high IQRs between 1790 and 2300 m, but not by SDs.

Although the aspects of cirques and glaciers in Bendor are less azimuthally concentrated than in Shulaps, the glaciation is still strongly asymmetric. Hence above 1900 m, vector means of steep ($>40^\circ$) slopes are consistently northward, and above 2100 m their vector strengths are above 0.14. The northward mean of 008° is very close to the vector means of cirques (018°) and of modern glaciers (011°). Thus strong and consistent asymmetry of steep slopes, restricted to appropriate altitudes, is a further geomorphometric indicator of cirque headwalls, and therefore of glacial modification.

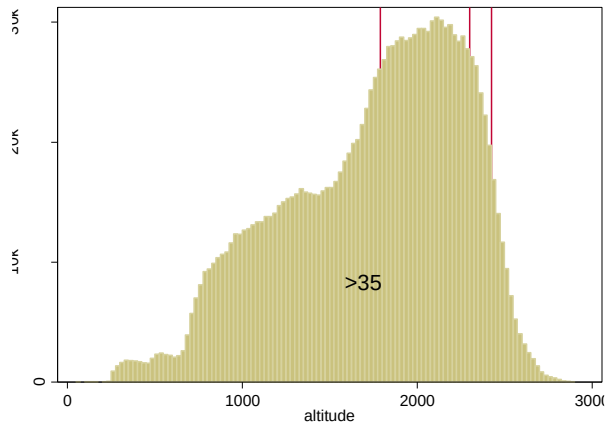
Table 1 Vector strength and vector mean (with confidence limits) for aspect, by altitude bands, for slope gradients over 40° in the Shulaps Range: from the 12.5 m DEM

Altitude	Strength	Mean	95% limits	Observations
Over 2610 m	0.287	001.0	358.1 – 003.9	7314
2456 – 2610	0.240	359.6	357.6 – 001.6	24433
2350 – 2456	0.180	356.5	353.9 – 359.1	25443
2250 – 2350	0.179	351.0	348.0 – 354.0	20074
2150 – 2250	0.214	341.9	339.0 – 344.8	15095
2050 – 2150	0.136	285.9	280.0 – 291.8	10554
1957 – 2050	0.208	216.8	212.9 – 220.7	10385
Over 2200 m	0.208	356.4	355.1 – 357.6	85615

**Figure 5** Frequency of gentle slopes (<20°) in the Bendor Range (50 m bins). The red lines at 1790, 2300 and 2425 m show the extent of cirque floors, with frequency peaking at average floor altitude. The lower peak, around 1300 m, relates to valley-side benches along Cadwallader Creek

3.3 Romania

Results from Niculița and Evans (2018), using SRTM data for Romania, support those for British Columbia. At present there are no glaciers in the Romanian mountains, but at the Last Glacial Maximum there were many cirque and valley glaciers, in numerous mountain ranges. In the Retezat Mountains of southwest Romania, the 84 cirque floors are mainly 1760–2190 m (5 to 95 percentiles of Modal

**Figure 6** Frequency of steep slopes (>35°) in the Bendor Range (50 m bins). The red lines at 1790, 2300 and 2425 m show the extent of cirque floor altitudes, at which there is a broad maximum of steep (as well as gentle) gradients. Headwalls start from the lowest cirque floors and extend to the highest summits

floor altitude: Mîndrescu et al., 2010; Mîndrescu and Evans, 2014, 2017). This shows in the hypsoclinometric plot as a decline in the lower quartile of gradient, from 1800 to 2100 m altitude (Fig. 8). Median gradient declines (gently) from 1600 to 2050 m, the latter being the median gradient of cirque floor altitudes. The upper quartile and the 95 percentile of gradient rise steeply from 1850 to 2350 m, and the median increases from 2100 to 2400 m: all these show the effects of high gradients from cirque

headwalls. The quartiles diverge above 1850 m: the increase in SD and IQR reflects the presence of both low-gradient cirque floors and high-gradient cirque headwalls. There is a relatively small area above 2350 (to 2500 m) and the declining gradients there are due to smoothing as gradients were calculated from a quadratic fitted to a 90 x 90 m window.

Similar results were found for other well-glaciated ranges. The 45 cirque floors of the Rodna

Mountains in northern Romania are mainly between 1520 and 1910 m altitude. They show up only weakly, in the lower quartile of gradient falling from 1700 to 1800 m. Headwalls (1620–2280 m) are more evident, in an increasing 95 percentile from 1650 to 2275 m, where (expressed as tangent) it reaches 1.2. Both SD and IQR rise from 1700 to 2300 m, while median gradient rises from 1800 to 2200 m.

Altitude (m)	Mean (°)	Median (°)	SD (°)	IQR (°)	<20° %	>45° %	Observations.
above 2425	36.2	35.7	13.8	16.8	11.3	22.6	153k
2300	35.8	35.2	12.8	14.5	9.9	19.4	235k
2080	31.0	31.4	12.6	15.2	18.9	10.7	708k
1790	29.6	30.1	12.1	14.9	21.0	7.8	1053k
1600	29.8	30.4	11.7	13.9	18.8	7.3	538k
1400	28.8	29.5	11.5	14.7	21.7	6.5	457k
Below	28.2	29.1	12.7	17.9	27.0	8.6	1236k

Figure 7 Statistics for Bendor altitudinal classes of gradient, including 1790–2300–2425 m (cirque floors) and 2080–2300 m and up (cirque headwalls)

The Parâng Mountains in the southwest Carpathians have 51 cirques. Again headwalls are more evident than cirque floors, with the 95 percentile of gradient increasing from 0.85 at 1775 m to 1.13 at 2275 m: the upper quartile rises similarly. Median gradient increases from 1950 to 2300 m. SD and IQR increase from 1850 to 2350 m (and 2450 m for SD).

The Romanian results, for 21 ranges, show strong concentrations of high gradients at altitudes of cirque headwalls in fourteen ranges with more than a few cirques. Cirque floors are less evident in hypsoclinometry, presumably because they cover on average only 28% of the map area of a cirque (Mîndrescu and Evans, 2014, 2017).

The relevant falling lower quartile is found in six ranges, with weaker indications in five others. 'Glacial signals' in altitudinal distributions of gradients are clearest in the Retezat, Făgăraș, Țarcu, Maramureș and Rodna Mountains. This is comparable to the ranking (of twelve regions) from seven attributes of cirque quality in Mîndrescu and Evans (2014): from most glacially modified to least, Retezat, Parâng, Făgăraș, Bucegi, Rodna, Lotru–Cindrel, Godeanu, Maramureș, Iezer, Țarcu, Bihor, Călimani.

Unglaciated ranges in Romania show a variety of altitudinal trends of gradient (Niculiță and Evans, 2018).

4. Further work

The work on British Columbia is at an early stage and will be extended to further mountain ranges, with differing degrees of past and present glaciation. (Large present-day glaciers cause problems as it is the unknown subglacial topography that is of interest). Data quality needs more detailed study, and it will be useful to compare results from 25 m resolution DEMs with results from these 12.5 m DEMs. Aspect distributions should be analysed in

relation to gradient as well as altitude. Finally, several measures of surface curvature can be analysed in relation to altitude.

5. Conclusions

The strong glacial modification of the Bendor Range shows in a high percentage of steep slopes (headwalls) at and above cirque floor altitudes, and of gentle slopes (above the upward decreasing trend) at cirque floor altitudes.

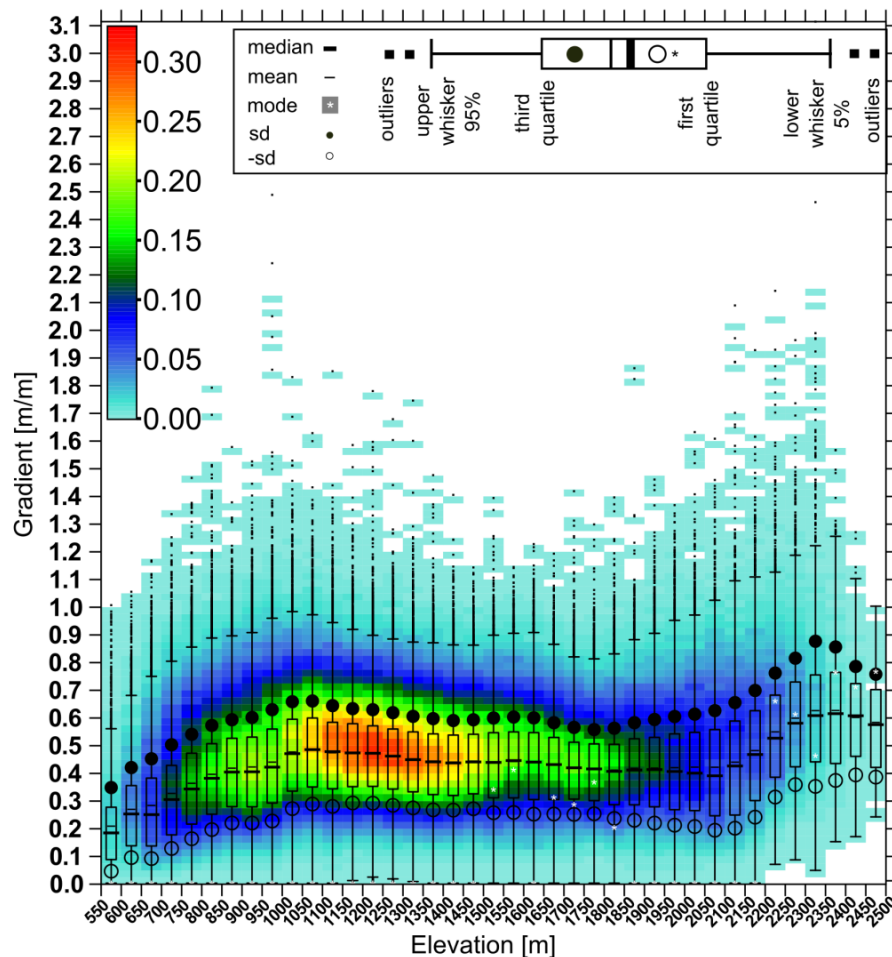


Figure 8 (from Mihai Niculiță) Combined boxplots and density distributions for the Retezat Mountains, southwest Carpathians. The boxes represent the Interquartile Range (IQR), from lower to upper quartile. The circles show one standard deviation (SD) above the mean (black) and one below (open). Colour shows percentage of observations, for bins of 50 m altitude $\times$ 0.025 gradient. Note that gradient (tangent) of 1.0 = 45°

Steep (and especially steepest) slopes are concentrated at cirque altitudes, increasing mean, median, SD and IQR especially above cirque floors. There is only a small increase of IQR and SD at cirque floor altitudes. The hypsometric maximum is at cirque

floor altitudes, unlike the expectation for fluvial topography.

The Shulaps Range is asymmetrically glaciated with fewer cirques and very short troughs. It shows a strong secondary mode of steep slopes above 2100 m altitude; but the 'glacial' signal in mor-

phometry is much weaker than for Bendor, reflecting its lesser degree of glacial modification. This is due to a former ELA which is higher in Shulaps, whereas summits are of comparable altitude. The present-day ELA is also higher in the Shulaps, and its lower precipitation may also make its glaciers less effective both today and in the past.

These results are supported by the Romanian evidence in Niculiță and Evans (2018). Romanian ranges can thus be ranked by degree of glacial modification, comparably to the ranking from specific geomorphometry of cirques in Mîndrescu and Evans (2014). In general, low gradients at cirque floor altitudes become clear only in well-glaciated ranges with high densities of cirques. The most general morphometric effect of glaciation is the increase in steep slopes at cirque headwall altitudes. This usually feeds through to increased variability and averages of gradient: SD, IQR, mean and median. Complications can arise where there are low-gradient summit surfaces, as in the Godeanu and Țarcu Mountains, or where extensive gentle slopes are found below cirque floors as in the Shulaps Range.

Slope aspects are much more azimuthally concentrated at the altitudes of headwalls. Vector means are northward above 1900 m in Bendor and 2200 m in Shulaps. Vector strengths for slopes on headwalls are >14% in Bendor above 2100 m and >18% in Shulaps above 2200 m. These are similar to vector means for cirque aspects and glacier aspects. Likewise in the English Lake District, slopes >45° at high altitude have a vector mean aspect of north-east, as do cirques and a vector strength of 37%. These results are characteristic of mountains glaciated asymmetrically, and give further objective evidence of a glacial imprint.

Although these results are preliminary, and analyses of further mountain ranges are required, it is possible to arrive at judgements on the three hypotheses. The first, that there are more gradients <20° at cirque floor altitudes, is weakly confirmed. The second, that there are more gradients >35° above cirque floors (representing cirque headwalls) is strongly confirmed, and in the British Columbian examples applies especially to gradients >45°. The third, that higher standard deviations and inter-

quartile ranges of gradients occur at cirque floor altitudes (because the altitude ranges of headwalls and floors overlap), is strongly confirmed. Thus it may be possible to rank mountain ranges by the degree of glacial modification, using several approaches of general geomorphometry.

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References

- Barr ID, Spagnolo M. 2015. Glacial cirques as palaeoenvironmental indicators: Their potential and limitations. *Earth-Science Reviews*, **151**: 48–78. <http://dx.doi.org/10.1016/j.earscirev.2015.10.004>.
- Crest Y, Delmas M, Braucher R, Gunnell Y, Calvet M, Team ASTER 2017. Cirques have growth spurts during deglacial and interglacial periods: evidence from 10Be and 26Al nuclide inventories in the central and eastern Pyrenees. *Geomorphology*, **278**: 60–77. <https://doi.org/10.1016/j.geomorph.2016.10.035>.
- Egholm DL, Nielsen SB, Pedersen VK, Lesemann JE. 2009. Glacial effects limiting mountain height. *Nature*, **460**: 884–887. <https://doi.org/10.1038/nature08263>.
- Evans IS. 1979. *An integrated system of terrain analysis and slope mapping*. Final report on grant DA-ERO-591-73-G0040, University of Durham, England.
- Evans IS. 1990. Climatic effects on glacier distribution across the southern Coast Mountains, B.C., Canada. *Annals of Glaciology*, **14**: 58–64.
- Evans IS, Cox NJ. 2017. Comparability of cirque size and shape measures between regions and between researchers. *Zeitschrift für Geomorphologie*, **61**(Suppl. 2): 81–103. https://doi.org/10.1127/zfg_suppl/2016/0329.
- Evans IS, Hall AM, Kleman J. 2015. Glacial cirques and the relationship between equilibrium line altitudes and mountain range height: COMMENT. *Geology*, **43** (e366). DOI: 10.1130/G36667C.1.
- Kühni A, Pfiffner OA. 2001. The relief of the Swiss Alps and adjacent areas and its relation to lithology and structure: topographic analysis from a 250-m DEM. *Geomorphology*, **41**: 285–307.

- Minár J, Evans IS, Krcho J. 2016. *Geomorphometry: Quantitative Land-Surface Analysis (2nd. Edition)*. In: Reference Module in Earth Systems and Environmental Sciences. Elsevier, Amsterdam. DOI: 10.1016/B978-0-12-409548-9.10260-X.
- Mîndrescu M, Evans IS. 2014. Cirque form and development in Romania: allometry and the buzz-saw hypothesis. *Geomorphology*, 208: 117–136. <http://dx.doi.org/10.1016/j.geomorph.2013.11.019>.
- Mîndrescu M, Evans IS. 2017. *Glacial cirques in the Romanian Carpathians and their climatic implications*. In: Rădoane M, Vespremeanu-Stroe A. (eds.): Landform Dynamics and Evolution in Romania. Springer Geography, 197–213. DOI 10.1007/978-3-319-32589-7_9.
- Mîndrescu M, Evans IS, Cox NJ. 2010. Climatic implications of cirque distribution in the Romanian Carpathians: palaeowind directions during glacial periods. *Journal of Quaternary Science*, **25** (6): 875–888. DOI: 10.1002/jqs.1363.
- Mitchell SG, Montgomery DR. 2006. Influence of a glacial buzzsaw on the height and morphology of the Cascade Range in central Washington State, USA. *Quaternary Research*, **65**: 96–107.
- Niculită M, Evans IS. 2018. Effects of glaciation on the climatology and hypsometry of the Romanian Carpathians. *Geomorphometry*, 2018. PeerJ Preprint-<https://doi.org/10.7287/peerj.preprints.27076v1>.
- Robl J, Prasicek G, Hergarten S, Salcher B. 2015. Glacial cirques and the relationship between equilibrium line altitudes and range height. *Geology*, **43** (e365). <http://dx.doi.org/10.1016/j.gloplacha.2015.01.008>.
- Robl JG, Prasicek G, Hergarten S, Stüwe K. 2015a. Alpine topography in the light of tectonic uplift and glaciation. *Global & Planetary Change*, **127**: 34–49. <http://dx.doi.org/10.1016/j.gloplacha.2015.01.008>.

Morphological changes in the proximity of the Greek colonies founded along the western (Romanian) Black Sea coast: Orgame, Histria, Tomis, and Kallatis

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ABSTRACT

This paper is a review of the up to date knowledge about the coastal environmental transformations around the Greek settlements along the present–day Romanian shoreline. The aim is to define a general pattern of the morphological configuration the Greeks were looking for when establishing their colonies. Existing quantitative and qualitative database on shoreline evolution both along the low lying deltaic sector (N) and along the soft rock cliffs along the southern sector of the present–day Romanian coast together with the present day morphological configuration analysis at each study site were used to assess large spatial (~180 km alongshore) and temporal scales (ca. 2500 yrs) of coastal behavior. The coastal dynamics during the late Holocene was controlled by the deltaic lobes development along the northern part of the present day Romanian coast which led to important shoreline progradation and subsequent isolation from the shoreline of Histria and Orgame Greek cities. The continuous sediment input depletion, sea level rise, storms set-up, longshore transport system and local tectonic activity drove the cliff line retreat along the southern sector, with important parts of the Tomis and Kallatis settlements being lost to the sea.

KEYWORDS

coastal evolution; sea level; ancient harbors; Greek colonization

1. Introduction

Black Sea (BS) was the last basin colonized by the Greeks during the 7–4th century (c.) BC. The first

Greek incursions are attested along the southern coast, which was the closest from the Aegean and Propontic (Marmara Sea) coasts where the Greeks

found a somehow familiar landscape as in their homeland. Yet, despite the familiar newly encountered rocky cliffs morphology, the marine conditions there were far from the mild Mediterranean climate as a passage from a Greek source translated by Pomponius Mela (1: 120) informs us: *"shallow, wild and nebulous, with only isolated places to anchor, surrounded by neither a gently sloping nor a sandy coastline, exposed to the north winds and, where it is not deep, stormy, undulating and surging"* (Summerer L., 2015).

The first Greek colonies were founded along the southern coasts during the 7th–6th century BC with Sinope settled by Milesians (and her colonies: Kotyora, Kerasous, Trapezous), Amisos by Phokaiaians and/or Milesians and Herakleia by Megarians and Boiotians). At the same time, the Milesians settled also along the western coast at Histria, Appolonia, Odessos and latter, towards the 4th c., merchants from Megara re-built other two sub-colonies of Byzantion and Herakleia: Messambria (Nessebar) and Kallatis (Mangalia). Further north, along Scythian coastlines, the Milesians emplaced at Olbia, Karkinitis, Tyritai and Nikonion, whereas the Megarans occupied Chersonesos. During the 6th c. BC, the colonization process of the western and northwestern coasts continued with Dyonisopolis (Balchik), Olbia and Tyras at the mouths of Southern Bug and Dniester, Akkerman, Nikonion at the mouth of Lower Dnieper. Phasis, Dioskouris and Gyenos were the Greek settlements founded along the eastern coasts of the Black Sea (Avram et al., 2004). Another pole of Greek colonization during the 6th c. BC was in the area of Kerch Strait and Taman Peninsula which, under the pressure of the Scythians from the northern steppe, united to form the Bosporean Kingdom in the 5th c.: Kerch, Pantikapaion, Tyritake, Phanagora, Kepoi, Sennoi, Temriuk, Taman, Hermonassa, Golubiskaya which were also settled mainly on islands, headlands or promontories on the top of which they built the fortified cities, where they benefited from the sheltered places at the lee and at the base of the cliffs for harboring their vessels (Kelterbaum et al., 2011; Giaime et al., 2016).

Most of the colonies were emplaced on islands, headlands or promontories connected, more or less, by the mainland through low laying sandy barriers.

This seems to be a Phoenician legacy of building coastal cities as despite the rarity of such morphological feature, offshore islands placed close by the mainland seem to have represented the preferred location of the Phoenicians to settle coastal areas during the Early Bronze Age in the Mediterranean such is the case of Tyre (Mariner et al., 2008), Utica in Tunisia (Delile et al., 2015), Alexandria's Portus Mareoticus (Flaux et al., 2017), Arados and Perea in Syria, Cadix and Castillo of Doña Blanca in Spain, Rachgoun and Siga in Algeria (Mariner et al., 2008).

Part of the ancient Greek cities founded along western and northern Black Sea are currently submerged at various degrees pointing toward major environmental coastal changes during the last almost two millennia.

Yet, no agreement exists between scientists regarding the cause of their decline, either human-related (invasions, disease, famine) or natural (sea-level changes, neo-tectonic movements, earthquakes, tsunamis) so that the ancient Greek colonies history and abandonment causes differ for each one. However, many of the specific sites geoarchaeological studies report natural causes as triggering the relocation of the harbor facilities and/or city abandonment. Studies dealing with geographical and environmental changes along the Black Sea coast mainly reports deltaic sedimentation and alluviation due to sea-level oscillations or sediment input fluctuations (Kelterbaum et al., 2011, 2012; Preoteasa et al., 2013; Vespremeanu–Stroe et al., 2013; Bony et al., 2015; Laermans et al., 2017, 2018, 2019; Giaime et al., 2016, 2018, Preoteasa et al., 2019) as primary causes of Late Holocene landscape changes.

Four Greek colonies have been built along the present-day Romanian coast roughly since the 7th c. BC: Orgame (near Juilovca), Histria, Tomis (Constanța) and Kallatis (Mangalia) (Fig. 1). Although they remain unevenly archaeologically and geomorphologically investigated due to constraints imposed by subsequent continuous inhabitation and the building of the largest Romanian maritime ports at Constanța (Tomis) and Mangalia (Kallatis) during the last century, roughly superimposing the ancient ports, this article attempts to provide a scenario of palaeogeographical transformations at the location of each of them. This work combines the existing

geoarchaeological information with geo-scientific data (large and medium-scales coastal dynamics data, new geophysical surveys and absolute ages) which complement the current knowledge in case of Histria and Orgame landscape changes and bring new information in the case of Tomis and Kallatis.

In the endeavor of reconstructing coastal palaeogeographic transformations a detailed analysis of the sea-level changes, large scale coastal dynamics and local configuration changes before, during and after settlements abandonment as reflected by dis-

placement, re-positioning or disappearance of any major civic architectural elements such as fortification walls, roads, aqueducts, harbors, necropolis or some other sort of built areas are required. Therefore, before a review of the landscape dynamics at each study site, an assessment of the existing post-glacial BS level curves are undertaken. Major Paleogeographical transformations at each study site will be discussed in terms of large scale coastal dynamics for a better understanding of the general morphodynamic context of their emplacement.

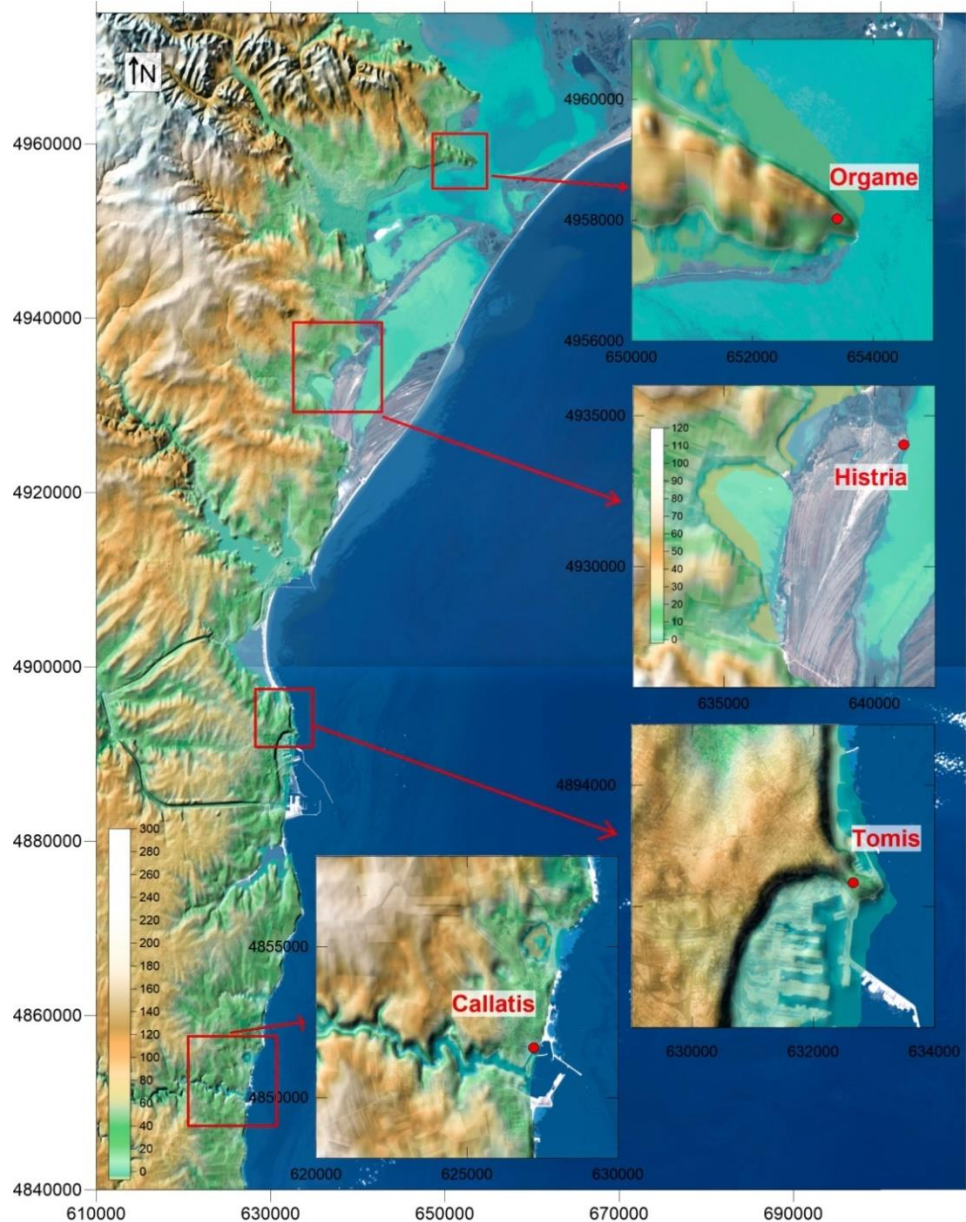


Figure 1 Black Sea Romanian coast and the position of the Greek cities: Orgame, Histria, Tomis and Kallatis

The coastal evolution during roughly the last 2.5 millennia (spatially extending from Orgame to the north and Kallatis to the south) is reconstructed based on existing geoarchaeological data documenting major landscape transformation at each study site as well as new geo-scientific data (Electrical Resistivity Tomography profiles, absolute ages) reflecting the structure and dynamics of the coastal barriers developed downdrift of the Danube delta.

2. Post-Glacial Black Sea level curve

An important contribution for assessing the coastal configuration changes during the last three millennia is to establish a post-glacial eustatic BS level rise curve during mid- and late-Holocene. This topic is still ardently disputed mostly because of the sea-level proxy scarcity, uncertainty, complexity which, when assessed globally, frequently generate contrasting scenarios. Basically, two theories confront the validity of major wiggles which are presented as a peculiar post-glacial sea level rise feature for this semi-enclosed basin. Although it is expected that the eustatic sea-level curve should be similar for the Black Sea and the World Ocean after the reconnection with the Mediterranean Sea through Bosfor strait and Marmara Sea ca. 9000 ka yrs BP, some studies report or assume several wiggles associated with transgressions/regression cycles (Fedorov and Skira, 1957; Chepalyga, 1984; Balabanov, 2007; Panin and Popescu, 2007; Caraivan et al., 2012; Bolikhovskaya et al., 2018; Filipova-Marinova, 2016). These variations are generally explained either through the sensitivity of the BS as a semi-enclosed basin to regional climatic variability as reflected in palynological data (Filipova-Marinova et al., 2016; Bolikhovskaya et al., 2018) or by the drowned parts of ancient coastal settlements. At the other hand, stratigraphic investigations undertaken at various locations along the Black Sea coastlines report a gradual sea level rise trend at various rates with the present-day level as the highest during the entire post-glacial period (Bruckner et al., 2010; Kelterbaum et al., 2011, 2012; Fouache et al., 2012; Vespremeanu-Stroe et al., 2013, 2017; Laermans et al., 2018). Otherwise, these latter studies frequently report eustatic sea level is locally affected by sub-

sidence associated either to sediment (peat) compaction or neo-tectonic activity (Fouache et al., 2012; Kelterbaum 2011, 2012; Preoteasa et al., 2013, 2018; Vespremeanu-Stroe et al., 2013).

Although beyond the temporal framework of the Greek colonization era, which is the subject of this paper, an illustrative example of sea-level proxies' interpretation worths being mentioned here. A recent article dealing with the multi-proxy records of the Holocene paleoenvironmental changes in Varna Lake area (Filipova-Marinova et al., 2016) reports a change in the palynological composition by the end of the Neolithic period and the beginning of the Bronze Age and interprets the 319 years long interval of absence of human related pollen spectra to the so-called Kalamitian BS transgression. Apparently, this change in vegetation composition coincides with the moment of Neolithic civilization decline. But, it is widely known among the archaeologists that the end of the flourishing Neolithic civilization in SE Europe occurred 4200–4000 BC when more than 600 tells are reported to have been burned in NE Balkans (Lazăr et al., 2012). In the aftermath of this sudden depopulation event recent studies found that new populations originating from the North Pontic Steppes (NPS) temporarily occupied the abandoned settlements, preserving the mud architecture, the house types, cult buildings (Bailey, 2000; Anthony, 2010) and cemeteries (Lazăr, 2018). Or, even if it is to admit the sensitivity of BS to climatic variations as the semi-enclosed basin, such a dramatic sea level rise to force humans to leave their settlements and to destroy those encountered in their flight from the uprising waters might be imaginable in case of a rather catastrophic event, not that of a gradual sea-level rise. It is therefore desirable to cautiously interpret the palynological data and even better to test them by confronting with results from complimentary (geochemical, paleontological) analyses, if possible.

However, the age-depth model of the sea-level proxies in the Danube delta as well from the northern and eastern BS show a continuous sea-level rise, with a recent (i.e. last two centuries) acceleration trend (Fig. 2).

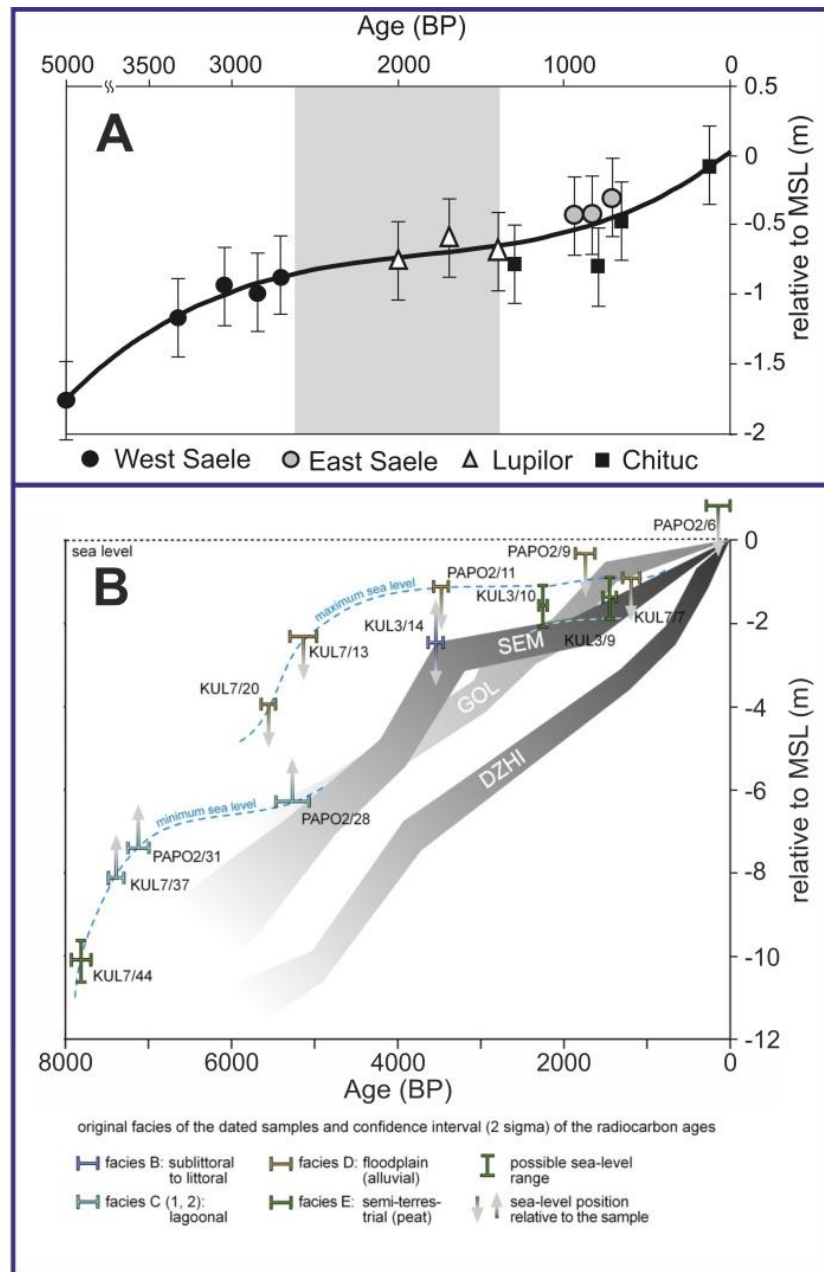


Figure 2 Sea Level A: Black Sea-level curve derived for the southern Danube Delta based on the age and altitude of the aeolian / marine deposits interface within the beach ridge plains (after *Vespremeanu-Stroe et al., 2013*); B: Compilation of 14C-dated samples from the Kolkheti lowlands (eastern BS) and their relative position to the local sea level. Horizontal bar shows 14C dating result (2 sigma). The arrows pointing up/down indicate that sea level was higher/lower than the dated sample. In case of paralic peat (facies E; KUL 7/44, KUL 3/10, KUL 3/9), the sea-level range was narrowed to ± 0.5 m. The data set is compared to sea-level curves from the Taman Peninsula in SW Russia, with the sites of SEM ¼ Semebratnee (Brückner et al., 2010), GOL ¼ Golobitskaya (Kelterbaum et al., 2011), and DZHI ¼ Dschiginka (Fouache et al., 2012). The differences are due to different tectonic settings. For Kolkheti area, a continued and rather moderate rise in sea level for the last eight millennia is assumed (after *Laermans et al., 2018*)

Yet, no other pieces of evidence (maybe excepting the only stranded platforms from Caraharman/Vadu and Cetatea Zaporijenilor which nature

is still unknown) were identified along the present-day Romanian coastline to support a past sea level higher than the present one.

3. Large scale coastal behavior

The Romanian coastline consists of a 175 km long low lying deltaic sector to the N of Cape Midia and 80 km of soft cliffs (loess overlaying Sarmatian limestone) to the south, between Cape Midia and Vama Veche. The loess cliffs sector is generally not higher than 25 m, at places being bordered by submerged platforms carved in limestone alternating along-shore with small pocket beaches and/or barriers closing limans. The coastal dynamics during the late Holocene generally consisted in adjustments between deltaic lobes development (i.e. initiation, extension and decay) along the northern coastal sector, and cliff line erosion under the influence of the sea level rise, storms setup, sediment input, long-shore transport and local tectonic activity for the southern sector. The instrumental record of sea level at Constanța gauge between 1933 and 2000 averages 1.3 mm/yr (Halcrow report, 2011).

The landslides which produce the cliff line retreat are controlled by both lithological and marine processes, frequently reinforced by local tectonic fault lines activity and earthquakes (Vâlsan, 1935). Tectonic movements have been reported as major controlling factors of the Black Sea basin genesis and its coastlines evolution since the first investigations of the deep sea sediments undertook by the Russian scientists starting from 1890 in the northern part of the BS basin which are thoroughly presented by Brătescu, 1944, Popescu and Ielenicz (2003), the idea of epirogenic movements contribution to shoreline dynamics over that of eustatic changes being also propagated and reinforced with new evidence by Fouache et al., (2012), Bruckner et al., (2010), Keltebaum et al., (2011). The hydrogeological characteristics of the limestone bedrock promotes a more vigorous endorheic system fed mainly by meteoric waters (Capotă, 1980, Rădoi, 1986) which favor intensive karstic processes affecting the limestone bedrock. This is reflected by the large caves (e.g. Limanu Cave) dolines, karstic depressions (e.g. Obanu Mare or present-day Herghelia Lake situated to the NW and N of Mangalia formed within former karstic depression) or encased valleys (e.g. Limanu, Tatlageac, Techirghiol) developed across the South Dobrudja Plateau. Large subsidence processes which reach the highest rates in Dobrudja along the

coastal strip where they amount to 3 mm/yr were documented by Dumitriu, 2012; Rădulescu et al., 2016. A survey across the submerged limestone platform at Agigea, south of Constanța Port intercepted numerous doline-like features on platforms lying at various depths which might result from limestone dissolution and marine erosion (see further, section 5).

Cliffs lithology and stratigraphy (quasi horizontal layers of loess and palaeosoils overlying limestone) favors frequent landslides triggered by both direct waves attack along the exposed loess sectors where the bordering submerged limestone platform is either missing or lies at greater depths or by subsurface seepage which is more intense in the proximity of the irrigated agricultural or inhabited areas (e.g. Tuzla, Costinești). Before the anthropogenic interventions especially from the '60s (Constanța port dykes and jetties, breakwaters) the spatial limit of the deltaic development influence on the downdrift coastline depended on the position of the active Danube's distributary, sediment volumes transported by the longshore currents system, coastline orientation and the seaward limit of the main natural headlands. However, the young ages of the southern part of Chituc beach-ridge plain, of ca. 200–130 yrs BP (Vespremeanu–Stroe et al., 2017) suggest that the last phase when Danubian sands reached and directly contributed to the sub-aerial beaches of the southern Romanian coast occurred recently and was spatially constrained mainly N of Constanța (Cape Singol). This fact is further endorsed by shoreline dynamics computed for the quasi-natural regime of the last century (1900–1960) which shows moderate shoreline progradation rate north of Cape Midia, amounting to ~2 m/yr and slowing down to ~1 m/yr along the downdrift Mamaia barrier (Constantinescu and Giosan, 2017) which acted as the last sediment trap of the Danubian sediments.

The shoreline dynamics computed for the southern part of the Romanian coastline during the last century (Constantinescu and Giosan, 2017) show averages rates ranging from -0.3 m/yr for the cliff sector between Cape Aurora and Mangalia Port to +2.5 m/yr between Cape Midia to Cape Gârgâlac. The overall shoreline dynamics trend during the last

century is slightly prograding updrift of Constanța Port, averaging +1.15m/yr while slightly erosive along the downdrift sector from Constanța to Vama Veche with an average retreating shoreline rate of 0.19 m/yr. However, these rates should not be considered as representative for the last two and half millennia as the sediment accumulation along the northern sector is a recent process occurring during the last centuries which was greatly amplified by the formation and abandonment of the deltaic lobes (Dunavăț lobes, Vespremeanu-Stroe et al., 2017) and later by the emplacement of Midia and Constanța port jetties which were constructed perpendicular to the prevalent southward directed long-shore transport, capturing thus most of the sediments or due to the fact that the computations were made for a time interval when the sea level rise trend was significantly accelerated since the post-industrial era (IPCC, 2002).

4. Ancient harbors

Harbors structures or at least shoreline configuration proper for harboring large maritime vessels are indisputable components of the coastal Greek cities territory. The intense commercial ties with other Greek colonies around the BS and Mediterranean (e.g. Khios, Lesbos, Thasos) is reflected by material exchanges documented by the numerous archaeological findings, especially pottery, allochthonous raw materials, literary, numismatic and epigraphic sources. Despite the numerous indices of ports presence, no mention exists about their emplacement. Their much hidden present-day status rendered them significant target for the geoarchaeological studies. They are now considered important proxy in deciphering the environmental changes as they account for sea level at the time of their building, shoreline position or site accessibility from the sea as well as post-abandonment environmental history. Therefore, most of the geoarchaeological studies aim at finding the location of the ancient ports in order to assess the environmental changes (Hochmann, 1997, 1998, 1999 cited in Alexandrescu, 2001, Scopan, 1973, Dăbâca, 2012, 2013, Bony et al., 2015, Angelescu, 2018).

Due to their post-colonial inhabitation and preservation degree Orgame, Histria, Tomis and

Kallatis enabled a various degree of archaeological survey of which only Histria and Orgame benefited from the lack of subsequent inhabitation after the roman-byzantine limes decline in the 7th c. AD (Histria) and 11th c. AD (Orgame) at one hand and more than a century of systematic archaeological investigations (at Histria) on the other hand.

I. Histria

Histria's Greek city ruins currently lie at 8 km inland from the modern shoreline. The way the natural landscape evolved since the first Greeks arrival (657 c. BC) was one of the first objectives of the archaeological research program at Histria and Orgame. The first hypothesis of the way the Histrian acropolis was related to the mainland was formulated by Pârvan in 1914. Archaeological excavations, geophysical investigations, aerial photographs interpretation and absolute datings gradually contributed to sketch a general picture of the local palaeogeographical transformations. A substantial contribution to understanding the palaeogeographical changes at Histria was brought by the aerial photographs taken by Ștefan (1974) which enabled the visualization of major discontinuities in the ancient roads connecting Histria with settlements from its rural territory. Examples of such a dramatic change documented by the aerial photographs are the western and northern roads which fade beneath the waters of Histria and Nuntași Lakes and under the present-day marshy area with reeds bordering the northern part of the acropolis. Additionally, pieces of aqueducts supplying water to Histria from Fântânele (NW) were found stranded within the northern loess bank and in the Histria Lake waters. Not only the roads and aqueducts but also tumuli, domestic buildings and segments from the roman defense wall extending about 64 m N have been reported as drowned within Histria Lake and the marshy area N of the acropolis (Dumitriu, 1966; Alexandrescu, 2002). Moreover, the quest for identifying the position of the harbor(s) of such a great city as documented by the intensive commercial exchanges with cities from the BS basin and the western Mediterranean, as well as by the marble anchors found on site lead to major findings indicating substantial local topographical changes since

the Greek settlers emplacement. Synthesis of the so far documented landscape changes and their interpretation were previously published: Hanganu, 2012, Vespremeanu–Stroe et al., 2013. One of the most significant reports about the ancient Histria topography (Alexandrescu, 2002) discusses the presence of several important elements in deciphering local morphological changes found into the Sinoe Lake waters and the marshy area from the north of the acropolis, as well as the basin (the present-day area called "Sărătura (the pond)") situated eastward of the late roman wall and investigated by geoelectrical, geophysical and bathymetrical surveys by a German team from Erlangen University lead by Olaf Hockmann and Chr. Borker during the '90s. The

structure reported by the locals as "the road" and thoroughly investigated (Höckman et al., 1998, 1999) lies at about 1 m beneath the Sinoe Lake water surface, at about 70 m seaward of the present-day easternmost green schist outcrop of the acropolis and about 200 m NNE from the sacred zone of man-made dyke-like structure made up of two parallel walls widening northward which function is still controversial (e.g. archaic defensive wall, harbor structure). This structure might have had served as an artificial channel whether or not used for small boats navigation or perhaps is part of the Hellenistic fortification wall before their collapse into the water, but the debate continues as no information about the distance between the two parallel walls exist.

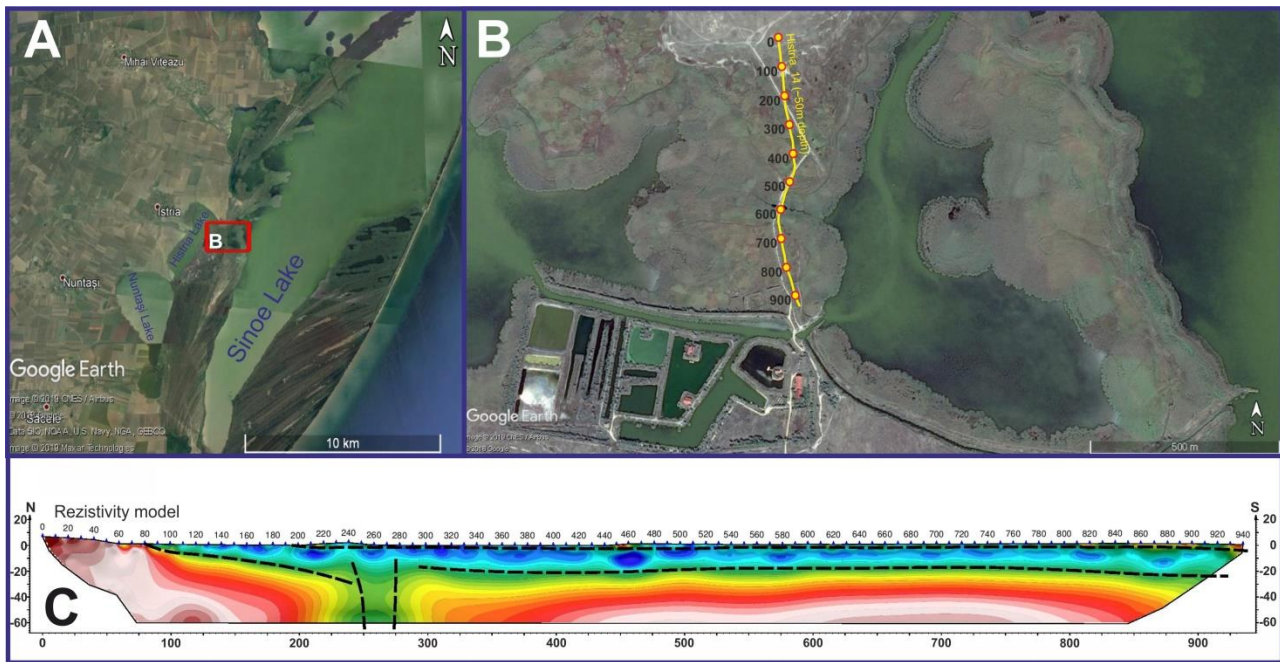


Figure 3 A&B Position of the Electrical Resistivity profile running N–S across the isthmus at the NW Histria acropolis; C. 60 m deep ERT profile intercepting a discontinuity within the greenschist fundament which might correlate with those intercepted further eastward by surveys reported by Hochmann et al., 1997, 1998, 1999 cited by Alexandrescu, 2001)

Another intriguing element reported in this paper is represented by the rectilinear WNW–SSE–E ditches found within the marshy flat to the north of Saele beach ridge plain (henceforth b.r.p.) and the acropolis and which is paralleled by other three smaller ridges. Given their spatial relationship with the artificial structure which is supposed to have been part of the Roman defense system (Alexandrescu, 2002), a recent (2016) 60 m deep Electrical Resistivity Tomography (ERT) profile, N–S orientated

across the isthmus situated N of the acropolis, revealed the presence of several profound disruptions extending down within the greenschist as W–E aligned (paleo)–valley (i.e. ancient Duingi or Istria river) or fault lines (Fig. 3). The sedimentary layers overlying the fundament shows a loosely folded structure which might reflect a mechanical tension probably related to an earthquake. Otherwise, earthquakes are frequently reported in ancient sources within the whole BS basin (Bony et al.,

2012), a synthesis of those affecting Histria during the antiquity being published by Florescu, 2001. Ancient sources (i.e. Strabo, Polybe) report Histria's port clogging by the year 260 BCE by sandbars formation which impeded maritime navigation starting from the second half of the 3rd c. BCE (Bounegru, 2003) and which probably imposed city's port relocation somewhere southward (Dăbâca, 2012).

II. Orgame

Orgame was founded during the 7th c. BC on the narrow, asymmetric sloping Doloşman Cape made up of limestone, which separates Razelm Lake to the north from Golovița Lake to the south. The northern slope of the cape is rectilinear, steep, W–E orientated while the southern slope is more gentle, providing a milder climate on the sunny and sheltered slope. This configuration readily suggests the position of the former harbor being emplaced at the southern slope foot in present-day Golovița Lake.

An important contribution to understanding Late-Holocene landscape evolution at Orgame was brought by the geo-scientific data published by Bony et al., 2005. Basically, the textural analyses and statistical interpretation of microfauna (ostracodes and forams) species found at different depths, together with radiocarbon ages lead to the differentiation of four main ecological contexts: marine bay, oligo to mesohaline infralittoral semi-closed lagoon, coastal oligohaline lagoon under fluvial influence, wetland populated with phragmites. The context of the identified ecological changes are ascribed to successive seaward development of different coastal barriers: the first, which partially closed the shallow marine bay formed 5200–3500 cal yrs BP resulting in present-day Zmeica Lake, corresponds to present-day Zmeica barrier, the second, Lupilor barrier, formed seaward and downdrift during 3500–2000 cal yrs BP interval generating Golovița Lake, while the latest, Chituc, started to form ca. 1200 yrs BP separating Sinoe Lake from the sea.

Yet, a different evolutionary scenario stems from the palaeogeographic information contained so far in the cores published in Vespremeanu-Stroe et al., 2017 paper with most of the barriers being a remnant of ancient deltaic lobes (i.e. Zmeica ridges as remnants of the barrier-marsh plain developed

downdrift of Sf. Gheorghe I lobe, Lupilor b.r.p as part of the Dunavăț lobe and Young Saele (eastward of C-ridge contact unit: see Preoteasa et al., 2013) and Chituc as b.r.p developed as continuous shoreline progradation following updrift Dunavăț lobe erosion), while the evolution of the lakes being mainly forced by tectonic and deltaic sediments compaction related subsidence.

III. Tomis

Tomis was set as a Milesian colony on the tomitan promontory during the 6th century which served as an important navigation hub along the western BS coast (Vulpe, 1969; Rădulescu and Scorpan, 1974) and, most probably declined during the 7th century CE (Rădulescu, 1966). It benefited from the highly indented embayment south of the peninsula which served as shelter for the city's harbor.

Despite the ruins found at the SE base of Tomis Peninsula facing the city's port no systematic research have been undertaken to establish the extension of the built structure, most of them being destroyed at the construction of the modern port. Constanța's shoreline is basically dominated by the Sarmatian limestone platform made up of quasi-horizontal layers with different roughness, rising up locally to 5 m above the sea level. Bathymetric surveys along Agigea shoreline sector, south of the present day Constanța Port intercepted three steps of the Sarmatian limestone platforms laying at different depths (-1.5... -3 m; -6... -8.5 m; -9... -11 m). Each limestone step shows obvious features of combined chemical dissolution and mechanical activity (Fig. 4). The platforms on the profile in Figure 4 reflect differential erosion of limestone layers and show the submerged morphological configuration in the proximity of the Constanța seafront.

IV. Kallatis

If disregarding the confusing and imprecise literary sources (i.e. Ps. Skymnos which mention the city's foundation at 761–764) and taking into account the material findings in archaeological excavation at Kallatis and within its rural territory (*chora*) the Doric colony of Kallatis was founded together with its territory during the 4th century BC by Herakleia Pontica. Considering the extension of its rural territory and

its fortification (e.g. Albești) and the large volume of grains trade documented as the main exported merchandise it seems that agricultural practices were the main source of its outcome. The large commercial activities should have been supported by extensive navigation. The underwater archaeological investigations were undertaken during the '70s (V. Cosma, 1973; C. Scarlat, 1973, 1976) in front of the modern city waterfront revealed the presence of submerged structures which were interpreted as port structures (Bounegru, 2002). During the under-

water surveys undertaken during the last century, the supposed harbor extension was established to the N up to the Hellenistic and Roman fortification wall which was found to extend seaward through a shore perpendicular dyke which turns S up to the entrance into the Mangalia Lake. This structure was interpreted as the siege of the military port. In front of the modern Limanu lake entrance a 1600 m long, shore parallel mole with storage spaces was identified made up of limestone sledge.

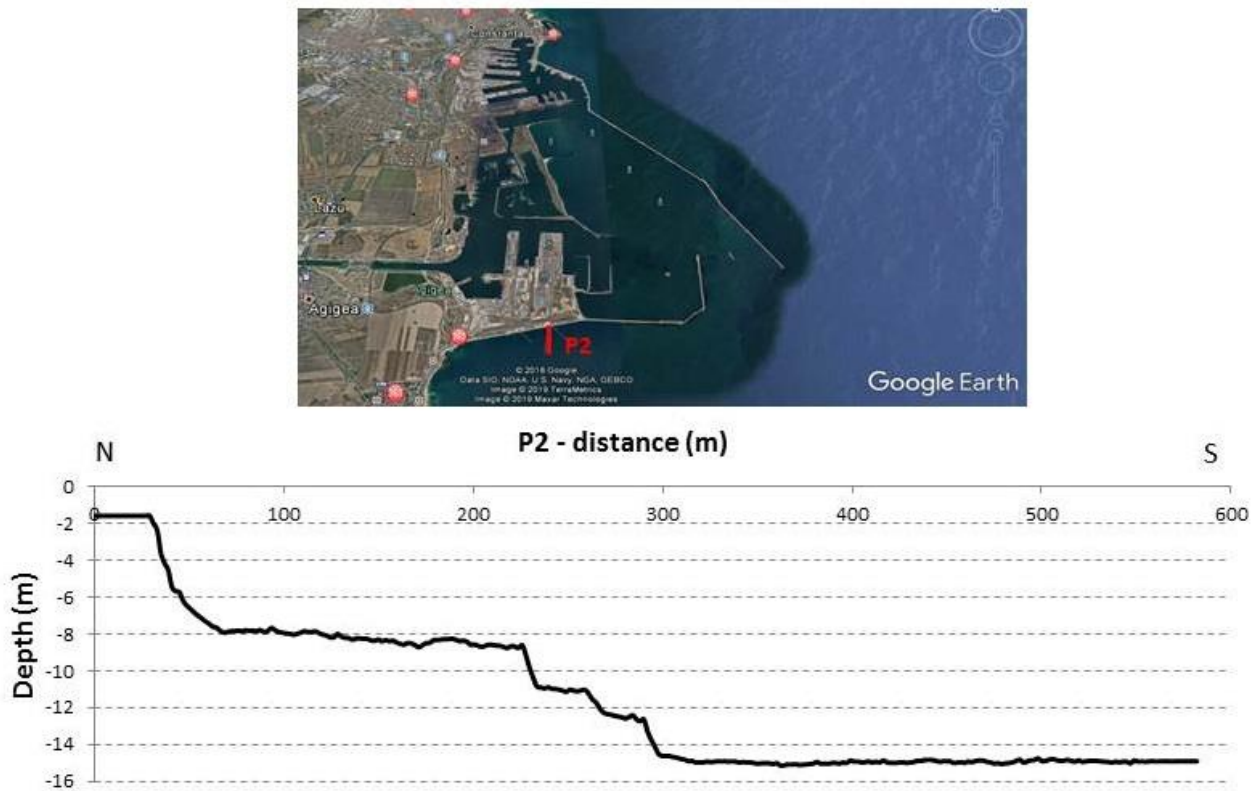


Figure 4 Upper panel: Google Earth image showing the location of the N–S orientated bathymetric profile; Lower panel: profile intercepting the limestone platforms at various depths on which circular depressions were sculpted in association with dissolution and mechanical processes

Recent bathymetric surveys confirmed the extension of a dyke in the proximity of the modern Mangalia Port southern dyke at 2 Mai. Similar findings along the banks of Limanu Lake was supposed to be large storage and mooring facilities which together with the submerged structures found in front of the city were supposed to reflect the existence of a double configuration port, consisting of an artificially built embayment in front of the city, harbouring the military vessels and a natural Limanu Valley

which was the shelter of the commercial port. Such complex harbour structures were frequent during the Greek and especially Roman Period, particularly at river mouths like it was the case of Portus, Rome's port (Keay et al, 2005) or Forum Iulii (Frejus) (Gébara and Morhange, 2011). However, subsequent archaeological surveys undertaken in the '90s within the city's walls interpreted the previously reported submerged findings as habitation area, not port structures (Alexandru et al., 2009). Yet, recent bath-

ymetric surveys intercepted a dyke like feature in the proximity of the southern dyke of modern Mangalia Port, while most of the submerged structures reported by Cosma (1973) and Scarlat (1976) are reported as lost during dredging activities undertaken for the modern port construction.

The planview shoreline inspection on cartographic documents between 1926 and 2002 reveals the existence of a sandy barrier at the mouth of the Limanu Valley in quasi-natural conditions (1926) which was further breached at its northern tip which

was the narrowest to permit the connection between the Limanu or Mangalia Lake with the sea. Its functioning was preserved by the construction of the northward dyke of the port (1960) which otherwise contributed to the sediment depletion and barrier destruction. The barrier was removed by 1979 once with the final configuration of the Mangalia Port (Fig. 5). A remnant of the former barrier persists today as the island in the NE part of the Limanu Lake entrance, where the present-day fishery is emplaced.

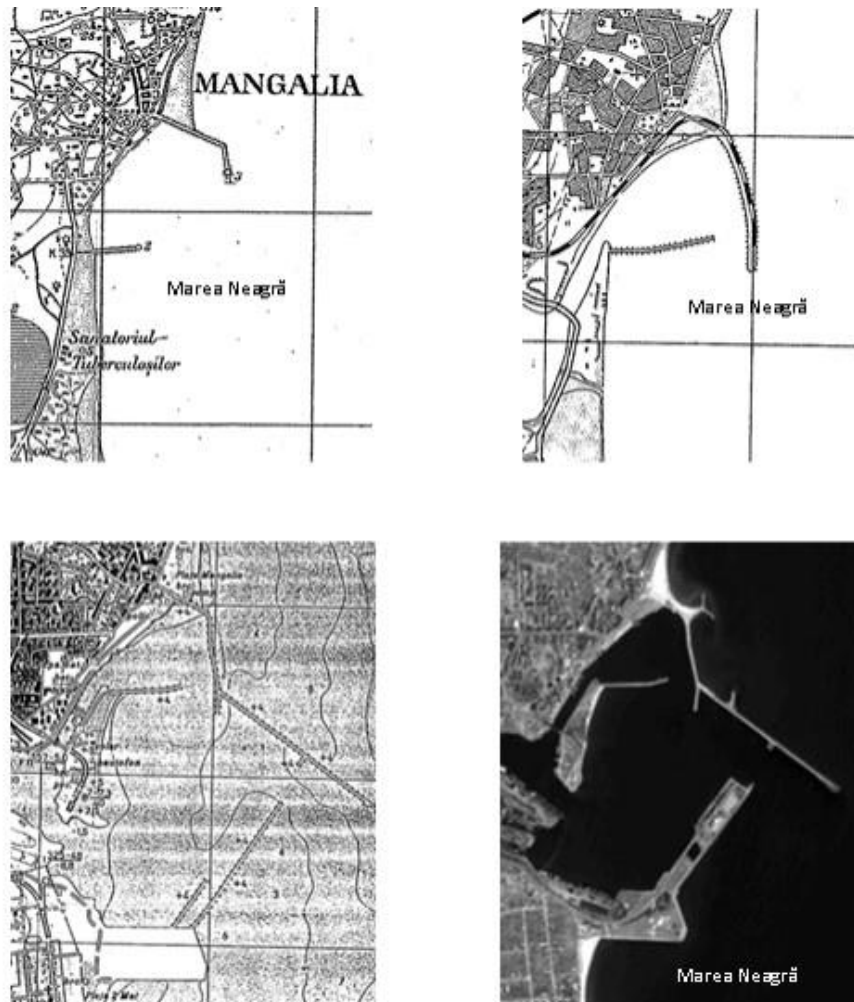


Figure 5 Mangalia (1926–2002). Cartographic documents showing Mangalia shoreline configuration at different times: 1926, 1960, 1979 and 2002 (*after Constantinescu, 2012*)

5. Discussions and Conclusions

A general pattern of morphological configuration could be identified as preferred setting for ancient Greeks to establish their colonies is represented by the presence of a river mouth lying in the proximity

of promontories or rocky heads directly into the sea or into a lake or lagoon. The promontories were particularly set as the fortified siege of political, cultural and administrative part of the city which encompassed the public buildings and the harboring structures, while the neighboring mainland was

occupied by the residential quarters. However, if taking into account the natural conditions of sand supply at the time of the Greek colonies foundation and the bidirectional character of wind and waves regime along the Danube delta coast (i.e. 59% winds coming from the N vs. 41% from the south, but due to wind speed and storm asymmetry to the North, the N/S ratio of the sediment longshore transport become as large as 2.53 cf. Vespremeanu–Stroe, 2004) it is unlikely that solely the natural shoreline configuration was exploited for harboring vessels. Great variability of the nearshore bathymetry and of the submerged nearshore bars is likely to have affected the navigability along the deltaic coast in natural conditions, therefore artificial harbor structures might have been emplaced in case of Histria. At places with comparatively less sediment input such in the case of Orgame, Tomis and Kallatis the reversing winds and waves might have been imposing an unbalanced marine energy affecting the navigability conditions which required the emplacement of harbors at relatively more sheltered locations that might be found at the southern part of the headlands or promontories. Otherwise, examples from other ancient Greek sites show that the port could have had also a remote position at several km from the city as is the case of Pergamum's Elaia harbor situated 26 km away from the city (Seelinger et al., 2014) or even Tomis which some scholars consider as Histrian *emporion* or harbor (cf. Memnon cited by Andrews, S., 2010).

All the colonies suffered from destructive events at different times caused either by inter-colonial wars, invasions, incendiaries such were those documented for the 3rd c. BC to which were added natural events such as earthquakes or natural siltation and coastline progradation. A combination of the latest natural events should have played an important role in the decline of Histria and Orgame cities which probably generated the collapse of various parts of the rocky limestone/green schist fundament across fault lines such as those intercepted on ERT profiles or investigated and reported in previous works: C–ridge formed at the contact between the old and the young ridge sets of Saele beach ridge plain (Preoteasa et al., 2013) at Histria

or visible on the maps at Orgame in the northern part of Doloşman Cape.

The drowned parts of Tomis and Kallatis with large sectors of built structures currently laying under seawater is the result of the marine erosion amplified by karstic and tectonic processes. Intense subsidence processes have been reported by the geophysical and geodynamic studies of the Romanian earth crust which yields the greatest subsidence rate in Dobrudja, reaching up to -3 mm/yr along the coastal strip (Dumitriu, 2012; Rădulescu et al., 2016).

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References

- Alexandru N, Constantin R, Ionescu M. 2009. Aspecte topografice ale cetății Kallatis în epoca romano-bizantină. *Pontica*, **37–38**: 419–438.
- Alexandrescu P. 2001. Noi cercetări și ipoteze cu privire la topografia și urbanismul Histriei. *Pontica*, **33–34**: 179–198.
- Andrews S. 2010. *Greek cities on the western coast of the Black Sea: Orgame, Histria, Tomis, and Kallatis (7th to 1st century BCE)*. PhD thesis, Iowa State University, Digital repository, 206p.
- Anthony DW. 2010. The rise and fall of old Europe. In: Anthony DW, Chi J. (eds.): *The lost world of Old Eu-*

- rope. *The Danube Valley, 5000–3500 BC*. New York: Institute for the Study of the Ancient World: 28–57.
- Avram A, Hind J, Tsetskhladze G. 2004. The Black Sea Area. In: Hansen MH and Nielsen TH (eds.): *An inventory of Archaic and Classical poleis*. Oxford Press, 924–973.
- Bailey D. 2000. *Balkan Prehistory: exclusion, incorporation and identity*. London and New York: Routledge.
- Balabanov I. 2002. Holocene sea-level changes in the Black Sea. In: Yanko-Hombach V, Golbert AS, Panin N, Dolukanov PM (eds.): *The Black Sea Flood Question: Changes in Coastline, Climate and Human Settlement*. Springer, Dordrecht, 711–730.
- Bolikhovskaya NS, Porotov AV, Richards K, Kaitamba MD, Faustov SS, Korotaev VN. 2018. Detailed reconstructions of Holocene climate and environmental changes in the Taman (Kuban River delta region) and their correlations with rapid sea-level fluctuations of the Black Sea. *Quaternary International*, **465**: 22–36.
- Bony G, Marriner N, Morhange Ch, Kaniewski D, Perincek D. 2012. A high-energy deposit in the Byzantine harbour of Yenikapi, Istanbul (Turkey). *Quaternary International*, **266**: 117–130.
- Bony G, Morhange C, Marriner N, Baralis A, Kaniewski D, Rossignol I, Lungu V. 2015. History and influence of the Danube Delta lobes on the evolution of the ancient harbour of Orgame (Dobrogea, Romania). *Journal of Archaeological Science*, **61**: 186–203.
- Bounegru O. 2002. *Comerț și navigatori la Pontul stîng și Dunărea de Jos (sec. I–III, p. Chr)*. Casa editorială Demiurg, 284p.
- Bounegru O. 2003. Portul Histriei în Antichitate în: *Economie și societate în spațiul ponto-egean sec. II AC–III PC*. Casa Editorială Demiurg, Iași (2003): 34.
- Brătescu C. 1944. Oscilații de nivel ale apelor și bazinului Mării Negre. *Bul. Soc. Reg. de Geografie*, **IX**: 66–107.
- Buzoianu L, Bărbulescu M. 2011. Materiale arheologice elenistice recent descoperite în teritoriul Callatian. *Peuce*, **IX**: 459–468.
- Brückner H, Kelterbaum D, Marunchak O, Porotov A, Vött A. 2010. The Holocene sea level story since 7500 BP – lessons from the Eastern Mediterranean, the Black and the Azov Seas. *Quaternary International*, **225** (2): 16–179.
- Capotă A. 1980. *Studiu geologic, hidrologic și chimic privind apele mezotermale sulfuroase din zona Mangalia de Nord*, București.
- Chepalyga A. 1984. Inlands sea basins. In: Velichko AA, Wright HE, Barnosky CW (eds.): *Late Quaternary Environments of the Soviet Union*. University of Minnesota Press, Minneapolis, 237–240.
- Constantinescu Șt. 2012. *Analiza geomorfologică a țărmului cu faleză între Cap Midia și Vama Veche*. Editura Universitară, 182p. (in Romanian)
- Constantinescu Șt, Giosan L. 2017. Marginal deltaic coasts in transition: from natural to anthropogenic along the southern Romanian cliffed coast. *Anthropocene*, doi.org/10.1016/j.ancene.2017.08.005.
- Dăbâca M. 2012. Instalații portuare în cetățile greco-romane din jurul Pontului Euxin. *SCIIVA*, **63**(3–4): 357–359.
- Dăbâca M. 2013. Noi cercetări arheologice în partea de sud a cetății Histria. Campaniile 2003–2009. *Materiale și cercetări arheologice*, SN **IX**: 157–188.
- Delile H, Abichou A, Gadhoun A, Goiran JP, Pleuger E, Monchambert JY, Wilson A, Fentress E, Quinn J, Ben Jerbania I, Ghazzi F. 2015. The geoarchaeology of Utica, Tunisia: The paleogeography of the Mejerda Delta and hypotheses concerning the location of the ancient harbor. *Geoarchaeology*, **30**(4): 291–306.
- Dimitriu RG. 2012. Geodynamic and hydro-geological constraints regarding the extension of the prospective archaeo-cultural area within the northern Romanian coastal zone. *Quaternary International*, **261**: 32–42.
- Fedorov PV, Skira IA. 1957. Epoca actuală în istoria geologică a Mării Negre. *Analele Rom. Sov. Seria Geol. Geogr.*, **3**.
- Filipova-Marinova M, Pavlov D, Giosan L. 2016. Multi-proxy records of Holocene palaeoenvironmental changes in the Varna Lake area, western Black Sea coast. *Quaternary International*, **401**: 99–108.
- Flaux C, El-Assal M, Shaalan C, Marriner N, Morhange C, Torab M, Goiran JP, Empereur JY. 2017b. Geoarchaeology of Portus Mareoticus: Ancient Alexandria's lake harbour (Nile Delta, Egypt). *Journal of Archaeological Science: Reports*, **13**: 669–681.
- Florescu R. 2001. Des tremblements de terre et des invasions en Schythie Mineure pendant l'antiquité et l'antiquité tardive. *Pontica*, **33–34**: 451–457.
- Halcrow 2011. *Iterim Report of the Romanian coastal zone*. Administrația Națională Apele Române.
- Fouache E, Kelterbaum D, Brückner H, Lericolais G, Porotov A, Dikarev V. 2012. The Late-Holocene evolution of the Black Sea: a critical review on the so called Phanagorian regression. *Quaternary International*, **266**: 162–164.
- Gébara C, Morhange C. 2011. Fréjus (Forum Iulii): le port antique/the ancient harbour. *Journal of Roman Archaeology*, supplement series, **77**, Oxford.
- Giaime M, Avnaim-Katav S, Morhange Ch, Marriner N, Rostek F, Porotov AV, Baralis A, Kaniewski D, Brückner H, Kelterbaum D. 2016. Evolution of Taman Peninsula's ancient Bosphorus channels, south-west Russia, Deltaic progradation and Greek colonization. *Journal of Archaeological Science: Reports*, **5**: 327–335.

- Hanganu D. 2012. *Histria – studiu de geoarheologie*. Unpublished PhD thesis, Bucharest University. (in Romanian).
- Kelterbaum D, Brückner H, Porotov A, Schlottzhauer U, Zhuravlev D. 2011. Geoarchaeology of Taman Peninsula (SW Russia): the example of the ancient Greek settlement of Golubitskaya 2. *Die Erde*, **142**: 235–258.
- Keay S, Millett M, Paroli L, Strutt K. 2005. *Portus: an Archaeological Survey of the Port of Imperial Rome*. British School at Rome.
- Laermans H, May SM, Kelterbaum D, Kirkitadze G, Opitz S, Navrozashvili L, Elashvili M, Brückner H. 2019. Coastal lowlands and floodplain evolution along the lower reaches of the Supsa River (western Georgia). *Quaternary Science Journal*, **68**: 119–139.
- Lazăr C. 2012. *The catalogue of the Neolithic and Eneolithic funerary findings from Romania*. Târgoviște, Cetatea de Scaun Publishing Press.
- Marriner N, Morhange Ch, Carayon N. 2008. Ancient Tyre and its harbours: 5000 years of human–environment interactions. *Journal of Archaeological Sciences*, **35**: 1281–1310.
- Panin N, Popescu I. 2002. The northwestern Black Sea: climatic and sea-level changes in the Late Quaternary. In: Yanko–Hombach V, Golbert AS, Panin N, Dolukhanov PM. (eds.): *The Black Sea Flood Question: Changes in Coastline, Climate and Human Settlement*. Springer, Dordrecht, 387–404.
- Popescu N, Ielenicz M. 2003. Relieful Podișului Dobrogei – caracteristici și evoluție, *Analele Universității București*: 5–58.
- Preoteasa L, Vespremeanu–Stroe A, Hanganu D, Katona O, Timar–Gabor A. 2013. Coastal changes from open coast to present lagoon system in Histria region (Danube delta). In: Conley DC, Masselink G, Russell PE, O'Hare TJ (eds.): *Proceedings 12th International Coastal Symposium (Plymouth, England)*, *Journal of Coastal Research*, SI **65**: 564–569.
- Preoteasa L, Vespremeanu–Stroe A, Panaiotu C, Rotaru S, Tuțuianu L, Sava T, Bîrzescu I, Dimofte D, Sava G, Mirea DA, Ailincăi S. 2019. Neolithic to modern period paleogeographic transformations in southern Danube Delta and their impact on human settlements from Enisala–Babadag region. *Quaternary International*, **504**: 139–152.
- Scorpan C. 1970. Ancore antice descoperite pe coastele submarine ale Kallatisului și unele probleme ale navigației în Pontul Stâng. *SCIV*, **21**: 639–647.
- Scarlat C. 1973. Portul antic Kallatis. Cercetări de arheologie submarină. *AMN*, **10**: 529–540.
- Seelinger M, Brill D, Feuser S, Bartz M, Kelterbaum D, Vött A, Klein Ch, Pirson F, Bruckner H. 2014. The purpose and age of underwater walls in the Bay of Elaia of Western Turkey: a multidisciplinary approach. *Geoarchaeology: An international Journal*, **29**: 138–155.
- Summerer L. 2007. Greeks and natives on the Southern Black Sea coast in antiquity. In: St. Michel (Hrsg.): *The Black Sea: Past, Present and Future, Proceedings of the inter-disciplinary conference in Istanbul*, 14–16 October, London, 27–36.
- Ștefan AIS. 1974. Cercetări aerofotografice privind topografia urbană a Histriei, I. Epoca romană (sec I–II e.n), *RMM–MIA* **2**.
- Rădoi A. 1986. *Probleme de Geografie*, III.
- Rădulescu F, Mocanu V, Nacu V, Diaconescu C. 2016. Study of recent crustal movements in Romania: a review. *Journal of Geodynamics*, **22** (1–2): 33–50.
- Rădulescu A. 1966. *Monumente romano–bizantine din sectorul de vest al Cetații Tomisului*. Constanța, 5–84.
- Rădulescu A, Scorpan C. 1971. Rezultate preliminare ale săpăturilor arheologice din Tomis, Parcul Catedralei. *Pontica*, **8**: 9–54.
- Vâlsan G. 1935. Sur une plateforme littorale en Roumanie. *Bul. Soc. Geogr.*, **LIV**: 23–31.
- Vespremeanu–Stroe A. 2004. Transportul de sedimente în lungul țărmului și regimul valurilor pe coasta Deltei Dunării. *Studii și cercetări de oceanografie costieră*, **1**.
- Vespremeanu–Stroe A, Preoteasa L, Hanganu D, Brown T, Bîrzescu I, Toms P, Timar–Gabor A. 2013. The impact of the Late Holocene coastal changes on the rise and decay of the ancient city of Histria (Southern Danube Delta). *Quaternary International*, **293**: 245–256.
- Vespremeanu–Stroe A, Zăinescu F, Preoteasa L, Tătui F, Rotaru S, Morhange Ch, Stoica M, Hanganu J, Gabor–Timar A, Cărdan I. 2017. Holocene evolution of the Danube delta: an integral reconstruction and a revised chronology. *Marine Geology*, **388**: 38–61.
- Vulpe R. 1969. Note de istorie tomitană. *Pontice*, **2**: 149–167.

Landforms and rural development: The evolution of human settlements at alpine alluvial fans in the Admont Valley, Austria, since 1784 AD

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ABSTRACT

We used two historical maps that cover vast areas of central and eastern Europe at rather large scales dating to 1784 (First Military Survey of the Habsburg Empire; total extent 640,000 km²; scale 1: 28,800) and 1824 (cadastral land register of Francis I; 670,000 km²; 1: 2,880) to extract individual buildings located at several alluvial fans in one valley in Austria (Admont Valley). Historic buildings were mapped and compared with present building (airborne–laserscanning based: 2008–2017), geomorphic (landform distribution), geomorphodynamic (documented damaging events at torrents), and spatial planning (hazard zonation maps) data. Results show that 69.2% of all present buildings are located at only 7% of the study area. Whereas the 1784–data are too inaccurate and unprecise for detailed spatial analyses, the 1824–data are very accurate and precise allowing spatial and socio–economic insight into the population and building evolution over a 190–year period. Results show for instance that despite a tremendous increase in buildings (911 in 1824; 3,554 in 2008–2017), the proportion of buildings exposed to torrents–related natural hazards significantly decreased by 10.4% for yellow (moderate–risk) and by 13.7% for red (high–risk) zones. Similar historio–geomorphological studies as presented here might be accomplished in other countries in central and eastern Europe covered by the indicated historical map products.

KEYWORDS

Landform–settlement linkage; alluvial fan; natural hazard zonation; Habsburg Empire; historical maps

1. Introduction

The initial establishment and evolution of settlements is very often determined by geomorphological conditions and constraints in a given area. Dur-

ing periods of settlement foundation, people commonly try to find locations which suit their diversified needs at best. Such needs might be related for instance to agricultural activities (e.g. gentle slopes

morphologically suitable for agriculture and with sufficient water and nutrient supply, but also with plant-growing favouring local topo-climatic conditions), to strategic considerations (e.g. mountain plateau or summit location for defence reasons and formation of hill-top settlements), to transport infrastructure (e.g. junction of trading routes or the intersection of a trading route with a river crossing in form of a bridge or ford) or to natural-hazard avoidance (e.g. avoiding flood-prone alluvial plains). Particularly in alpine valleys, the issue of natural-hazard avoidance is a very important one. But areas without the risk of being exposed to natural hazards are rare.

Areas prone to landslides, floods, debris floods, debris flows, or snow avalanches reduce the possible settlement area of alpine regions. Thus, people settling in such regions had to decide the lesser of two (or even more) evils such as annual floods at alluvial plains versus occasional debris flows or floods from torrents at alluvial fans. Alluvial plains of large, meandering rivers in alpine valleys of Austria, for instance, were mainly avoided, because of more-or-less regular spring floods during the snow-melt period inundating the plains. Thus, people settled and reclaimed land more commonly at alluvial fans adjacent to the alluvial plains which were formed by tributary creeks. Damaging events such as debris flows or floods also occurred on fans, but not on an annual basis. People were surely aware of the threat of potential natural hazard events at alluvial fans. Patzelt (1987) for instance studied the evolution of alluvial fans in western Austria at a Holocene-time scale, revealing that sediment accumulation prevails in a sequence of sediment accumulation, erosion and stagnation. According to Patzelt, periods of accumulation correlate with periods of climatic deterioration (e.g. the Little Ice Age) inferred from the development of vegetation and glaciers. Based mainly on archaeological excavations, Zanesco et al. (2008) report from massive sedimentation at the alluvial fan of Hall in Tyrol (Fig. 2) where more than two meters of sediments were deposited during one single flooding event in the year 1275 AD. This suggests the importance of high-magnitude but low-frequency events for geomorphic changes at (settled) alluvial fans.

Archaeological research at alluvial fans also helps to understand the long-term relationship between settlement and fan evolution. Excavations at the ancient town of Aguntum (Figs. 1, 3), the only antique city in the Austrian province of Tyrol, revealed a substantial surface elevation increase during the c. 500 years of building activities. Aguntum was founded at the alluvial fan of an alpine torrent named Debant Creek. Figure 1 illustrates parts of the city with the eastern city wall as well as surface elevation change markers during the settlement period (1st to 6th century AD) as it is presented to modern visitors of this roman settlement site. The depicted stepwise rise of the surface over time must be seen in a schematic way. The reason for the raising of the terrain between c.100 and 400 AD was – according to archaeologists – mainly artificial filling by the Romans and only to a minor extent by natural sources such as debris-charged floods. Unterweger (2018) suggests that the inhabitants of Aguntum protected their settlement by water protection constructions diverting the water course of the Debant Creek to the west and thus letting it pass the city of Aguntum at its western periphery. After the city was abandoned, the creek reclaimed its alluvial fan and moved towards the central part of Aguntum. This partly covered the ancient surface with a complex debris layer resulting from repeated flooding events and with a thickness of up to three meters (Auer, 2013; Unterweger, 2018).

The growth of settlements in higher-elevated zones of alpine areas – as the European Alps – was slow in historical times as pointed out by Slaymaker and Embleton–Hamann (2009). This contrasts with the bottoms of the main valleys with their large alluvial fans. At the valley bottoms and particularly at alluvial fans, a strong population growth occurred with a continuous trend over the past 150 years (Slaymaker and Embleton–Hamann, 2009). Such an increase in population and thus housing development over time is not always straightforward to bring into a temporal-spatial dimension due to lacking or only poor-quality maps.

The increased availability of historic maps with a reasonable scale and accuracy in digital formats, allows to perform long-term (in our case >200 years) studies related to settlement evolution. In the

present study we aimed to quantify and illustrate the settlement evolution of a historically important valley in alpine Austria, focussing on one landform type, namely alluvial fan. More specifically, the aims of this paper are to (a) compare the spatial pattern and distribution of buildings and settlements at eight alluvial fans in the Admont Valley (cf. Fig. 1) between the early period of official land mapping at rather large scale in 1784 (1:28,800), in 1824 (1:2,880) and today (1:500), and to combine this information with (b) present-day hazard-zone plans as well as with (c) documented damaging natural hazard events, and finally (d) to discuss these relationships in a broader historio-geomorphological context.

2. Study area

The study area named Admont Valley is a ca. 20 km long valley segment of the Enns valley, and its surrounding mountains in central Austria (Fig. 2). The Admont Valley was first mentioned in written sources in 859 AD as *Adamundi valle* (List, 1974). One interpretation of this name is that it originally comes from the Latin word *ad monte* meaning near the mountains. In 1074 AD, a Benedictine abbey was

founded in this valley (Wichner, 1880). As passed on by a legend, the originally selected location of the abbey north of the Enns River near its riverbank was prone to floods and snow avalanches (Krause, 1966). Thus, the archbishop of Salzburg decided to establish the abbey at the lower part of an alluvial fan formed by the Lichtmessbach torrent, south of the Enns River (Fig. 3a). The torrent originates from further to the south (named Kaiseraubach there) and flows through easily erodible phyllitic rocks. The torrent repeatedly harmed the settlement of Admont, which eventually led to the construction of a large retention dam in 2013–2015 in the upper section named Kaiserau (Fig. 3a).

The Enns valley at Admont is morphologically dominated by a broad alluvial plain with distinct meander loops partly filled by oxbow lakes. As depicted by the historical maps listed further below and recent airborne laser scanning (ALS) data, the meandering Enns River in the Admont Valley changed the course substantially over time – at least until the mid-19th century. In the 19th century, water regulation measures modified the channel course and lowered the water level of the Enns River by several meters (Reismann et al., 2015).



Figure 1 Ruins of the former roman settlement of Aguntum in western Austria built on the alluvial fan of the Debant Creek. (a) Overview map of the archaeological site with the city gate and city wall to the left; (b) schematic chronological evolution of the increase of surface elevation over time between ca. 100 and 400 AD. Source of photos: authors.

For location, see Fig. 2

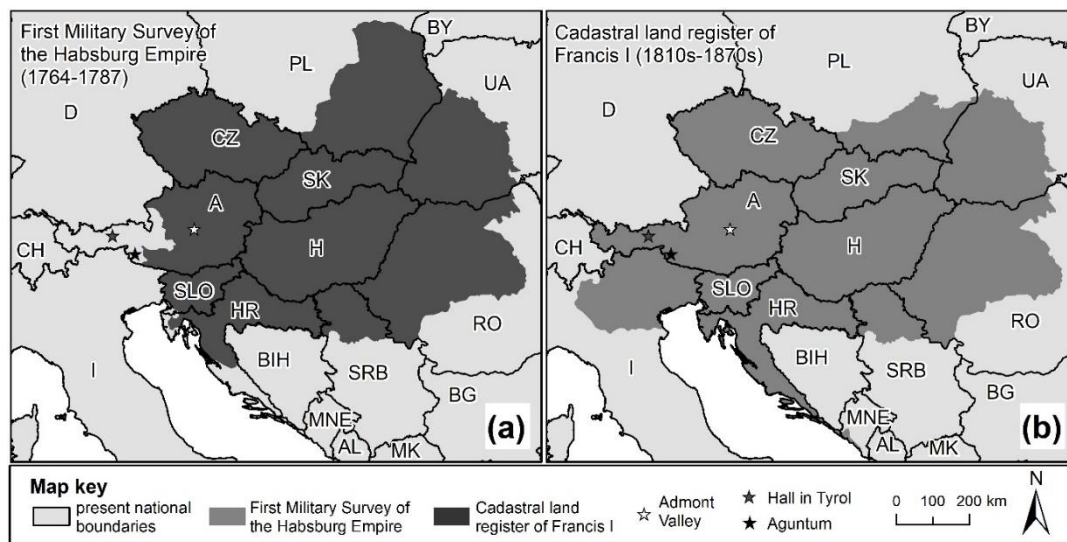


Figure 2 Location of the study area Admont Valley in Austria and its spatial relationships to the (a) First Military Survey of the Habsburg Empire (1764–1787) – excluding present-day Belgium – as well as the (b) cadastral land register of Francis I (1810s–1870s). Two settlements located on alluvial fans mentioned in the text are indicated. Data base for (a) is Hofstätter (1989) and mapire (<https://mapire.eu/en>); data base for (b) is Fuhrmann (2007)

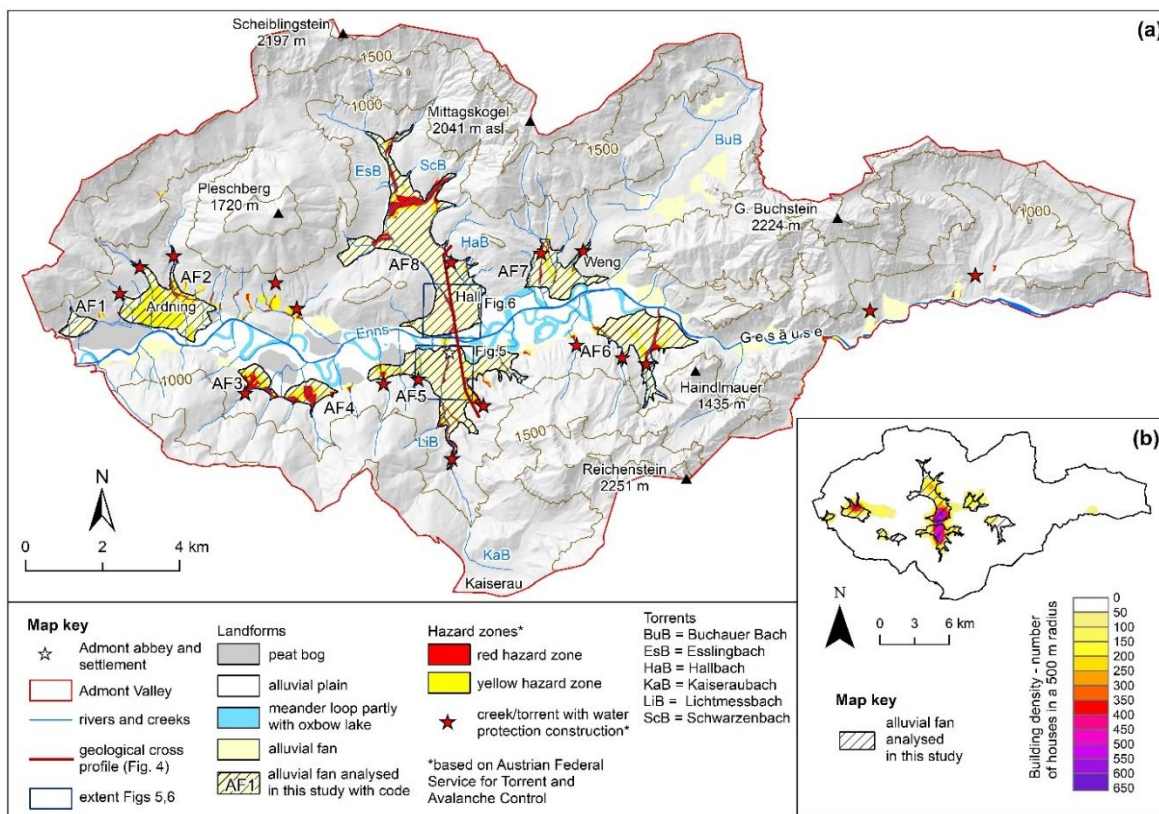


Figure 3 Study area Admont Valley: (a) overview map with the location and extent of the eight studied alluvial fans (AF1–8), relevant fluvial landforms as well as the spatial extent of yellow (moderate-risk) and red (high risk) hazard zones along torrents (mostly with protection constructions) as defined by the hazard-zone maps of the Austrian Federal Service for Torrent and Avalanche Control (zonation based on Federal Ministry for Sustainability and Tourism 2017). (b) Building density in the Admont Valley in relation to the eight studied alluvial fans (building data taken from Land Steiermark)

Topographically connected and sedimentologically interlocked with the alluvial plain are the numerous alluvial fans on both valley sides. Two large fans (AF5, AF6 in Fig. 3a) are at the southern side and further three large ones are on the northern side (AF2, AF7, AF8). The reason for the existence of the alluvial plain is that the valley east of alluvial fan AF6 is narrowing. There, the Enns River enters a gorge named Gesäuse attributed to the noise-making cataracts of the Enns River. Repeated mass-movement events during the Lateglacial and Holocene period at the western end of this narrowing called Haindlmauer (Büchner, 1974) caused backwaters of the Enns River leading to the formation of

temporal lakes with related sedimentation (alternating strata of pebbles, sand, silt and peat) as indicated by drillings (cf. Fig. 4).

The main landforms of interest with their settlement evolutions are eight alluvial fans covering a total area of 16.6 km², which is 7% of the entire Admont Valley (236.1 km²). Table 1 lists names, codes used in this study and areal extent of the eight fans. As indicated by the building-density map in Figure 3b, by far most of the present buildings in the Admont Valley (n=5135; see further below for data source) are located at the eight alluvial fans (n=3554; i.e. 69.2%) highlighting the importance of alluvial fans for settlement evolution.

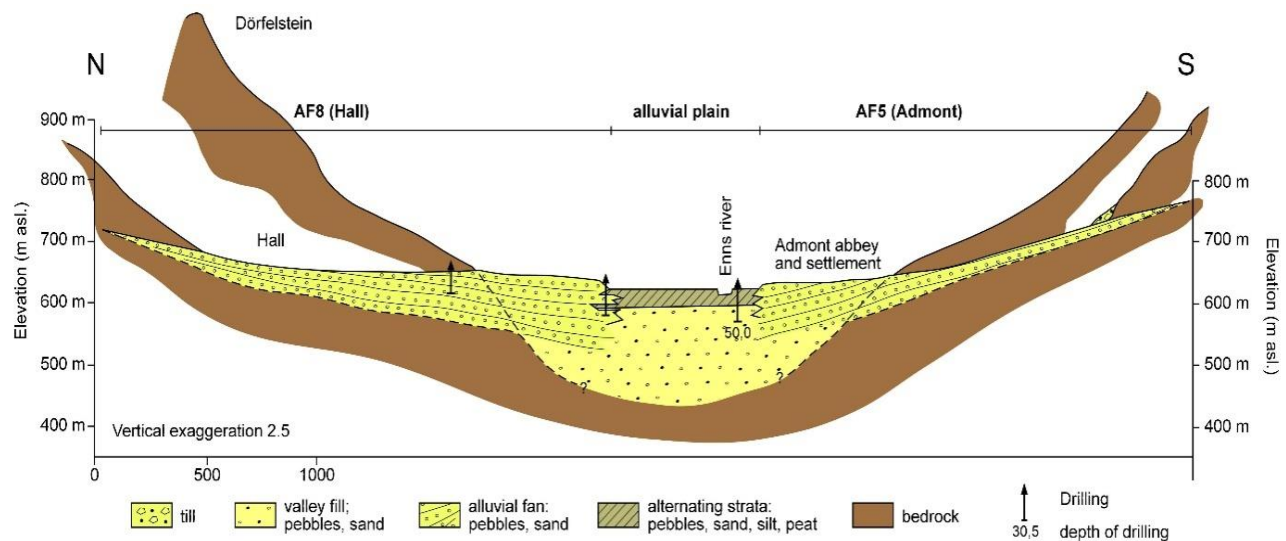


Figure 4 Geological cross profile through the Admont Valley from north to south crossing the two large alluvial fans at Admont (AF5) and Hall (AF8). Note the interlocked sedimentary structure in the valley bottom related to the repeated damming of the Admont Valley by mass movements further east (data source: Kellerer-Pirklbauer et al., 2004, modified)

Table 1 The eight studied alluvial fans (AF) in the Admont Valley listing codes, total area of the alluvial fans as well as their shares (km²) and percentages, respectively, considered by yellow (moderate-risk) and red (high-risk) hazard zones (cf. Fig. 3)

Code	Name	Area (km ²)					Area (%)			
		total	yellow	hazard zone red	both	outside	yellow	hazard zone red	both	outside
AF1	Pürgschachen	0.37	0.00	0.00	0.00	0.37	0.0	0.0	0.0	100.0
AF2	Ardning	2.36	1.25	0.11	1.36	1.01	52.7	4.7	57.4	42.6
AF3	Dörfler Siedlung	0.43	0.14	0.14	0.28	0.15	33.2	33.0	66.2	33.8
AF4	Treffner	0.57	0.15	0.17	0.32	0.25	26.7	29.7	56.4	43.6
AF5	Admont	3.41	0.43	0.31	0.74	2.68	12.5	9.1	21.6	78.4
AF6	Krumau	2.15	0.19	0.12	0.31	1.85	8.9	5.4	14.3	85.7
AF7	Weng	1.41	0.19	0.11	0.30	1.11	13.3	7.8	21.1	78.9
AF8	Hall	5.94	0.33	0.72	1.05	4.88	5.6	12.2	17.8	82.2
All		16.64	2.68	1.68	4.36	12.28	16.1	10.1	26.2	73.8

3. Material and Methods

3.1 Historical maps: 1784 and 1824

A substantial improvement of the quality of maps of Central Europe was the First Military Survey of the Habsburg Empire carried out between 1764 and 1787 (Hofstätter, 1989). The First Military Survey of the Habsburg Empire (or Josephinische Landesaufnahme) was initiated by the order of Empress Maria Theresia in the 1760s and finalised more than two decades later during the reign of Emperor Josef II. Decisive for this survey were military interests related to the disadvantages of the Austrian army during the Seven Years' War in 1756–1763. The scale of the survey sheets (about 4,000) was 1:28,800. The survey had neither a triangulation basis, nor clearly defined projection (Hofstätter, 1989) impacting severely georeferencing procedures (Mólnar et al., 2014). Figure 2a depicts the spatial extent of the First Military Survey of the Habsburg Empire – excluding present-day Belgium – covering about 640,000 km².

During the First Military Survey of the Habsburg Empire in the period 1764–1787, the Admont Valley belonged to the administration unit Innerösterreich (Hofstätter, 1989). This part of the former Habsburg Empire was surveyed in 1784–1785 (for simplicity hereafter considered as 1784). The sheets from this survey are nowadays available online (digital access <https://mapire.eu/en>) even as georeferenced products with a rather good geometric accuracy (Mólnar et al. 2014). For the present study we had access to a georeferenced map of the First Military Survey computed by the Federal Government of Styria. Furthermore, we also used the relevant maps from Mapire for accuracy-assessment reasons. At Mapire, we exported the relevant map sections from their website and georeferenced them in ArcGIS 10.5. Suitable objects for georeferencing were churches (Weng, Ardning, and Hall), historical buildings (Admont Abbey) and bridges which still exist today and where the building geometry in the historical map seemed comparable to the one of today. The georeferencing procedure was enabled by using high resolution terrain data (1 m digital elevation model based on air-borne laserscanning data) provided by the Federal Government of Styria, freely

available optical remote sensing data (ArcGIS base data) and the open street map.

The First Military Survey was followed by the substantially improved Second Military Survey of the Habsburg Empire (or Franziszeische Landesaufnahme) in 1808–1869 and the Third Military Survey of the Habsburg (or Franzisco–Josephinische–Landesaufnahme) in 1869–1887 (Hofstätter, 1989). An important further development during the Habsburg Empire was the detailed mapping and development of the cadastral land register of Francis I (Franziszeischer Kataster or Stabiler Kataster) accomplished between 1817 and 1861 (Fuhrmann, 2007). The scale of the cadastral land register was (apart from alpine and urban areas) 1:2,880 consisting of more than 53,200 sheets covering a total area of about 670,000 km² (Fig. 2b).

The survey for the cadastral land register of Francis I in the Admont Valley was performed in 1824. The data from this survey were also taken from Mapire (digital access <https://mapire.eu/en>) where we exported the relevant sections from the website and georeferenced them in ArcGIS 10.5 using the same remote sensing data as indicated above. Suitable objects for georeferencing were again churches, historical buildings, and bridges.

After georeferencing both historical maps (1784 and 1824), we digitised the spatial geometry of buildings that were located during those times at one of the eight alluvial fans. The accuracy of the georeferencing procedure for the cadastral land register of Francis I (scale 1:2,880) was high with about 10 m as judged from georeferencing quality control checks. The accuracy of the georeferenced maps of the First Military Survey of the Habsburg Empire is, however, much poorer due to the distortion of the map related to triangulation and projection problems (Mólnar et al., 2014) but also due to the substantially smaller scale (1:28,800).

3.2 Further data sources and data analyses

A high-resolution terrain model with a 1 m resolution (provided by the Federal Government of Styria) derived from ALS-data and freely available optical remote sensing data were used to map the different landforms in the Admont Valley focusing particularly on alluvial fans. Based on ALS data primarily

dating to 2008–2012 and occasionally to 2017 (for simplicity hereafter considered as 2008–2017), the Federal Government of Styria extracted the geometry of all buildings in the federal province of Styria mapped at scale 1:500. This dataset comprises 5135 buildings for the Admont Valley, 69.2% of them

($n=3554$) are located on one of the eight studied alluvial fans (Land Steiermark, 2019). The building density for the Admont Valley (Fig. 3b) was calculated using these data and the point density function (with 10m grid size, 500m radius) in ArcGIS.

Table 2 Documented damaging events at the eight studied alluvial fans (AF) in the Admont Valley in 1851–2017 distinguished between floods (flood), fluvial sediment transport events (notable but <20% volumetric debris content; flu-se), debris floods (20–<40% debris content; de-flood), debris flows (>40% debris content; de-flow), landslides (landsl) and snow avalanches (avala). Data taken from WLK 2019

Code	flood	flu-se	de-flood	de-flow	landsl	avala	sum
AF1	0	0	0	0	0	0	0
AF2	7	7	1	2	0	2	19
AF3	0	0	0	1	0	0	1
AF4	0	0	0	0	0	0	0
AF5	3	0	0	4	1	0	8
AF6	0	10	0	0	0	1	11
AF7	3	5	2	0	0	0	10
AF8	6	4	0	0	0	0	10
<i>all</i>	<i>19</i>	<i>26</i>	<i>3</i>	<i>7</i>	<i>1</i>	<i>3</i>	<i>59</i>

Data about the population evolution between 1869 and 2018 in the study area were taken from Statistik Austria (2019). The Austrian Federal Service for Torrent and Avalanche Control (WLV) provided digital hazard zonation maps that define yellow and red hazard zones for torrents and avalanche areas (Federal Ministry for Sustainability and Tourism, 2017). The delineation of these hazard zones in the Admont Valley was accomplished in the period 1981–2015. Red hazard zones indicate areas where construction of new houses is prohibited (high-risk zones). Yellow hazard zones define areas where significant damage to properties or infrastructure must be expected and therefore construction is restricted (moderate-risk zones).

The WLV also provided data regarding flood and debris-flow protection structures (pers. comm. Markus Mayerl) for this study. Finally, damaging events related to snow and water processes in the Admont Valley were also kindly provided by the WLV containing the period 1851–2017 (WLK, 2019). Spatial analyses were accomplished in ArcGIS. Statistical analyses were performed in Excel and SPSS.

4. Results

4.1 Alluvial fans and natural hazards related to torrents

The eight studied alluvial fans in the Admont Valley vary in size from 0.37 to 5.94 km² summing up to 16.64 km² (Table 1). About 26% of this area is considered in modern hazard zonation plans; 16% of it is in yellow hazard zones and 10% in red hazard zones. As depicted in Figure 3 and summarized in Table 1, the relative proportions of the two hazard zone types at the eight different alluvial fans vary substantially. No hazard zones are designated at AF1 related to a (building-sheltering) road construction (highway A9/E57) at the upper part of the fan. About 57% of AF2 are either classified as yellow (52.7%) or red hazard zone (4.7%) even though water protection structures were built at three torrents flowing onto the fan. AF3 and AF4 are of similar size and similarly considered by hazard zones. The relative shares of red and yellow zones at the two fans AF5 and AF7 is similar with 21% in both cases. At AF6 hazard zones are by one third less important regarding relative proportion. Finally, at the very lar-

ge alluvial fan AF8 (36% of the entire study area) red zones are extended along the Schwarzenbach and Esslingbach torrents. However, the total relative share regarding hazard zones at this fan is moderate with 18%.

Altogether, 95 damaging events related to snow and water were inventoried by the Austrian Federal Service for Torrent and Avalanche Control (WLK, 2019) for the period 1851–2017 in the Admont Valley. Most of the 95 events occurred along creeks and torrents all over the Admont Valley. 59 out of these 95 events (62%) occurred on the eight alluvial fans, by far most of them at AF2 (19) followed by AF6–8 (10–11 events). The Lichtmessbach for instance caused damaging floods (1897, 1951) and debris flows (1851, 1885, 1949) at the AF5. Regarding process types, most importantly are fluvial sediment transport events (26) and floods (19) followed by debris flows (7). These results imply that the largest and most-populated alluvial fans are also the ones which experienced most damaging events in the past. It is the question if this result reveals the natural circumstances or if it originates in the fact that only the incidences that caused damage to human infrastructure were noted. Without further field analysis this question cannot be answered.

4.2 Building structure in 1784

199 buildings were mapped at the eight studied alluvial fans for 1784. By far most of the buildings were delineated at AF8 (81) followed by AF5 (38) and AF2 (30). Table 3a lists the number of houses at the eight alluvial fans and their spatial relationship to yellow and red hazard zones. The table contains furthermore the spatial extent and some spatial statistics for all mapped buildings for 1784. The average size of all mapped 199 building is 1074 m². The buildings ranged from 271 to 15,953 m² in size. Figures 5a and 6a show exemplarily the mapping results of sub-areas AF5 and AF8. As depicted, the buildings look generalized attributed mainly to the original map scale of 1:28,800. The four largest buildings in 1784 are all at AF5 also shown in Figure 5a. The third-largest building is the Benedictine Abbey of Admont, presented as a U-shaped polygon; the other three are elongated blocks. Figure 7a distinguishes graphically the number of buildings per

alluvial fan located within or outside hazard zones. 29% of the buildings were partly or entirely in a present-day red zone area whereas 41% would have been within a yellow-zone area. Figure 8 presents the relative shares of the studied alluvial fans covered by buildings during the three different stages. Results show that the relative shares of the alluvial fans covered by buildings varied in 1784 between 0.5 (AF4) and 2.3% (AF5) averaging to 1.3% of the total area. In absolute numbers, this is 0.21 km² of the 16.61 km² large study area.

4.3. Building structure in 1824

For the year 1824 altogether 911 buildings were mapped at the eight alluvial fans. At this stage – different to 1784 – most of the buildings were delineated at AF5 (303) followed by AF8 (282) slightly behind (Table 3b). Table 3b contains the spatial extent and spatial statistics for all mapped buildings from this year. The average size of all 911 buildings is 164 m² and hence only about 15% of the mean building size mapped in 1784. The buildings in 1824 ranged from only 6 (much smaller than in 1784) to 14,977 m² (like 1784) in size. The smallest buildings were often barns distributed over the agricultural land. Figures 5b and 6b show selected mapping results for parts of AF5 and AF6. As depicted, the building structure is substantially different and much more detailed compared to the previous stage 1784 attributed also to the 10-times larger scale of the original maps. The by far largest building in the entire study area was at that time the building-complex of the abbey in Admont (14,977 m²). The second-largest building (also at AF5) only covered 3625 m². Figure 7b distinguishes graphically the number of buildings per alluvial fan located within or outside different hazard zones. 233 (26%) of the altogether 911 buildings were partly or entirely in a present-day red zone area whereas 335 of the buildings (37%) would have been within a modern-day yellow-zone area. At an alluvial fan-scale, these figures are even more dramatic for AF3 and AF5 (Table 3b). Figure 8 shows that the relative shares of the studied alluvial fans covered by buildings in 1824 where on average 31% less compared to 1784.

For 1824, results show that the relative shares of the alluvial fans covered by buildings varied between only 0.3 (AF6) and 2.0% (AF5) averaging to 0.9% of the total area, which is 0.15 km².

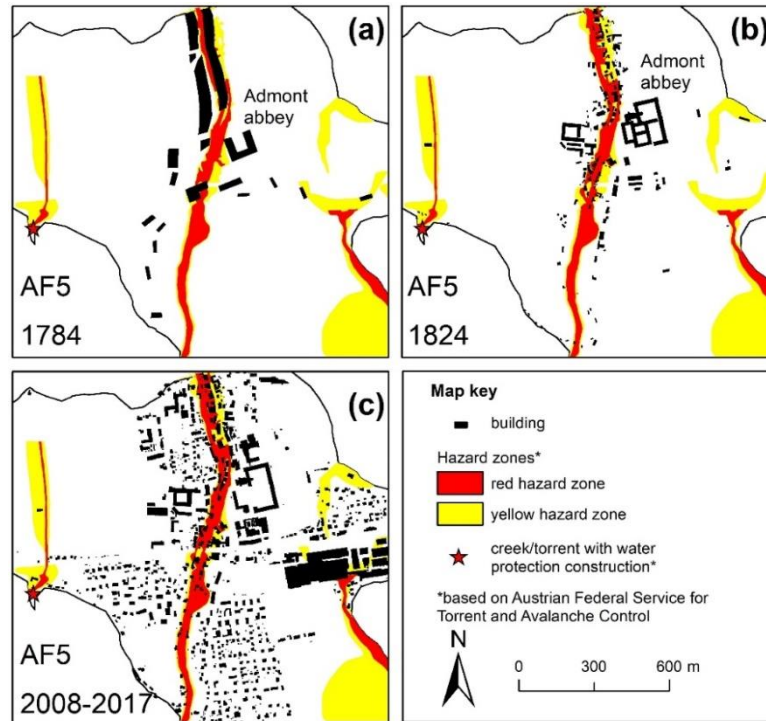


Figure 5 Spatial building distribution at the central part of alluvial fan AF5 (Admont) in 1784 (a), in 1824 (b) and in the time period 2008–2017 (c) in relation to the present hazard zonation (for location see Fig. 3a)

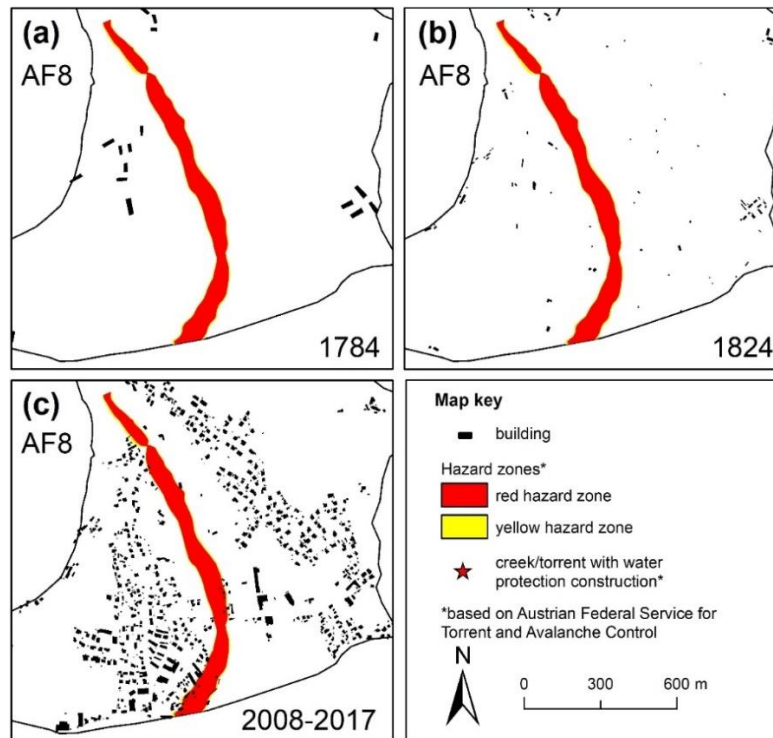


Figure 6 Spatial building distribution at the central part of alluvial fan AF8 (Hall) in 1784 (a), in 1824 (b) and in the time period 2008–2017 (c) in relation to the present hazard zonation (for location see Fig. 3a)

Table 3 Number of buildings and related spatial statistical parameters at the eight studied alluvial fans in the Admont Valley in 1784 based on historical maps (a), 1824 based on historical cadastral data (b), and today based on ALS–Data (c)

Code	Buildings							Percentage of alluvial fan cov- ered by buildings (%)
	number (n)	entirely or partly in hazard zone:		area (m ²)	min.	max.	mean	
		red	yellow					
(a) 1784								
AF1	8	0	0	8229	809	1496	1029	2.3
AF2	30	17	21	26212	398	2750	874	1.1
AF3	5	2	4	6522	1066	1756	1304	1.5
AF4	5	0	1	3058	461	926	612	0.5
AF5	38	14	19	78457	435	15953	2065	2.3
AF6	15	0	3	11908	447	1476	794	0.6
AF7	17	8	13	24212	317	3387	1424	1.7
AF8	81	16	20	55138	271	1291	681	0.9
all	199	57	81	213736	271	15953	1074	1.3
(b) 1824								
AF1	30	0	0	2818	23	197	94	0.8
AF2	93	13	58	16187	19	686	174	0.7
AF3	32	21	18	3095	21	277	97	0.7
AF4	31	8	12	4707	21	1019	152	0.8
AF5	303	108	130	67903	6	14977	224	2.0
AF6	52	0	10	6794	7	566	128	0.3
AF7	88	24	47	15222	15	1260	173	1.1
AF8	282	59	60	32336	10	861	115	0.5
all	911	233	335	149062	6	14977	164	0.9
(c) 2008–2017								
AF1	104	0	0	13827	6	769	133	3.8
AF2	502	79	364	84086	6	3083	168	3.6
AF3	77	23	54	6786	7	529	88	1.6
AF4	24	5	7	2937	8	683	122	0.5
AF5	1126	147	243	256047	6	31137	227	7.5
AF6	93	3	15	11136	7	700	120	0.5
AF7	235	41	119	55512	6	5374	236	3.9
AF8	1393	125	137	207279	4	1841	149	3.5
all	3554	423	939	637610	4	31137	179	3.8

4.4 Building structure in 2008–2017

For the most recent of the three analysed stages, a total number of 3,554 buildings were counted at the eight alluvial fans (Table 3c). This value is about 4 times higher than 190 years earlier. 71% of all buildings are located at the two alluvial fans AF5 (Admont) and AF8 (Hall). This massive increase in buildings since 1824 is also well illustrated in Figures 5c (for AF5) and 6c (for AF8). Most buildings were counted for the last stage at the alluvial fan in Hall (AF8; 1393 buildings) followed by the one in Ad-

mont (AF5; 1126). The third most important alluvial fan for settlement in the Admont Valley is – although far behind the other two – the one in Ardning (AF2; 502). Table 3c lists the number of houses at the eight alluvial fans, their spatial relationships to yellow and red hazard zones and areal information about building–extend conditions. The average size of all 3,554 buildings is 179 m² which is only 9% larger than 190 years earlier. The buildings range from 4 to 31,137 m² in size.

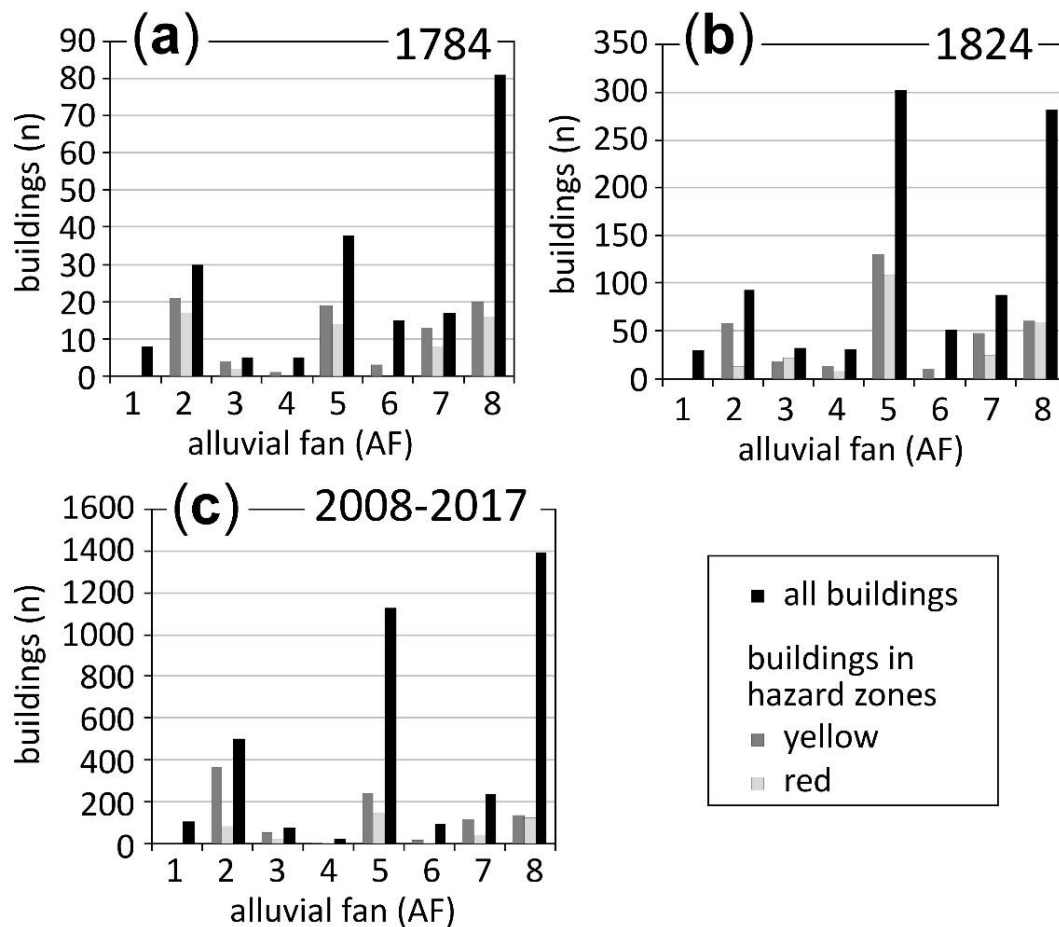


Figure 7 Number of buildings at the eight studied alluvial fans in 1784 (a), in 1824 (b) and in the time period 2008–2017 (c) and their relationship to the present hazard zonation plans (cf. Fig. 3). Considered buildings in the hazard zones are either entirely or partly in the indicated hazard zones. Note the different scale in the axis of ordinates

However, a high number of small but also one very large building (for wood industry; 31,137 m²) were added. The main building of the Admont Abbey covers 13,105 m² (=second largest building) which is 12% less compared to 1824. Figure 7c distinguishes graphically the number of buildings per alluvial fan located within or outside hazard zones. Only 12% of the buildings are partly or entirely in present-day red zones whereas 26% are partly or entirely in a yellow-zone area.

Figure 8 shows that the relative shares of the alluvial fans covered by buildings vary at present between 0.5 (AF4 and AF6) and 7.5% (AF5) averaging to 3.8% of the total area which is 4.2 times (or 0.49 km²) more compared to 1824. In absolute numbers, some 0.64 km² of the study area is covered by buildings.

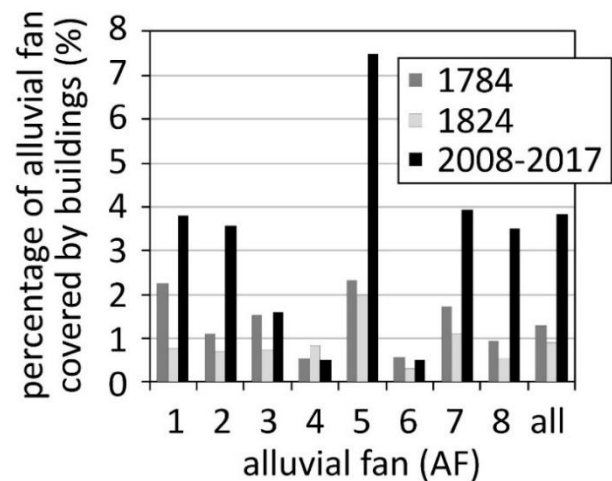


Figure 8 Relative shares of areas covered by buildings distinguished for each of the eight studied alluvial fans and the mean for the three periods for 1784, 1824 and 2008–2017.

4.5 Demographic development 1784–2019

Figure 9 depicts the population changes in the Admont Valley area since 1869 considering also the two communities Ardning (in the west) and Admont separately. For Admont, the c.150 inhabitants of the outside the study area located cadastral commune Johnsbach are included. In 1869 some 4,500 people lived in the Admont Valley and in Johnsbach. The number of people linearly increased until 1934 with a peak in 1939 (possibly related to WW2). Afterwards and until 2001 the number of inhabitants was only slightly increasing. Between 2011 and 2019 the population was rather stable with about 6,200 inhabitants. No accurate data regarding number of inhabitants in the study area were available from earlier times. However, if we extrapolate the population evolution linearly further back in time, we could assume c. 3,500 people in 1824 and c. 2,800 in 1784.

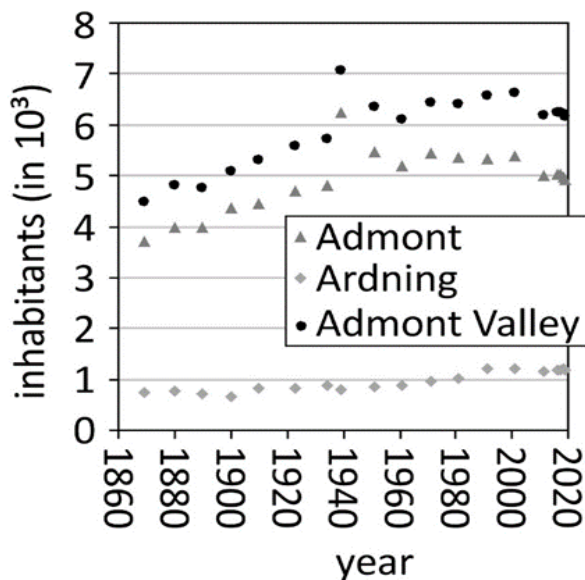


Figure 9 Evolution of the population of the Admont Valley (including the cadastral commune Johnsbach with c.150 inhabitants in 2019) between 1869 and 2019. For data source see text.

5. Discussion

5.1 Building evolution since 1784 at the studied alluvial fans

Our analyses regarding building evolution between 1784 and present at eight different alluvial fans in the Admont valley revealed a substantial increase in

the number of buildings and in the spatial extent of build-up land. However, two main problems occurred in the mapping procedure of the 1784–dataset limiting the meaningfulness of the oldest dataset substantially. First, due to the general distortion of the historic map it was not possible to superimpose in a geometrically satisfying manner the historic map over the present-day data. Mólnar et al. (2014) concluded that georeferencing is well feasible with a remaining error is in the order of 100–200m. Furthermore, they point out that further refinement is possible using a rather dense ground control point network (GCP). However, in case of missing candidates for GCP on the original map, this is simply not possible.

This uncertainty implies that buildings that were located at one of the alluvial fans were not accounted for as such and vice-versa. In a geometric context this means inaccurate data. Second, due to the scale of 1:28,800 of the original maps, most of the houses and buildings were cartographically presented in a generalized manner such as depicted in Figure 5a for Admont (AF5) or 6a for Hall (AF8). This generalisation gets also evident when we look on the calculated area values for houses for 1784 (e.g., mean 1,074 m²) in relation to the two later stages (164 m² for 1824; 179 m² for 2008–2017). Thus, the cartographic representation of the conditions in 1784 is not only inaccurate but also not precise. This implies that the 1784–cartographic representation is certainly of high value for describing general patterns of buildings and in particular settlement distributions, but it is not feasible at all to compare the areal data calculated for 1784 with those for 1824 or later.

The cadastral land register of Francis I, dating to 1824 in the Admont Valley, provides a substantially different picture. The cadastral land register is the result of detailed geodetic and cartographic work accomplished over a 44-year period and covering an area of 670,000 km² (Fuhrmann, 2007). The 1824 data in the Admont Valley are accurate and precise in terms of geometry and localization, and surely comparable to the ALS-based building data of 2008–2017. This is for instance illustrated in Figure 5 where the geometry of the Admont Abbey is shown for 1824 (b) and 2008–2017 (c). The church and

most of the wings of the building complex have identical or only slightly different plan views in both periods. However, as visible in the central part of the abbey, several buildings are missing today. This loss in build-up area is attributed to a big fire in 1865 destroying particularly the central wings of the building complex (List, 1984) reducing the size of the building complex from 14,977 m² in 1824 to 13,105 m² today.

The ALS-based building distribution mapped at a scale 1:500 (Land Steiermark 2019) is also regarded as accurate and precise data. The thus feasible comparison of the two latter data sets show a 3.9-fold increase in the number of buildings from 911 to 3554 in c.190 years. In the same time, the entire population in the Admont Valley increased from c. 3500 to c.6200, i.e. only 1.8 times. This difference in multiplications of buildings and population between the two stages implies inhabitants per house also attributed to substantial socio-economic changes during the last 190 years.

5.2 Relationship between hazard-zones, damaging events and building evolution

The comparison of official hazard-zone plans with our mapping results (1784 and 1824) and existing building distribution data (2008–2017) show that a significant amount of buildings are located partly or entirely in yellow (moderate-risk) and red (high-risk) hazard zones. Whereas the analysis results for the 1784 data (Table 3a) are only of limited meaningfulness due to inaccurate and unprecise data, the results for the latter to stages (Table 3b, c) are of great significance. At present, 11.9% of all 3,554 buildings are partly or entirely in a red hazard zone. 26.4% are partly or entirely in a yellow hazard zone. Some 190 years earlier (and with 911 buildings), these percentage values would have been even higher with 25.6% for red and 36.8% for yellow hazard zones. These values clearly show that despite a tremendous increase in buildings at the eight alluvial fans (cf. Fig. 5c, 6c), the proportion of buildings exposed to torrents-related natural hazards significantly decreased by 10.4% for yellow and by 13.7% for red zone areas.

The documented damaging events at the eight studied alluvial fans highlight the importance of floods (32.2% of all events) and fluvial sediment transport events with notable but <20% volumetric debris content (44.1%). Debris flows were only 11.9% of all documented damaging events since 1851. The alluvial fan AF2 was very much affected by damaging processes in the past which is also considered in the hazard zone plan (Fig. 3a). 57.4% of the entire alluvial fan is still in a high-risk (red) to moderate-risk (yellow) zone, despite the fact that protection constructions were installed in several of the torrents (Fig. 3a) that flow onto the large alluvial fan. This potential threat to floods and flood-related geomorphic processes at AF2 had only to a limited extent an impact on the building evolution at this fan. 72.5% of all buildings at AF2 are entirely or partly in the yellow zone. Comparable high values for yellow zones were revealed for AF3 and AF7. Regarding red zones, 15–30% of all buildings at AF2, AF7, AF4, and AF3 are partly or entirely in such high-risk zones.

The fact that so many present buildings are in high- and moderate-risk areas is attributed to the age differences between the buildings and hazard zonation plans in the Admont Valley. A total of 102 hazard zones were identified at the eight alluvial fans dating to different years: 42 dates to 1981, 33 to 1998, 21 to 2014, and 6 to 2015 (Federal Ministry for Sustainability and Tourism, 2017). These age dates illustrate that it is quite normal – in the Admont Valley but also all-over alpine Austria – that many hazard zonation plans are younger (e.g. central part of Admont; Fig. 5) compared to the buildings within them. New buildings at yellow zone areas are possible, but restricted and with building obligations (e.g. at AF2).

5.3 The wider significance of the present study

What is now a wider significance of such a study in more regional to national context? As stated in the material and methods section the existence and the increasing availability of historic maps allow longer-term studies on settlement and building evolution even at a landform-scale. The spatial extent of the First Military Survey of the Habsburg Empire excluding present-day Belgium covers some 640,000

km². This is obviously a huge part of central and Eastern Europe (Fig. 2a). The spatial extent of the cadastral land register of Francis I is similar with 670,000 km² (Fig. 2b; Fuhrmann, 2007). The considered areas in both map products are not the same. However, for many areas in present-day Czech Republic, Slovakia, Hungary, Ukraine, Romania, Poland, Serbia, Croatia, Slovenia and Italy digital historic maps are available for similar studies.

Regarding landform–relevance, particularly in alpine areas alluvial fans played a major role for settlement and housing establishment in the past and even today. As we showed with the example Admont Valley (236.1 km²), by far most present-day buildings (69.2%) are located at only eight alluvial fans (total area 16.6 km²). Topographically comparable conditions in other areas of the former Habsburg Empire (e.g. Carpathians, Dinaric Alps) might allow alluvial fan–settlement evolution studies using the Habsburg–data. Furthermore, such data might contribute to understand long-term man–landscape interactions at landform scale (Zygmunt, 2009). Furthermore, also other specific landforms could be assessed using historical data regarding their settlement evolution significance as for instance shown for a depression basin in eastern Romania (Chirilă–Acatrinei, 2015) or the urban development in Sibiu, Central Romania (Costea, 2016). Thus, analysing historical maps that are relatively accurate and precise have a high potential in historio–geomorphological research.

6. Conclusions

From this study, the following main conclusions can be drawn:

- Historical maps at large scale and as georeferenced products are increasingly available for geographical and historical research question. In this study we used (and partly re-georeferenced) historical maps from 1784 (at scale 1:28,800) and 1824 (1:2,880) from an alpine valley (Admont Valley) and combined this information with geomorphic (landform distribution), geomorphodynamic (documented damaging events at torrents) and spatial planning (hazard zonation maps) data.

- We showed that the used map product from the 18th century is useful for general settlement evolution assessments. However, a detailed spatial analysis and a comparison with present-day data (in terms of buildings but also hazard zonation plans) at a building-scale is not feasible, due to the distortion of the map related to triangulation and projection problems and the generalisation of objects. This implies geometrically inaccurate and unprecise data.

- The analysis and comparison of the large scale, accurate and also precise (horizontal accuracy in the order of 10 m) building data from the year 1824 with present-day data (2008–2017) revealed spatial and socio-economic insight into the population and building evolution over a 190-year period at eight alluvial fans. Whereas the number of buildings increased 3.9 times, the population only grew 1.8 times. Despite a tremendous increase in buildings (911 in 1824; 3,554 in 2008–2017), the proportion of buildings exposed to torrents-related natural hazards significantly decreased by 10.4% for yellow (moderate-risk) and by 13.7% for red (high-risk) zones.

- The large spatial extent of the used historical data with 640,000 km² (excluding present-day Belgium) for the First Military Survey of the Habsburg Empire dating to 1764–1787 and 670,000 km² for the cadastral land register of Francis I dating to 1817–1861 implies that similar historio–geomorphological studies as presented here might be accomplished in other countries in central and eastern Europe.

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The Austrian Federal Service for Torrent and Avalanche Control – particularly Markus Mayerl – is kindly acknowledged for providing data of natural hazard events which happened between 1851 and 2017 and for information regarding technical control measures against debris flows and floods in the Admont Valley. The Geographical Information Service of the Federal Government of Styria (GIS–Steiermark) is very much thanked for providing a digital terrain data. The authors acknowledge the financial support by the University of Graz.

References

- Auer M, Bleibinhaus F, Tschurtschenthaler M, Unterwurzacher M. 2013. Municipium Claudium Aguntum – Georadar-Messungen in geologisch schwierigem Terrain. *Jahreshefte des Österreichischen Archäologischen Institutes*, **82**: 7–21.
- Büchner KH. 1974. Ergebnisse einer geologischen Neuaufnahme der nördlichen und südlichen Gesäuseberge (Ober-Steiermark, Österreich). *Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich*, **22**: 71–95.
- Chirilă-Acatrinei A. 2015. Interactions between human settlements and Geomorphology in Huși Depression, NE Romania. *Studia Ubb Geographia*, **LX** 2: 17–26.
- Costea M. 2016. Landforms and urban development. An example of urban geomorphology from Romania (Sibiu, Transylvania) January 2016. Brukenthal. *Acta Musei*, **11**(3): 491–506.
- Fuhrmann S. 2007. Digitale Historische Geobasisdaten im Bundesamt für Eich- und Vermessungswesen (BEV) – Die Urmappe des Franziszeischen Kataster. *Vermessung & Geoinformation*, **1**: 24–35.
- Hofstätter E. 1989. *Beiträge zur Geschichte der österreichischen Landesaufnahmen: Ein Überblick der topographischen Aufnahmeverfahren, deren Ursprünge, ihrer Entwicklungen und Organisationsformen der vier österreichischen Landesaufnahmen*. 1. Teil. Bundesamt für Eich- u. Vermessungswesen, Vienna, 196 p.
- Kellerer-Pirklbauer A, Proske T, Untersweg T. 2004. *Darstellung der Talbodenbereiche des Steirischen Ennstals*. Project Report. Institut für Digitale Bildverarbeitung, Joanneum Research, Graz, 50 p.
- Krause A. 1966. *Admont und das Gesäuse in Geschichte und Sage* – 2. Auflage, Oberösterreichischer Landesverlag, Linz, 144 p.
- Land Steiermark. 2019. *Katalog ALS Gebäudemasken (2008–2012) Steiermark (Extraction of buildings from Airborne Laserscanner data)*. CC-BY-4.0: Land Steiermark – data.steiermark.gv.at [last access 02 September 2019].
- List R. 1974. *Stift Admont 1074 – 1974*. Festschrift zur Neunhundertjahrfeier. Ried im Innkreis: OÖ. Landesverlag, 559 p.
- Mólnar G, Timár G, Biszak E. 2014. Can the First Military Survey maps of the Habsburg Empire (1763–1790) be georeferenced by an accuracy of 200 meters? *9th International Workshop on Digital Approaches to Cartographic Heritage*, Budapest, 4–5 September 2014, 1–7. DOI: 10.13140/2.1.1447.8724
- Patzelt G. 1987. Untersuchungen zur nacheiszeitlichen Schwemmkegel- und Talentwicklung in Tirol. 1. Teil: Das Inntal zwischen Mötz und Wattens. *Veröffentlichung des Tiroler Museum Ferdinandeum*, **67**: 93–123.
- Patzelt G. 1994. Holocene development of alluvial fans and the floor of the Inn Valley. *Mountain Research and Development*, **14** (4): 283–284.
- Reismann B, Wiedner J, Bergmann H, Kainz H, Kauch P. 2015. *Wasserwirtschaft in der Steiermark – Geschichte und Gegenwart*. Graz. Steiermärkisches Landesarchiv, Graz, 504 p.
- Slaymaker O, Embleton-Hamann C. 2009. Mountains. In: Slaymaker O, Spencer T, Embleton-Hamann C (eds.): *Geomorphology and Global Environmental Change*. Cambridge University Press, Cambridge, 37–70. DOI: <https://doi.org/10.1017/CBO9780511627057.003>, pp 37–70.
- Statistik Austria. 2019. *Population evolution of the two communities Admont and Ardnig between 1869 and 2018*. <https://www.statistik.at/blickgem/index.jsp> [last access 02 September 2019].
- Unterweger O. 2018. Zur Geomorphologie des Debantbaches und dessen Einfluss auf das Stadtgebiet von Aguntum. In: Auer M, Stadler H (eds.): *Von Aguntum zum Alkuser See – Zur römischen Geschichte der Siedlungskammer Osttirol*. Harrassowitz Verlag, Wiesbaden, 167–172.
- Wichner J. 1880. *Geschichte des Benediktiner-Stiftes Admont, 4: Vom Jahre 1466 bis auf die neueste Zeit. Festgabe zur Feier der Erinnerung an den 1400 jährigen Geburtstag des hl. Benedikt*. Graz: Selbstverlag des Verfassers, 343 p.
- WLK. 2019. *WLK.Digital.Ereigniskataster – Das Ereignisportal des digitalen Wildbach- und Lawinenkatasters des Forsttechnischen Dienstes für Wildbach- und Lawinenverbauung*. [online] Forsttechnischen Dienstes für Wildbach- und Lawinenverbauung. Available from: <https://naturgefahren.die-wildbach.at/V3/index.aspx> [last access 02 February 2019].
- Zanescio A, Nicolussi K, Patzelt G. 2008. Die Überschwemmung der Unterstadt von Hall im Jahre 1275. In: Zanescio A, Schmitz-Esser R. (eds.): *Forum Hall in Tirol*, Neues zur Geschichte der Stadt, Hall, 40–53.
- Zygmunt E. 2009. Alluvial fans as an effect of long-term man-landscape interactions and moist climatic conditions: A case study from the Glubczyce Plateau, SW Poland. *Geomorphology*, **108**: 58–70.

Multi-risk quantitative assessment in Reghin city, Transylvania, Romania

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ABSTRACT

Multi-risk assessment supposes an integrated analysis of various processes and phenomena generating risks across the territory, highlighting the individual and cumulative impact at different levels of analysis. This paper aims at creating an assessment model of multi-risk generated by the cumulative effects of landslides and floods, processes considered as significant in the study area, the administrative unit of the city of Reghin in the Transylvanian Basin. To obtain the multi-risk, two GIS spatial analysis models have been created. The first model means to identify the probability of landslide occurrence (built on GIS databases in vector and raster format, correlatively analysed by means of spatial analysis functions and equations), and is adapted according to legislative regulations stipulated in the Government Decision no. 447/2003. The second one is a database regarding the floodable area with a 1% probability in raster format, resulted from a nation-wide model created to identify the flooded areas. The multi-risk map was created using the mediation method, in which every class of individual (geomorphological or hydrological) hazard receives equal weight within the final result. As a consequence of applying the above-mentioned models, we obtained areas with different probabilities for cumulative risk processes, which are rendered as favourable or restrictive in terms of locating different structures (roads, settlements, functional areas, shopping centres). According to the degree of validation, these may be used for a more precise determination of the development areas and for territorial planning.

KEYWORDS

multi-risk; G.I.S.; landslide; floodable areas; territorial planning

1. Introduction

At regional level, integrated predictive models of sustainable territorial development, created according to the spatial analysis of resources, vulnerabilities and opportunities, are nowadays used in the studies concerning sustainable territorial development (Filip, 2009).

In order to achieve this, many studies and reports that have a strategic or programmatic nature are currently carried out, such as General Urban Plans (PUG), Zoning Plans (PATZ), regional and local development strategies and so on. Most of them have several substantial common shortcomings: the majority start from desirable subjective goals which are not consistent with the local and regional territorial opportunities; the insufficient and inexact quantitative data needed for a deeper knowledge of the defining states of a territory that is impacted, in the last years, by an unprecedented urban pressure (Benedek, 2016); and the almost total absence of an integrated multidisciplinary vision provided by a large range of specialists, obtained by the interconnection and synergic exploration of data and preliminary conclusions within an integrated model able to respond to the real fundament of the planning decision act to the benefit of all actors and factors involved in the complex process of territorial dynamics.

In order to highlight the punctual impact of the different integrating elements of risk, several initial vulnerability assessment models have been derived, both from the point of view of extreme hydrological processes (flash floods and floods) and of landslides, which have the main impact on continuously expanding urban areas (Ianoș, 1987).

The integrated approach of the two processes generating vulnerability for risk identification is less used in the process of assessment and diagnosis of territories for the provision of feasibility studies, while it is more often found in the applied research studies carried out to underlie impact studies (Micu et al., 2016).

In order to reduce the cumulated risks on a territory, it is necessary to integrate some methodological concepts to assess multi-hazard and multi-risk (UNISDR, 2015), starting from the traditional individual approach for each risk to approaches

identifying the complex interactions between risks (Gallina et al., 2016). The issue of modelling innovative approaches regarding multi-risk assessment has been raised in different recent studies, starting from the identification of common causes for the occurrence of different risk processes, to the necessity of quantitative assessment of the elements exposed to risks identified across the territory and the identification of cross-components relations (Terzi, 2019). Landslides and floods have a common triggering factor, the excessive amount of rainfall, higher than a certain threshold, concerning the river transport capacity in the case of floods, and the slope degree of stability in the case of landslides. Therefore, there is a cumulated effect of landslides and floods, involving a need for a cumulated analysis of these risks due to their cascade effect and the higher temporal and spatial probability for the values to exceed such thresholds (Gill, Malamud, 2016; Jurgilevich et al., 2017).

The unprecedented urban development registered in Romania in the last decades has been chaotically performed (Sestraș et al., 2019), according to the wish of the private owners and developers, expanding housing development in such ways that one may identify parts of neighbourhoods or even full neighbourhoods subject to the risk induced by landslides and floods (Cocean et al., 2004). This situation leads to significant financial efforts to be made by the local public authorities to diminish the impact and reduce the associated risks. Such cases could have been avoided if the local public authorities, responsible for the planning issues within the administrative units, had practiced a sustainable territorial planning based on pre-feasibility and feasibility studies oriented towards the probable risks in the territories proposed for development (housing estates, transport and communication infrastructure, other facilities).

This study provides a GIS spatial analysis integrated model based on the derivation and modelling of databases needed for model structuring. It also presents the concept of database integration into a complex spatial analysis model for the assessment of cumulative risk induced in the territory by the two main vulnerabilities (floods and landslides) which have a visible impact in the study area. The

model has in its centre the overlay type analysis of the main components, based on the principle of equal importance in terms of the risk classes impact on the territory, quantified by cumulating the punctual value of the impact assessed at the same scale on the basis of qualitative scores.

Under these conditions, the cumulated analysis of natural hazards becomes necessary, as well as a higher detailing degree of the database used and the use of a method involving the statistical analysis of the distribution, requirements meant to make possible the identification of the degree of influence of the factors included in the modelling of the analysed process or phenomenon (Bilaşco et al., 2017).

2. Study Area

The city of Reghin is located in the hilly Reghin Basin, near the confluence of Mureş and Gurghiu rivers, in the central–northern part of Mureş County (Fig. 1). The administrative unit of Reghin municipality covers an area of about 5658 ha and is located on the Mureş River floodplain and terraces, but also on the lower and middle sectors of Reghin Hills (Conţiu, 2005). Most of this area provides favourable conditions for the building of housing estates and infrastructure elements. The present landscape, a tableland strongly fragmented by valleys, corridors and watersheds, landslides and powerful torrential erosion, is the consequence of the relatively recent morphological evolution in clays and marls, with some Helvetian sandstone layers (Ciocârdel, 1949).

The administrative territory of Reghin municipality is characterised by a small altitude range, of only 171 m, as the lowest height, 337 m, is recorded in the Mureş floodplain, while the highest point is located in Reghin Hills at an altitude of 508 m. The low floodplain area (at a height of 337–350 m) covers 8.4% of the territory (476.6 hectares), while the floodplain terraces (at a height of 350.1–370 m) cover 35.6% of the administrative unit (2014.5 hectares). Both are subject to the risk of flash floods and floods.

The current trend to locate residential areas as far away as possible from the city centre is also pre-

sent in the case of Reghin municipality, where buildings are migrating towards the area located far from the centre, in the low hills (401–500 m), which cover 35.2% of Reghin administrative territory. This area is characterised by relatively steep slopes and geological features favourable to landslide processes if the slopes are overcharged (Irimuş and Szilágyi, 2017). The necessity for the existence of a multi-risk assessment carried out at least at national level has been stipulated at European level since 2009 (Marzochi et al., 2009).

3. Methodology and Database

GIS spatial modelling has the main goal to identify the possible ways in which processes become manifest on the basis of known facts about them or similarities with other resembling processes by means of the integrated analysis of the components using expert knowledge and cause–effect methods (Sestraş et al., 2019).

The proposed methodology to reach the final research objective is structured according to the requirements of GIS spatial analysis model, substantiated on databases, the study of relations between them and their inclusion in three stages to define the final model (Table 1). Each stage marks the creation of a spatial analysis submodel which, interconnected with the other submodels, leads to the identification of the cumulated risk across the territory. One remarks the last stage, concerning the proper risk assessment in the territory by means of an integrated analysis of the raster format database representing the cumulated vulnerability to landslides and floods with the vector format database representing housing estates and transport infrastructures on the basis of vector–raster overlay in order to achieve average vulnerability values per infrastructure unit, therefore identifying the weight of loss resulting from the two cumulated processes. The proper assessment and ranking of the factors involved in modelling represents an important stage in the models that determine the probability of landslide occurrence (Carrara et al., 1992; Guzzetti et al., 1999; Zezere et al., 2004; Van Western et al., 2006; Petrea et al., 2014; Roşca et al., 2015).

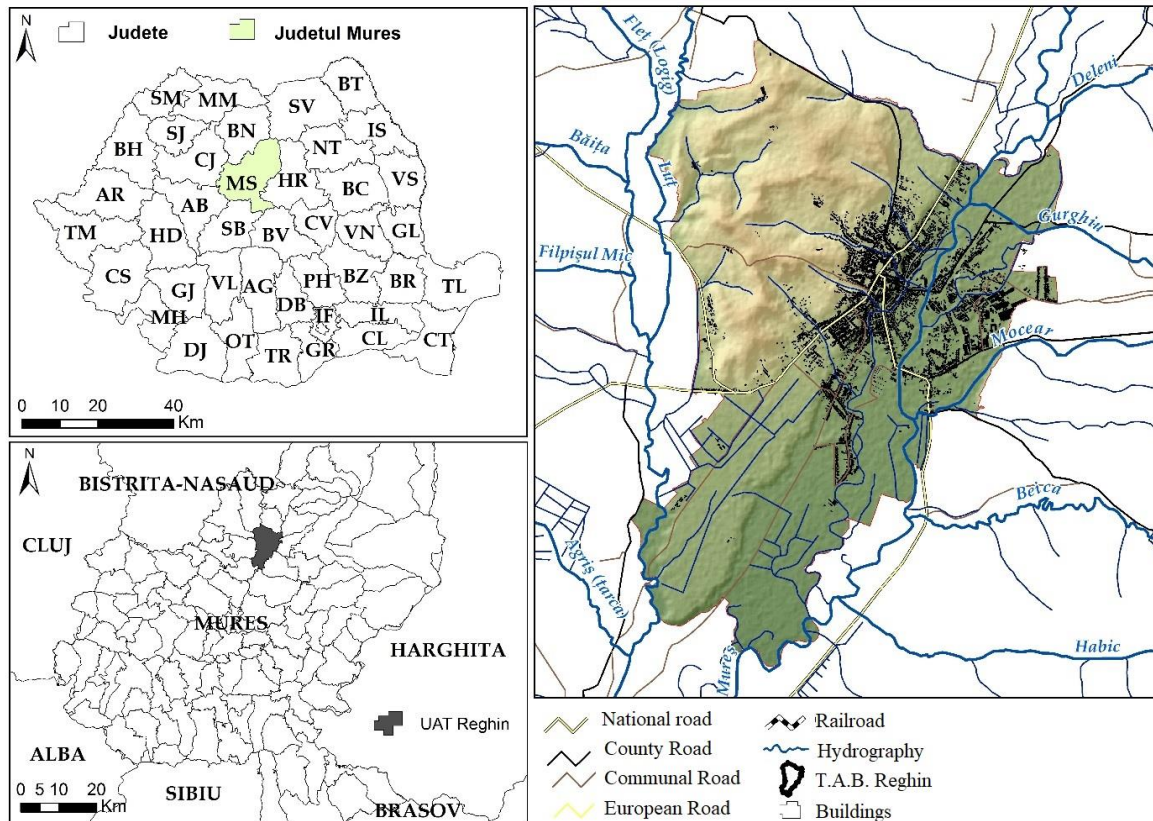


Figure 1 Geographical position of the study area

In this case, in order to achieve this database, a GIS spatial analysis model has been developed, according to the methodology imposed by the Romanian legislation (Government Decision no. 447/2003) regarding the technical and methodological standards for the mapping of landslides. In terms of floods, we used the floodable stripes of 1% probability of occurrence according to the legislation in force, achieved through vectorization from the cartographic database in analogous format concerning the floodable areas, mapped by INHGA (according to the Flood Risk Management Plan issued by the Mureș Water Catchment Administration).

4. Multi-Risk G.I.S. based Assessment

The spatial database acquisition represents the fundament of any integrated and multidisciplinary spatial analysis model. The high amount of data needed for the implementation of a spatial analysis model that is correct and valid from the point of view of the final results makes that the human component

involved in their acquisition and processing to come from different research fields, which do not exclude each other, but interfere even more in their research area.

4.1 Landslides Probability

The geomorphological risk is induced in the territory of Reghin administrative unit by the presence of landslides. They are either active or have a potential to reactivate, and there is a probability of their occurrence as a result of morphological features and the changes emerged on the average and steep slopes due to construction works and vibrations produced by transport. Also, the state of balance of the slopes has been affected due to the accumulation of large amounts of water as a result of rainfall, but also due to leaks in the underground water supply pipes.

Generally, the landslide risk and the proposals for solutions regarding its mitigation are found in the fifth section of the National Master Plan (Law

no. 575 on the 22nd of October 2001). The definition of classes for geomorphological risks is found in the Government Decision no. 447/2003, where one finds Methodological norms regarding the manner of achievement and the contents of natural risk maps concerning landslides. These norms stipulate the classification of the probability of landslide

occurrence by providing influence scores to the factors causing and triggering landslides, such as geology, geomorphological features (slope and altitude), as well as structural, hydro-climatic, hydro-geological, seismic, forestry and anthropogenic features (Figs. 2–9).

Table 1 Database structure

No.	Database name	Type	Structure	Attribute	Origin	Modelling level
1	Hypsometry	Raster	GRID	Altitude (m)	Primary	for Model level I (LANDSLIDES)
2	Slope	Raster	GRID	Slope angle (%)	Modelled	
3	Aspect	Raster	GRID	Aspect (8 direction)	Modelled	
4	Geology	Vector	Polygon	Geology classes	Digitised	
5	Precipitation Grid	Raster	GRID	Ka	Derived	
		Raster	GRID	Precipitation average value (mm)	Modelled	
6	Hydrogeological classes	Vector	Polygon	Value	Digitised	
		Raster	GRID	Ke	Derived	
7	Seismic coefficient	Vector	Polygon	Value	Digitised	
		Raster	GRID	Kf	Derived	
8	Forestry coefficient	Vector	Polygon	Land-use classes	Digitised	
		Raster	GRID	Kg	Derived	
9	Anthropogenic coefficient	Vector	Polygon	Value	Digitised	Database model II (floodable areas)
		Raster	GRID	Kh	Derived	
10	Landslide probability	Raster	GRID	Value (0–0.45)	Modelled	Model level III (RISK EVALUATION)
		Raster	GRID	Value (0–0.45)	Modelled	
11	Floodable stripes	Raster	GRID	1%	Digitised	Model level III (RISK EVALUATION)
		Vector	Polygon		Derived	
12	Landslide probability	Raster	GRID	Value (0–0.45)	Modelled	Model level III (RISK EVALUATION)
13	Floodable stripes	Raster	GRID	–	Derived	
14	Vulnerability	Raster	GRID	Surface of cumulative probability / landslide/floodable areas	Modelled	Model level III (RISK EVALUATION)
15	Exposure	Vector	Polygon	Surface/vulnerability	Modelled Statistical Analysis	
16	Risk	Raster	GRID	Surface/vulnerability /infrastructures	Derived	Model level III (RISK EVALUATION)

In this case, the average hazard coefficient regarding landslides achieved as a result of applying the above-mentioned methodology is between 0 and 0.45, corresponding to a class of low, average and average-high probability.

The class of average-high probability of landslide occurrence is identified with a value of the average hazard coefficient above 0.35 and is spatially located across an area of 3667.5 hectares (65.57% of Reghin municipality area), generally in the middle

sectors of Reghin Hills (Fig. 10), where there are slopes above 15 degrees and geological layers made of clays and marls, therefore increasing the probability of landslide occurrence and implicitly leading to a relative instability of these areas.

The class of average probability of landslide occurrence involves an average hazard coefficient between 0.15 and 0.35 and covers 1783.82 hectares, about 31.89% of Reghin municipality (Table 2). It characterizes the lower sectors of the medium and low hills, with slopes between 5 and 15 degrees, where there is a lower probability for landslides to occur. Such processes may take place as a result of reaching a high degree of wetness within the supporting clay layers, either as a consequence of heavy rainfall amounts or because of earthquakes able to destabilize the initial balance.

The class of low probability of landslide occurrence covers only 2.53% of Reghin municipality territory, and is characteristic for the tops of Mureș terraces and its floodplain. The morphometric and morphographic features provide stability from the point of view of landslides. However, some of these areas are prone to the risk of flooding.

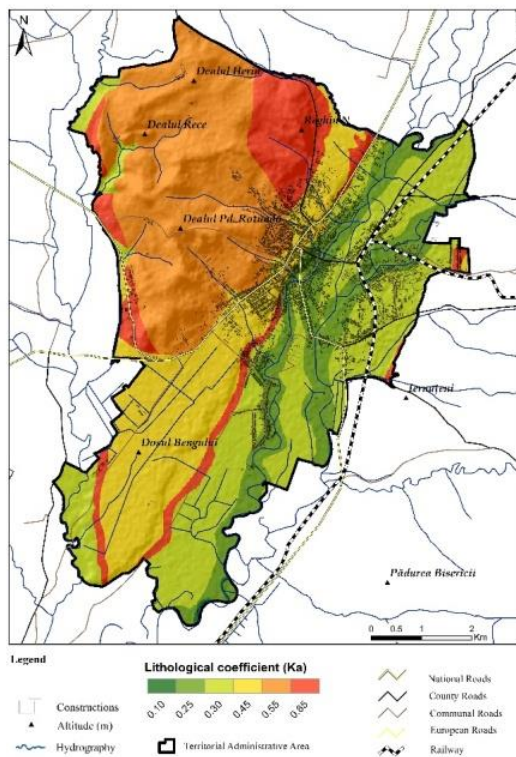


Figure 2 Map of Lithological coefficient

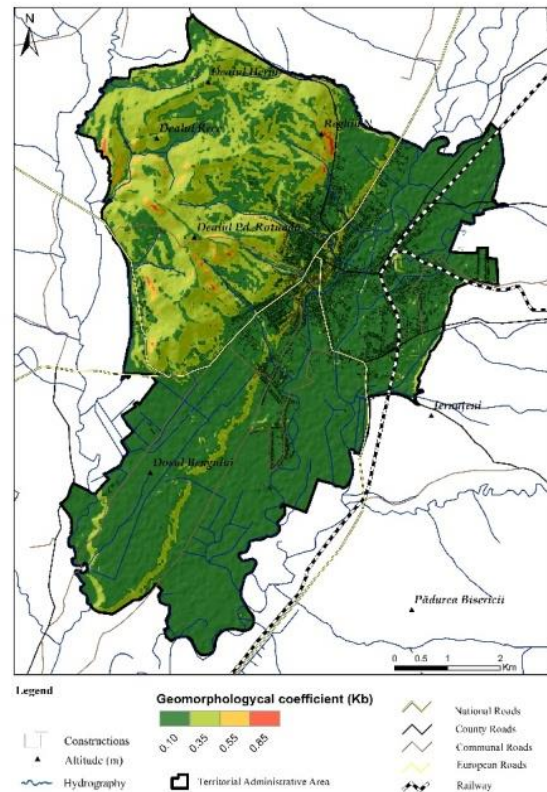


Figure 3 Map of Geomorphological coefficient

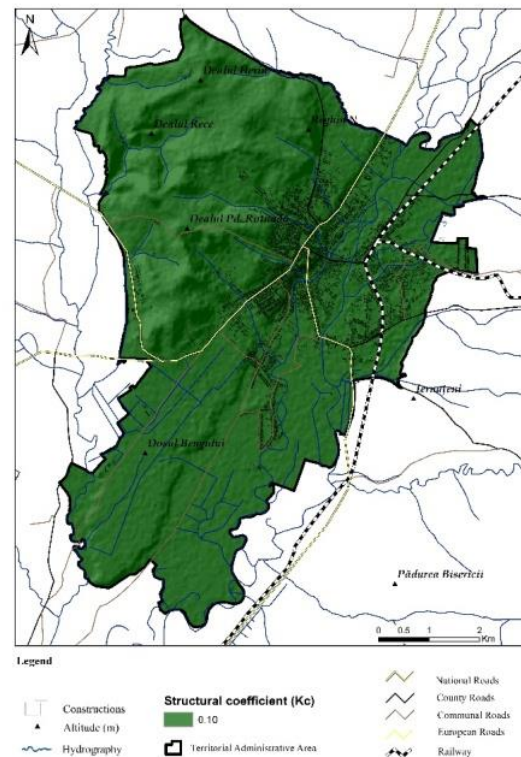


Figure 4 Map of Structural coefficient

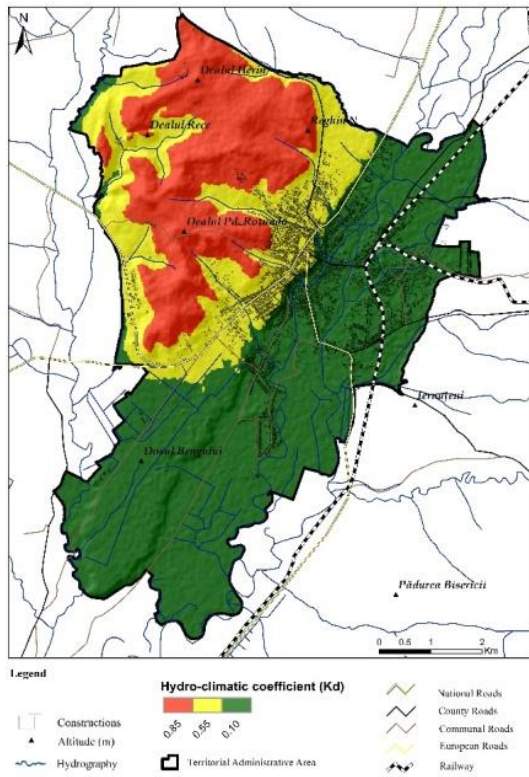


Figure 5 Map of Hydro-climatic coefficient

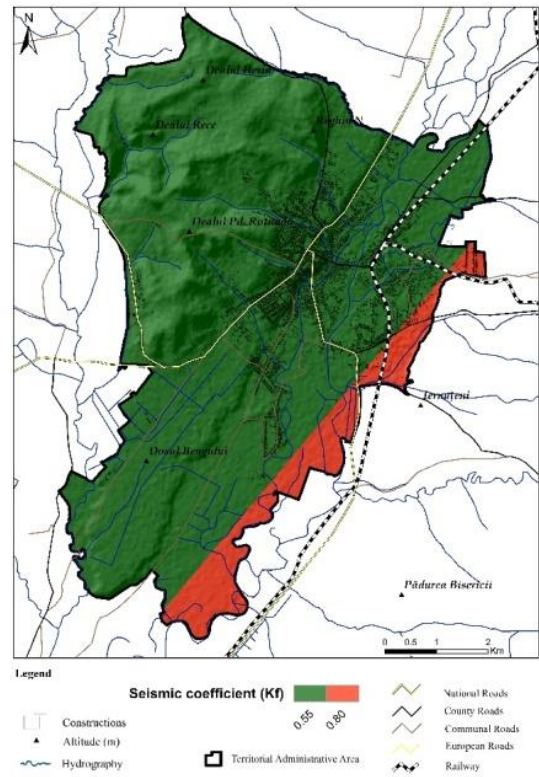


Figure 7 Map of Seismic coefficient

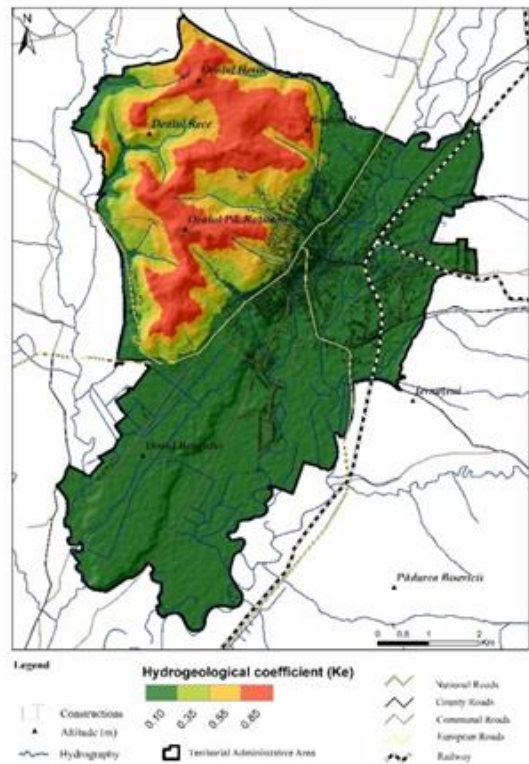


Figure 6 Map of Hydrogeological coefficient

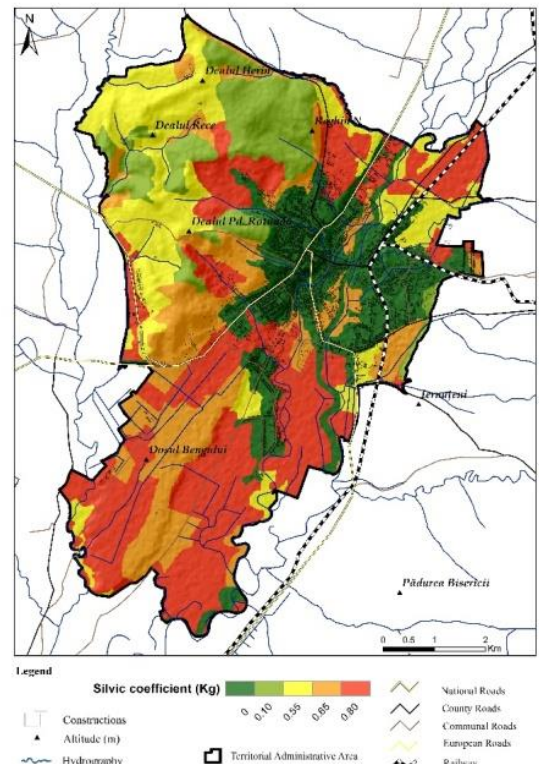


Figure 8 Map of Forestry coefficient

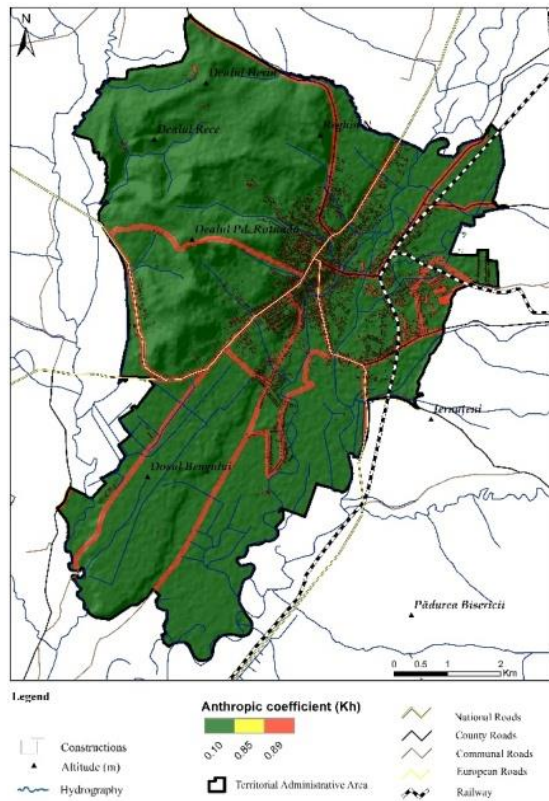


Figure 9 Map of Anthropogenic coefficient

Regarding the damages that might occur as a result of landslides across the territory of Reghin municipality, the value of material damage and loss of human life associated directly with the landslides has been estimated, where the risk is defined as a product of the landslide occurrence probability expressed by the hazard average coefficient (K_m) and the value of material damage (expressed by the totality of elements prone to landslide hazards).

4.2 Flood Assessment

For the administrative territory of Reghin municipality, the flood risk has been identified by assessing the elements prone to flooding. The floodable stripes mapped in the studies carried out by the Romanian Water Administration (Fig. 11) have been modelled as a spatial extension of the area to be flooded in case of reaching a maximum discharge with a 1% probability of exceeding, i.e. floods that may occur once in 100 years. Within the limits of the studied administrative unit, the floodable stripes cover an area of 633.76 hectares, and they are lo-

cated relatively symmetrical on the two sides of Mureș river bed. In case of reaching the maximum discharge, only small parts of Unirii, Topliței and Iernuțeni may be affected, considering that most of Mureș river bed is confined by banks meant for defence against flooding.

However, there might be water overflows in the case of secondary tributaries, such as Trandafirilor brook or Bodogaia Valley. They have a less developed river bed and therefore a small capacity to transport water. When abundant rainfall occurs, there are local floods and the water pouring down the slopes may stagnate due to poor sewerage and the large area covered by buildings and asphalt.

Regarding flood risk assessment, Willems et al. (2003) proposed a matricial classification depending on land use categories and their exposure to flooding. According to it, grasslands, meadows, forested areas and deforested shrub areas, are included in the exposure class 0. Fields covered by orchards, vineyards, as well as agricultural lands mixed with natural vegetation are included in the exposure class 1. The residential urban and rural areas are included in the exposure class 2, while transport infrastructure elements (roads, railways), industrial and commercial units are included in the exposure class 3 (Table 3).

4.3 Multi-Risk Assessment

The mapping of risks for the current geomorphological processes represents a necessity in the territorial planning proposals (Carrara et al., 1999). For this purpose, there are several methods involving the use of GIS technology, statistical methods to determine the spatial occurrence probability (Guzzetti et al., 1999), quantitative-probabilistic methods (Coe et al., 2004; Polemio and Petrucci, 2010) and qualitative methods (Latelin, 1997). There are also matricial assessments of classifying the territory according to risk classes, which highlight the relations established between susceptibility classes (the landslide occurrence probability) and the potential damage that may result if they are triggered.

In order to identify the geomorphological risk, the elements of the built-up area have been overlapped with the raster of the average hazard coefficient calculated according to the methodological

regulations stipulated in the Government Decision no. 447/2003, which presents the stages needed to perform a risk study to mitigate the negative effects of landslides. Concerning floods, one may highlight clearly the high risks caused by them in the territory, as about 14.54% of the buildings are in this risk

category. This fact is explained by the location of Reghin built-up area, very close and along the main stream that causes the risk, Mureş River. The same thing is true for the transport infrastructure (roads and railways), of which 25% are in this risk category.

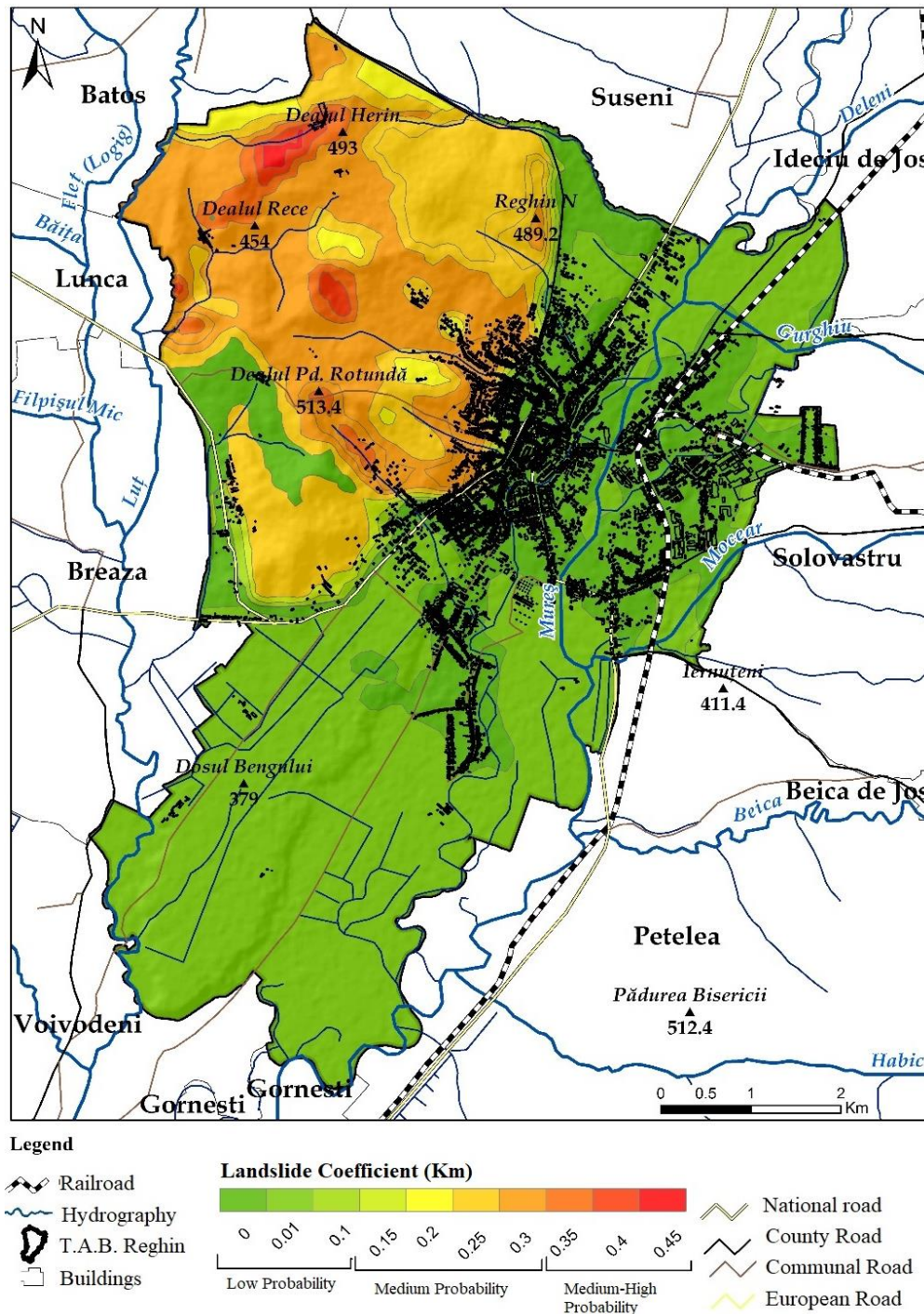


Figure 10 Map of geomorphological risk in Reghin municipality

Table 2 Territorial distribution of classes regarding landslide occurrence probability

Nr.	Hazard average coefficient (Km)	Probability class	Area	
			ha	%
1	0.5	<i>Average-high probability</i>	0.20	0.00
2	0.45		1375.51	24.59
3	0.4		2291.85	40.98
4	0.35	<i>Average probability</i>	70.89	1.27
5	0.3		58.90	1.05
6	0.25		75.74	1.35
7	0.20		733.16	13.11
8	0.15	<i>Low probability</i>	845.13	15.11
9	0.1		97.58	1.74
10	0.01		35.33	0.63
11	0		8.73	0.16

Table 3 Distribution of land use classes according to exposure to risk

Area (km ²)	Flood exposure classes			
	<i>E0</i>	<i>E1</i>	<i>E2</i>	<i>E3</i>
	0.2	3.6	1.7	0.93

In the study area represented by Reghin municipality, one remarks that 0.43% of the buildings (46 buildings) in the city of Reghin are located in the area with a high probability of landslide occurrence and 14.54% (1345 buildings) in the area prone to flood risk (Table 4).

The identification of areas that are favourable or restrictive in terms of the location of housing estates and transport infrastructures is vital for a proper territorial planning. It has been achieved by creating a model which integrates by means of mediation (EPA, 2003) the databases used for the individual risk assessment. There is also the possibility to achieve the multi-risk map by using the maximization method, but in this case there is an overestimation of the cumulated risk (Roşca, 2015).

In order to bring the databases at the same scale of values in terms of territorial impact, the standard interval from 1 to 4 has been chosen for landslide risk classes, where 1 corresponds to the

class of practically no risk, and 4 to a high risk of landslide occurrence. For the flood risk, the standard value 1 corresponds to areas without any chance of flooding and 4 to areas that may be flooded once every 100 years, so there is a high flood risk (Fig. 12).

The spatial assessment to identify the multi-risk is based on the spatial analysis of attribute tables by means of spatial analysis equations based in their turn on mathematical identifiers that integrate the numerical information stored within the attribute table. In the final model, the two analysed databases, the landslide risk and the flood risk, are managed as vectoral databases, the landslide risk obtained by converting the raster qualitatively scored from 1 to 4, and the flood risk by spatially merging the floodable stripes and the administrative unit of the study area, as well as by adding the specific qualitative scores in the attribute table.

Table 4 Classification of residential and transport infrastructure according to landslide and flood risk classes

Exposed elements	Landslide risk				Flood risk	
	Practically zero	Low	Medium	High	Practically zero	High
Buildings (%)	67.12	17.98	14.46	0.43	85.46	14.54
Roads (%)	51.75	35.87	11.92	0.46	81.87	18.13
Railways (%)	68.50	31.50	0.00	0.00	93.06	6.94

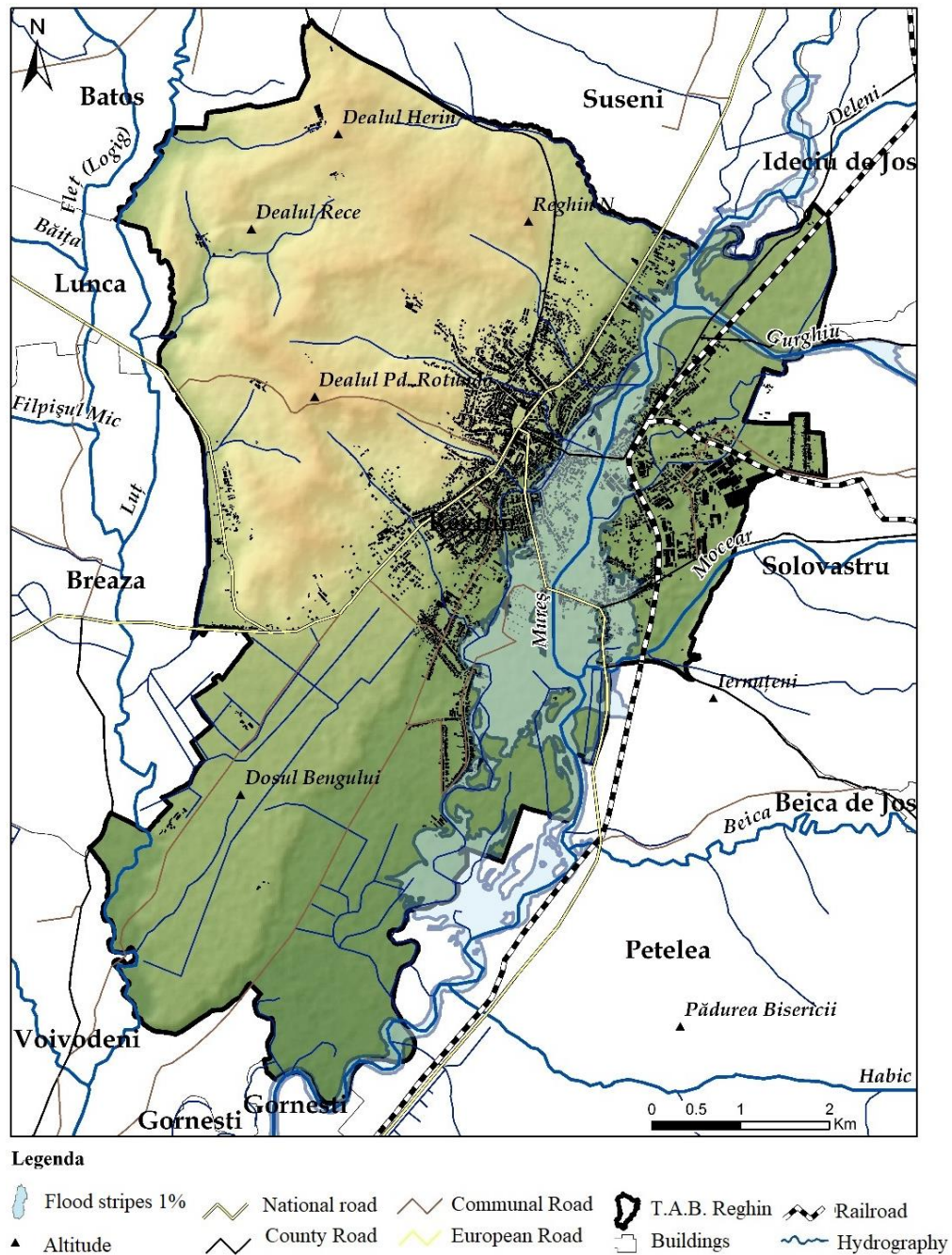


Figure 11 Flood map

The integration of polygon-type vectoral databases supposed the use of identify function to obtain a polygon-type spatial database including attribute information that is spatially identified correctly from the point of view of the risk it represents across the territory. Therefore, two new columns were obtained in the attribute table, each of them storing information concerning the individual risk class for a certain area. The spatial analysis equation

was applied to cumulate the corresponding values in the attribute table for every area, on the basis of the mathematical identifier sum and equal weight, which allowed the risk to be cumulated and stored as a numerical score information in a new column in the attribute table. This column represents the value of the risk impact on the territory and includes values between 1 and 4.

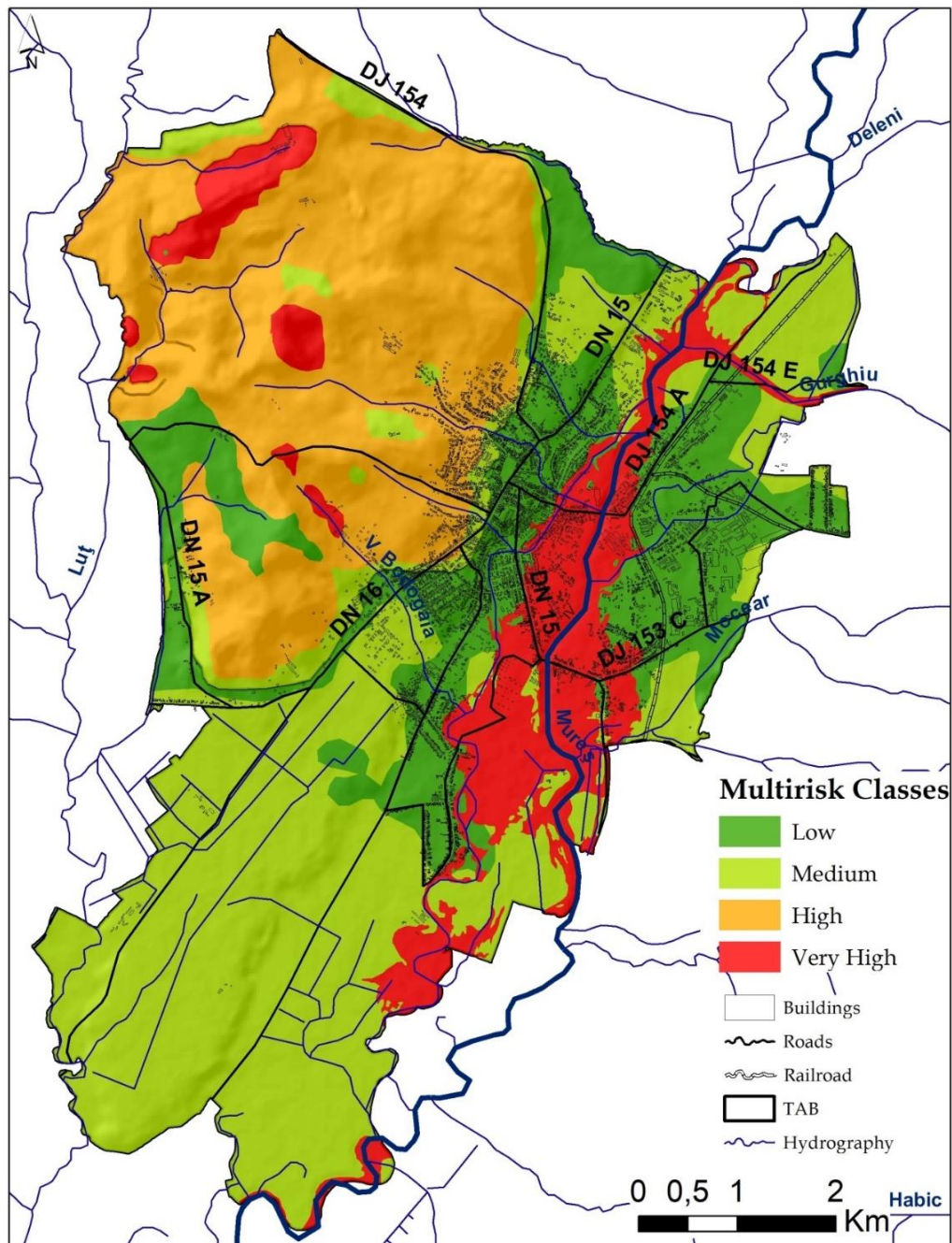


Figure 12 Multi-risk assessments in Reghin municipality

5. Conclusions

The analysed territory, corresponding to the City of Reghin administrative area, is affected by landslides along the slopes. The residential areas and the transport infrastructure located in areas prone to landslides are at risk due to the overcharging of slopes with buildings and the existing favourable conditions for the landslide processes to become

manifest. To these geomorphological risk phenomena, one may add the high density of constructions along the Mureș river bed, which brings into discussion the flood risk in the context of increasing discharges, exceeding the danger level. It is therefore necessary to perform a multi-risk type analysis to highlight the areas exposed to risk-generating processes in order to reduce or eliminate the material damage and the potential loss of human life.

As a result of applying the GIS spatial analysis techniques, the probability of landslide occurrence has been identified according to the methodological norms established by the Government Decision no. 447/2003, which lays stress on the causing and triggering factors at national level. Accordingly, there are large areas across Reghin municipality characterised by an average-high probability of landslide occurrence. At the level of these areas, detailed geotechnical studies are needed to mitigate the negative effects, laying the basis for specific drainage works and for the decrease in the number of building certificates issued by the authorities for new constructions on the slopes characterised by instability.

The flood risk for a discharge with a 1% probability of occurrence is significant for 11.31% of the Reghin administrative area, endangering a number of 1345 buildings, 5.52 km of roads and 0.52 km of railways. The presented model highlights a useful method to identify the degree of territorial functionality of parts of the built-up areas where risk studies are needed to be performed for detailed urban plans that have the main purpose of planning the areas and delineating functional zones such as the category of residential areas proposed for development and areas proposed for industrial development. The areas proposed for the development of transport infrastructure and services are tightly linked to the previous ones, as the infrastructure is highly sensitive to the landslide and flood risks, which may determine the danger of accidents in case that the infrastructure is developed in improper areas from the point of view of the impact.

The multi-risk type assessment, performed by the method of mediation, led to the multi-risk map, where each individual risk class received an equal weight in the final result. As such, the very high multi-risk class highlights the presence of residential buildings and transport infrastructure in the areas with the highest probability of landslide or flood occurrence. In these areas, it is strongly recommended not to build anymore, to create events to inform the inhabitants about the risks they are exposed to and to make structural decisions to mitigate the potential negative effects.

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References

- *** Government Decision no. 447 of April 10, 2003, concerning the approval of the methodological rules related to the drafting and content of the natural hazard maps regarding floods and landslides, published in Monitorul Oficial, May 7, 2003 (in Romanian).
- *** Flood Risk Management Plan, Mureş Water Catchment Administration, available online: <http://www.inhga.ro/documents/10184/121027/3+P+MRI+Mures.pdf/f5fd79d8-237d-4ced-ab11-e883f6620825>
- *** EPA 2003. *Report on the environment technical document*, Unites States Environmental Protection Agency, Washington.
- *** UNISDR. 2015. Sendai Framework for Disaster Risk Reduction 2015–2030.
- Benedek J. 2016. The role of urban growth poles in regional policy: the Romanian case. *Procedia – Social and Behavioral Sciences*, **223**: 285–290.
- Bilaşco Şt, Roşca S, Fodorean I, Vescan I, Filip S, Petrea D. 2018. Quantitative evaluation of the risk induced by dominant geomorphological processes on different land uses, based on GIS spatial analysis models. *Front. Earth Sci.*, **12**(2): 311–324. <https://doi.org/10.1007/s11707-017-0679-3>.
- Carrara A, Cardinali M, Guzzetti F. 1992. Uncertainty in assessing landslide hazard and risk. *ITC J*, **2**: 172–183.
- Carrara A. et al., 1999. Use of GIS Technology in the Prediction and Monitoring of Landslide Hazard. *Natural Hazard*, **20**: 117–135.
- Ciocârdel R. 1949. Geologia regiunii Bistriţa–Reghin. *Dări de seamă ale şedinţelor*, **37**: 131–141.
- Cocean P, Irimuş IA. et al. 2004. *Planul de Amenajare a Teritoriului Regiunii de Nord-Vest*, Editura Presa Universitară Clujeană, Cluj–Napoca.
- Coe JA, Godt JW, Baum RL, Bucknam RC, Michael JA. 2004. *Landslide Susceptibility from topography in Guatemala*. In: Lacerda WA, Erlich M, Fontoura SAB, and Sayao ASF. (eds.): Landslides, evaluation and stabilization. Proceedings of the 9th international Symposium on Landslide, Rio de Janeiro, **1**: 69–79.

- Conțiu Hadrian-V, Conțiu A. 2005. Percepția inundațiilor în culoarul Mureșului dintre Reghin și confluența cu Arieșul. In: *Riscuri și catastrofe*, **4**(2): 99–108.
- Filip S. 2009. *Planning urban*. Presa Universitară Clujeană, Cluj-Napoca.
- Gallina V, Torresan S, Critto A, Sperotto A, Glade T, Marcomini A. 2016. A review of multi-risk methodologies for natural hazards: consequences and challenges for a climate change impact assessment. *J. Environ. Manag.*, **168**: 123–132.
- Gill JC, Malamud BD. 2017. Anthropogenic processes, natural hazards, and interactions in a multi-hazard framework. *Earth Sci. Rev.*, **166**: 246–269.
- Guzzetti F, Carrara A, Cardinali M, Reichenbach P. 1999. Landslide hazard evaluation: a review of current techniques and their application in a multiscale study, Central Italy. *Geomorphology*, **31**(1–4): 181–216.
- Ianoș I. 1987. *Orașele și organizarea spațiului geografic*. Editura Academiei, București.
- Irimuş IA, Szilágyi JM. 2017. Geomorphological hazards from the Reghin Hills with risk potential. In: *Riscuri și catastrofe*, **16**(20): 151–159.
- Jurgilevich A, Räsänen A, Groundstroem F, Juhola S. 2017. A systematic review of dynamics in climate risk and vulnerability assessments. *Environ. Res. Lett.*, **12**. <https://doi.org/10.1088/1748-9326/aa5508>
- Lateltin O. 1997. *Berücksichtigung der Massenbewegungsgefahren-beiraumwirksamen Tätigkeiten*. Empfehlungen, Swiss Federal Office for Water and Geology (FOWG). <http://www.bwg.admin.ch/themen/natur/e/index.htm>
- Marzocchi W, Mastellone M L, Di Ruocco, Novelli A, Romeo P, Gasparini P. 2009. *Principle of multi-risk assessment, research performed in the frame of Na.R.As (Natural Risks Assessment) FP6 SSA Project No. 511264*, Napoli, Italia.
- Micu M, Jurchescu M, Șandric I, Mărgărint C, Chițu Z, Micu D, Ciurean R, Ilinca V, Vasile M, 2016. Mass movement. In: Rădoane M, Vespremeanu-Stroe A. (eds.): *Landform Dynamics and Evolution in Romania*. Springer Geography, Springer International Publishing Switzerland.
- Petrea D, Bilașco Șt, Roșca S, Vescan I, Fodorean I. 2014. The determination of the Landslide occurrence probability by spatial analysis of the Land Morphometric characteristics (case study: the Transylvanian Plateau). *Carpath J Environ Sci*, **9**: 91–110.
- Polemio M, Petrucci O. 2010. Occurrence of landslide events and the role of climate in the twentieth century in Calabria, southern Italy. *Quarterly Journal of Engineering Geology and Hydrogeology*, **43**: 403–415, DOI:10.1144/1470-9236/09-006.
- Roșca S, Bilașco Ș, Petrea D, Fodorean I, Vescan I, Filip S. 2015. Application of landslide hazard scenarios at annual scale in the Niraj River basin (Transylvania Depression, Romania). *Nat Hazards*, **77**: 1573–1592, DOI 10.1007/s11069-015-1665-2.
- Roșca S. 2015. *Bazinul Nirajului studiu de geomorfologie aplicată*. Editura Risoprint, Cluj-Napoca.
- Sestras P, Bilasco S, Rosca S, Nas S, Bondrea MV, Galgau R, Veres I, Salagean T, Spalevic V., Cimpanu SM. 2019. Landslides Susceptibility Assessment Based on GIS Statistical Bivariate Analysis in the Hills Surrounding a Metropolitan Area. *Sustainability*, **11**(5), DOI: 10.3390/su11051362.
- Terzi S, Torresan S, Schneiderbauer S, Critto A, Zebisch M, Marcomini A. 2019. Multi-risk assessment in mountain regions: A review of modelling approaches for climate change adaptation. *Journal of Environmental Management*, **232**: 759–771. doi.org/10.1016/j.jenvman.2018.11.100.
- Van Westen CJ, Van Asch TWJ, Soeters R. 2006. Landslide hazard and risk zonation – why is it still so difficult? *Bull Eng Geol Environ*, **65**: 167–184. [doi:10.1007/s10064-005-0023-0](https://doi.org/10.1007/s10064-005-0023-0).
- Willems P, Thompson S, Barbieri M. 2003. *Flood risk and damage Assessment using Modelling and Earth observation techniques (FAME)*. Final Report, Data User Programme (DUP-2), ESA, 48 p. <http://www.kuleuven.be/hydr/fame.htm>.
- Zezere JL, Rodrigues ML, Reis E, Garcia R, Oliveira S, Vieira G, Ferreira AB. 2004. Spatial and temporal data management for the probabilistic landslide hazard assessment considering landslide typology. In: Lacerda WA, Ehrlich M, Fontura SAB, Sanyal ASF (eds.): *Landslides: evaluation and stabilization*. Taylor & Francis Group, London, 117–123.

Historical geomorphic analysis of Someșul Mic River (NW Romania) channel spatial and temporal behavior, as a background for the assessment of present day morphological state of the river

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ABSTRACT

In the context of the increased interest on integrating the complex spatial and temporal response of fluvial systems to human impacts into the process of assessing the ecological state of the rivers and in promoting a sustainable river management European countries have developed a multi-scalar, hierarchical, process based hydro-morphological framework focused on understanding the river functioning and evolution as a basis for interpreting current conditions. In this context, the goal of this paper is to demonstrate the usefulness of systematic historic and present day geomorphic analysis along channel reaches with distinct typologies in order to generate a better image of river morphology as a background for assessing its present morphological state. The historical geomorphic analysis of Someșul Mic River's channel dynamics during the past 250 years has shown that the main controlling factor is climate through its centennial – decadal scale variations in magnitudes and amplitudes of flood events, while the local geological conditions and hydrotechnical works having subordinate effects. The reference condition in assessing the present day morphological state of the river was defined based on channel typology and dynamics between AD 1860 – AD 1970, reflecting a river state far from a pristine condition, but characterized through human impacts maintained below the river sensitivity to disturbances. The Morphological Quality Index (MQI) was calculated for 17 distinct channel reaches. Its values indicate the high geomorphic degradation of the river induced by hydrotechnical interventions along the channel. Very poor conditions are concentrated mainly along the upper reaches of the river, while further downstream the river is in a dominantly moderate deterioration state. The resulted image has the potential to better identify the critical reaches along this river, and the main disturbatory elements acting on them, in order to support better projections on possible channel trajectories and subsequently river management actions.

KEYWORDS

channel planform dynamics; evolutionary trajectory; boundary conditions; sensitivity; resilience; present day morphological state

1. Introduction

River channelization and diversion, gravel extractions, groyne and dam constructions are known to have significant impacts on fluvial forms and processes. Some of these interventions have rapid and perceptible effects on river hydro-morphology and its social and ecological functions, while others impact rivers decades after construction as a consequence of long term channel adjustments (Knighton, 1998; Brierley and Fryirs, 2005; Kondolf and Piégay, 2016).

In the context of the increased interest on integrating the complex spatial and temporal response of fluvial systems to human impacts into the process of assessing the ecological state of the rivers and in promoting a sustainable river management (e.g. Brierley and Fryirs, 2005; Brierley et al., 2008; Brierley et al., 2013; Rinaldi et al., 2013 a, b; Rinaldi et al., 2016; Kondolf and Piégay, 2016; Gurnell et al., 2016 a, b) European countries have developed and/or extended a series of hydro-morphological tools in order to assess, manage and monitor the ecological status of rivers (Rinaldi et al., 2017). This process has been accelerated by the implementation of the EU Water Framework Directive (WFD; Directive 2000/60/EC) which introduced hydro-morphology as an important component in the process of assessment and management of river ecosystems. In the initial approach, hydro-morphological assessment was considered equivalent to physical habitat survey, used to offer a rapid overview on river status. A series of limitations have become evident (Belletti et al., 2015; Rinaldi et al., 2017), the most evident ones being related to: a) limited space of investigation (fixed length of the investigated river reaches, few hundred meters long) which cannot offer a good perspective on the context of river condition and do not permit an accurate diagnosis on causes of alterations; b) the ambiguous notion of "reference conditions", defined based on the statistical analysis of empirical data, not always being relevant at local scale; and c) the terminology used

to describe geomorphic units that seemed to lack a good correspondence with present state-of-the-art classifications in fluvial geomorphology. Therefore, in opposition with the physical survey procedure, an increased tendency to develop frameworks of hydro-morphological approaches and methods which focus on understanding the river functioning and evolution as a basis for interpreting current conditions emerged (e.g. Winterbottom, 2000; Liébault and Piégay, 2001, 2002; Brierley and Fryirs, 2005; Dufour and Piégay, 2009; Surian and Rinaldi, 2003; Rinaldi et al., 2003, Rinaldi et al., 2013 a,b). These perspectives introduced process-based methods which explicitly take into consideration both spatial and temporal changes of the investigated river channels.

In Romania, the present-day monitoring system ("Sistemul de Monitorizare Integrată a Apelor din România" – S.M.I.A.R.) for assessing and classifying river sectors ("*corpuri de apă*") is connected to the national network of gauging stations, totalizing a number of ca. 1750 evaluation points. S.M.I.A.R. is projected to cover the entire diversity of river typologies defined for the Romanian territory in accordance with the broad river typologies established at European level, and includes habitat evaluation, completed by physico-chemical measurements and hydro-morphological characterization of the selected river sectors. The evaluation process covers 500 m standard river reaches, centered on the gauging stations. The outcomes of the present monitoring system are translated in qualificatives on the quality of river ecosystems and the degree of river change when compared with a reference condition, defined as "*natural conditions*". The rivers are evaluated with a periodicity of 6 years, the last evaluation being included in the National Plan of Water Management 2016 – 2021 (<http://www.rowater.ro>).

The existing studies on spatial and temporal channel changes in Romanian rivers (e.g. Amăriucăi, 2000; Rădoane and Rădoane, 2005; Dumitriu, 2007; Rădoane et al., 2010; Perșoiu, 2010; Perșoiu and Rădoane, 2011; Ioana Toroimac et al., 2010; Armaș

et al., 2012; Rădoane et al., 2013 a, Rădoane et al., 2017) are still limited in temporal and spatial coverage. Further, they are not unitary in terms of resolution and offer different perspectives on channel responses to various controlling factors (e.g., the adjustment of river channels downstream from dams, the effects of meander cutting and river channel corrections, the effects of decreasing sediment loads etc.). Even with this inconvenient, these studies show that human interventions on the geomorphological fluvial systems are responsible for significant changes in sediment delivery rates, variability of riverbed deposits, as well as in the hydrologic regimes of the present-day channel dynamics, with large consequences on river ecosystems. However, none of these indicators are included in the process physical survey procedures used in the evaluation and classification of Romanian rivers.

The goal of this paper is to demonstrate the usefulness of systematic historic and present-day geomorphic analysis along channel reaches with distinct typologies in order to obtain a better image of river morphology as a background for assessing the ecological state of the rivers and project sustainable management actions. The case study ex-

emplified here is Someșul Mic River, located in NW Romania that has been heavily impacted by human activities in the past several decades. Our objectives are 1) analysis of the general spatial and temporal patterns of the river's channel over the past ca. 250 years; 2) disentangling the natural and human controls over the river's dynamics; 3) establishment of the moment and meaning of reference condition and 4) evaluation of the present-day morphological status of the river.

2. Study area

Someșul Mic River is a medium size river (100 km long, $QI = 22 \text{ m}^3/\text{s}$, $A = 3774 \text{ km}^2$), formed at Gilău (presently in the Gilău Reservoir) at the junction of Someșul Cald and Someșul Rece Rivers, two tributaries draining the northern flank of Apuseni Mountains. Its upper basin overlaps the high-altitude Apuseni Mountain (Muntele Mare – Gilău Mountains and Bihor Mountains) and the median and lower basins are located within the Transylvanian Depression (Someșan Plateau, Feleac Hills and Transylvanian Plain, Fig. 1).

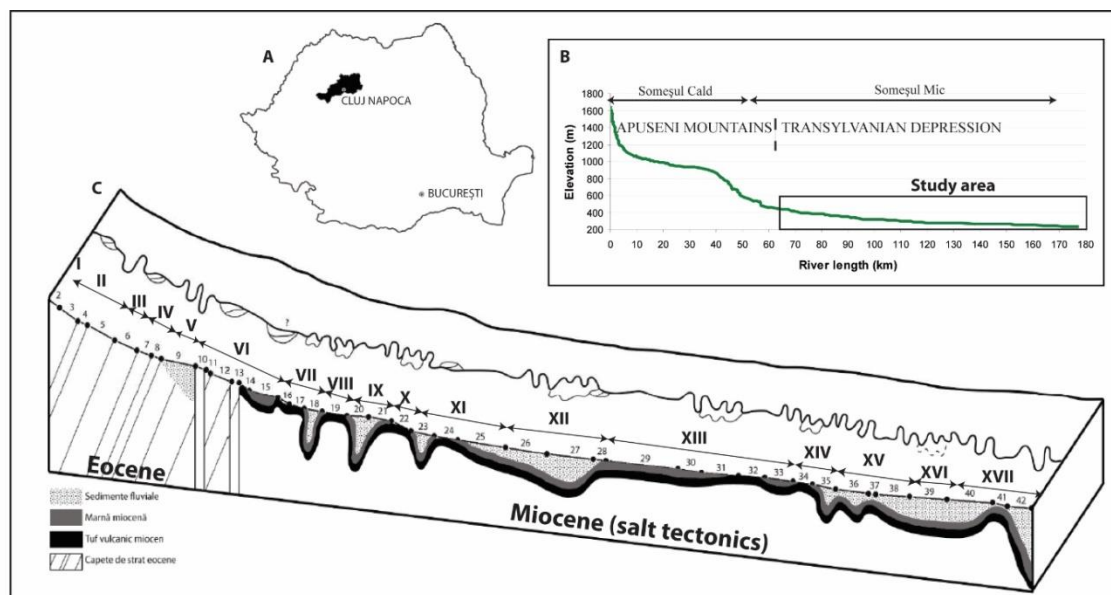


Figure 1 A – Location of Someșul Mic drainage basin; B – Someșul Mic River: location of the study area along its longitudinal profile; C – Model of longitudinal profile channel patterns alternation as adjustments to local geological conditions, reference year AD 1860 (IInd Austro–Hungarian military survey). The 42 natural channel reaches were grouped in 17 main ones, based on their present-day status related to human impact, i.e. reaches completely disturbed from its previous patterns alternating with those with more local interventions, which partly preserve their natural forms

The climate of the area is temperate continental, with mean annual temperatures of 8.4°C and mean annual rainfall of 582 mm. The main source of discharge (> 50 %) is in the mountainous area (23 % of the drainage basin). By contrast, the suspended load is mainly delivered from the hilly area in the middle and lower parts of the drainage basin, where the presence of friable rocks and the less protective vegetation cover favors an increased land susceptibility to erosion (Pandi, 1997).

The lithology of the drainage basin is dominated by sedimentary rocks (80 %), whereby 94 % are Eocene and Miocene deposits in the hill domain (limestone, marls, clays, volcanic tuffs). Metamorphic (crystalline schists) and magmatic (the Gilău Granite, Paleocene andesite) rocks preferentially located in the mountainous area, make-up the remaining 20 %. Two large scale knick points, hundreds of meters high, are present along the longitudinal profiles of the two tributaries, imposed by different resistance to fluvial erosion of the crystalline schists and Gilău Granite (Posea et al., 1974, Ficheux, 1996, Fig. 1). The drainage basin is completely included in the area of minimum seismic activity in Romania, with an uplift rate of 0–1 mm/year in the Apuseni Mountains (lower in the Transylvanian Depression, Zugrăvescu et al., 1998). The vegetation is represented by deciduous forests at low and mid altitudes (230 – 800 m), mixed forests of *Fagus* and *Picea* at 800 – 1300 m altitudes, followed by coniferous species at 1300 – 1800 m and subalpine associations over 1800 m. At lower elevation, the natural vegetation was largely replaced by agricultural fields.

Someșul Mic River has a 4 km wide and 170 m deep valley, with 8–9 fragmentary distributed fluvial terraces (Posea, 1962; Savu, 1964). The floodplain is well developed with a maximum width of ca. 2 km. Its main particularities are the frequent change of the width associated with a complex alternation of channel types (sinuous – meandering – anabranching reaches; alluvial and mixed channels) and humid – dry areas (Perșoiu and Rădoane, 2011). This complex morphology is imposed by slight vertical displacements (0.1 – 1 mm/year, Zugrăvescu et al., 1998) with local uplifts and subsidence in the Palaeogene domain (Gilău – Cluj–Napoca) and diapiric

alignments in the Miocene domain (Cluj–Napoca – Dej) (Ciupagea et al., 1970; Krezsek and Bally, 2016).

3. Human impact

Palaeoenvironmental reconstructions and synthesis in NE Hungary and NW Romania (e.g. Sümegy, 1999; Feurdean and Astaloș, 2005; Feurdean et al., 2013a, b; Feurdean and Tanțău, 2017) attribute the first signs of agriculture in the Someș drainage area to early Neolithic communities, approximately 7500 years ago. More continuous and abundant signals of human impacts on vegetation are associated with pastoral activities and agriculture during the late Bronze/early Iron Age (3500 years ago), Roman Age (2000 years ago), and the onset of Middle Age (the last 1000 years), with a maximum reduction of natural deciduous forest assemblages during the last ca. 500 years. These human induced changes on drainage basin vegetation composition and structure had probably notable consequences on sediment load discharges as reported elsewhere in Europe (e.g. Hoffmann et al., 2008). Recent data on palaeofluvial archives from NW Romania attest an increased vertical aggradation rates of the floodplains starting with the Bronze Age along the small rivers draining Transylvanian Plain (Feurdean et al., 2013b; Perșoiu et al., 2016) and during the last 450 years as reported along the lower Someș Plain (probably related to intensive *Fagus* forest exploitation at mid elevations, Robu, 2018).

At local scales, the archeological and historical findings along the river and in its floodplain perimeter show continuous presence of humans since the Bronze Age (and likely before), with permanent settlements, roads, bridges. The medieval documentations of mills attest direct human induced deviations of flows along selected reaches, while local to regional scale channel straightening and drainage of humid areas are reported starting with the 18th century.

For more recent times, i.e. the last ca. 150 – 50 years, Romanian rivers were subjected to significant changes similar to those reported throughout Europe (Rădoane et al., 2017). The main human interventions with traceable effects on river flow regimes and morphologies are:

Regional land use changes triggered by policy/governance

Massive forest exploitation in the mountainous catchment areas emerged since the late XIXth century (related to the first waves of industrial revolution); this phenomenon accelerated during the first decades of the XXth century (Munteanu et al., 2014). After the implementation of the 1921's agricultural reform (that endowed the local communities with forests and pastures, Ciomac and Popa – Necșa, 1936), large areas of former forested fields were replaced by extensive agricultural and pastoral areas (Giurgiu, 2010). The next important land use changes occurred since 1950 – 1955, being related to the large scale collectivization programs and erosion control works, including reforestation (Chiriță, 1981). After 1989, the abandonment of a series of agricultural and pastoral fields was complemented by deterioration/destruction of many of the previous erosion control works and a new increase in forest cover loss in the mountainous areas (Griffiths et al., 2014; Munteanu et al., 2014).

Dams construction

Between 1960 and 1989, approximately 260 large dams were built along the main Romanian rivers. They control over 13 billion cubic meters of water, ca. 1/3 of the total discharge along the fluvial network, and have retained more than 200 million m³ of sediments. In the study area, the most extensive hydrotechnical interventions were performed between 1959 and 1983 (Pop, 1996). Sixteen dams were constructed along Someșul Cald, Someșul Rece (i.e., Beliș – Fântânele, Tarnița and Gilău Lakes) and Someșul Mic River (Florești Reservoir). They have the capacity to retain 84% of the flow discharge, and impose its artificial redistribution throughout the year. A second important modification is the almost complete elimination of floods, especially after 1983, when Beliș – Fântânele Reservoir became functional. Sediment trapping behind the dams induced channel incision along the Someșul Mic River, Armencea et al. (1980) showing a 2.5 m incision downstream of Gilău Reservoir within four years after the construction, while Șerban (2007) have shown a generalized channel

incision along the first 30 km after Gilău, attenuated downstream and then replaced by aggradation.

An explosive development of micro-hydro-power stations along the mountainous rivers draining the Carpathians was recorded during the past 10 years, with a peak between 2008 and 2013, with a still not well understood impact on local flow regimes and further downstream hydro-morphological consequences.

Riverbank protection structures and levees

Local interventions in the humid areas along the floodplain were already reported during the late XVIIIth century, mainly along the lower reaches of Someșul Mic. They became more extensive in the XIXth century, when desiccations and artificial meander cutoffs were performed in urban areas. The river bank protection structures and levees were extended in the XXth century (ca. 1950 – 1990, especially after the large scale 1970–1975 flood events). Direct interventions along the Someșul Mic River (bank stabilization, artificial meander cutoffs and dykes) were made within or adjacent to settlements, in areas susceptible to high rates of lateral erosion, avulsion or frequent floods. Between Gilău and Florești Reservoirs the flow is diverted through an artificial channel, while the natural channel is partly abandoned. In the perimeters of Cluj-Napoca and Gherla towns, the river is completely channelized. Dykes and bank stabilization works dominate the river morphology between Cluj-Napoca and Apahida, while further downstream they are more local and fragmentary, which give the river a more natural aspect, characterized by alternation of sinuous and meandering reaches, and one anabranching reach (between Răscruci and Bontida).

Gravel extractions

This activity peaked during the communist era (1970–1989) along the entire Romanian territory, and diminished considerably after 1989, with a new increase related to economic developments of the 2000s (Rădoane et al., 2017). Along Someșul Mic River, more than 30 gravel extraction points were active during the last 40 years, located both in the channel perimeter and in its near vicinity, and concentrated preferentially along the channel reach

between Gilău and Florești Lakes and downstream from Sânnicoara (Fig. 1).

No data is available on the volume of extracted gravels or on the impact of this activity on channel morphologies and their temporal behavior. However, similar patterns with the ones reported elsewhere along the Romanian rivers (e.g. Moldova, Siret; Rădoane and Rădoane, 2009) are expected. These studies reported at least a doubling of volumes extracted during the past 20 years compared with 1969–1981 period, resulting in channel incision (1.5 – 4 m) and increase of suspended load.

In synthesis, the above mentioned aspects offer a still incipient image on millennial and historical human impacts on fluvial network and flow regimes. But even so, they do attest that *"the river, before the large scale human interventions from the last six decades, was not in pristine conditions, as the human imprints on flow regimes and channel morphologies have roots traceable to at least the past 3000 years"*.

4. History and evolutionary trajectory of the river morphology

4.1 Materials and methods

The investigations on the spatial and temporal behavior of Someșul Mic River is based on seven sets of cartographic maps and one set of orthophotos, with the years AD 1764, AD 1860, AD 1890, AD 1945, AD 1956, AD 1970, AD 1977 and AD 2005 as reference moments (Table 1). The materials covering the last ca. 150 years were used to provide successive morphometric measurements along the longitudinal profile of the following parameters: floodplain width and number of channels; and, along the unique/main channels, measurements of length, sinuosity, radius of curvature (R_c) in the meander bents, bank elevation and bankfull channel width and slopes. With the exception of R_c , determined from the circumscribed circles of the considered meander bents, the measurements were performed at the intersection points along the 250 m spaced cross sections on the central axis of the floodplains with the central axis of the main/unique channels. Further, we defined channel reaches with distinct planform typologies, using AD 1860 as reference

moment. Additional information on present-day channel and floodplain characteristics (field surveys), historical channel planform behavior (visualization of planform river changes during the past 250 years) and available data on local geological conditions (geological maps, hydrogeological investigations) were used to establish the limits between successive channel reaches (Figs. 1, 5).

Flow regimes before AD 1974 (Anițan, 1974), together with measurements on unique/main channel bankfull slopes and bankfull widths for the AD 1970 reference moment, and GIS based estimated on drainage basin surfaces associated to each considered channel reach were used to generate specific stream power (W/m^2) at bankfull flow, (Table 2, Fig. 6), using the following formula:

$$sSP = \rho g Q_{1.5} S / w \quad (1)$$

where,

ρ = density of water (1000 kg/m³),

g = acceleration due to gravity (9.81 m/s²),

$Q_{1.5}$ = bankfull discharge (m³/s),

S = bankfull channel slope (m/km),

w = bankfull channel width (m).

Bankfull discharge ($Q_{1.5}$) is defined as being the maximum discharge that the channel can convey without overflowing onto the floodplain, and is defined to be the channel forming discharge in alluvial rivers, with a general recurrence interval of 1.5 years (Leopold et al. 1964; Knighton, 1998). Its estimates at the four gauging stations along Someșul Mic River (Gilău, Cluj–Napoca, Apahida, and Salatiu) were represented in relation with their corresponding drainage surfaces. The resulting relation was further used to extrapolate the bankfull discharge values for each of the 42 considered reaches, by projecting the known values of their equivalent drainage surfaces (GIS estimates) on the resulting curve.

Bankfull channel slope and width were estimated for the unique/main channel. Slope (S) was obtained from the difference in elevation between the two extremes of the considered channel reach (indicated on map at the channel bank level or interpolated from two successive values, at the same level) and the corresponding channel length, measured along central axis of the channel. Bankfull

channel widths (w) were measured in successive cross sections on the central axis of the floodplain. In equation (1), w was introduced as the median values of channel width at channel reach scale. More details on the methodologies of measure-

ments, together with a full description on historical channel dynamics of Someșul Mic River are given in Perșoiu, 2010, Perșoiu and Rădoane, 2011, and Rădoane et al., 2013b.

Table 1 Summary of the cartographic supports used in this study

Map	Projection	Topographic survey	Edition	Scale	Map resolution	Reference year considered in this study
The First Austro–Hungarian Military Survey (Institute of Military Geography, Vienna, Austria)	–	1763–1773 1785/1787*	1787*	1:28.800	Not geo-referenced	1764
The Second Austro–Hungarian Military Survey (Institute of Military Geography, Vienna, Austria)	Cassini–Soldner projection, Zach–Oriani Ellipsoid	1859–1860	1869–1870	1:28 800	4 m/pixel	1860
The Third Austro–Hungarian Military Survey (Institute of Military Geography, Vienna, Austria)	Tg. Mureș stereo projection, Besel 1841 Ellipsoid	1869–1884	1890–1910	1:25 000	2 m/pixel	1884
Topographic maps (Romanian Military Topographic Service, Bucharest)	Gauss–Kruger projection, Pulkovo 1942 Ellipsoid	Field survey: 1908–1914 Aerophotos: 1956	1957	1:25 000	2 m/pixel	1956
Topographic plans (Institute of Geodesy, Photogrammetry, Cartography and Territorial Planning, Bucharest, Romania)	Stereo 70 projection, Krasovschi Ellipsoid	Aerophotos: 1968–1976 Field survey: 1970–1977	1971–1979	1:5000	0.4 m/pixel	1970
Topographic maps (Military Topographic Department, MApN, Romania)	Gauss–Kruger projection, Pulkovo 1942 Ellipsoid	1977	1978–1979	1:25 000	2 m/pixel	1977
Orthophotos (National Agency for Cadaster and Land Registration, Bucharest, Romania)	Stereo 70 projection, Krasovschi Ellipsoid	2005	–	1:5000	0.5 m/pixel	2005
Google Earth	WGS 1984	–	–	–	Google Earth Data Repository	2017 – 2019

4.2 Temporal trends in channel planform behavior

During the last ca. 150 years, the considered channel planform morphometry reveals a general tendency of channel narrowing, channel planform sim-

plification and an increased planform stability with some opposite tendencies at decadal scales: increase of sinuosity between AD 1860 – AD1890, followed by decrease during AD 1890 – AD 1956, and a slight recovery during AD 1977 – AD 2005 (Fig. 3).

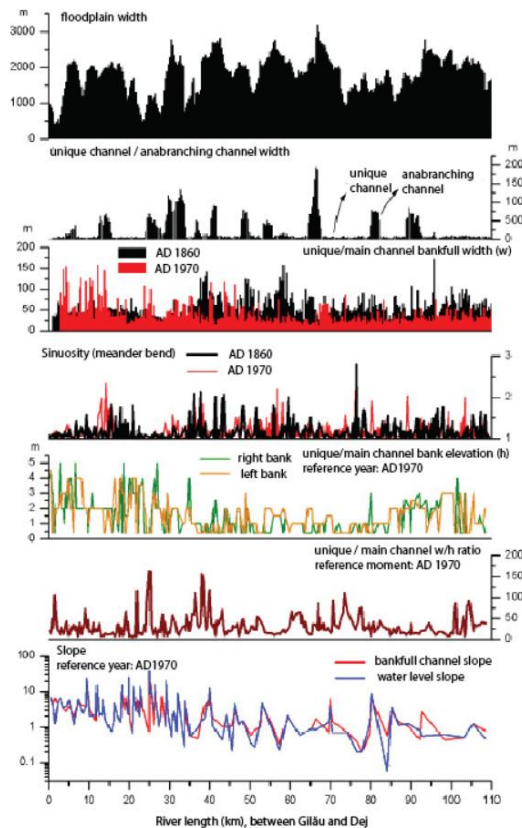


Figure 2 Longitudinal profile variability in the morphometry of Someșul Mic River and its floodplain (reference years: AD 1860 and AD 1970), revealed by systematic measurements in 250 m successive floodplain cross sections and at meander bend scale. It attests a complex spatial succession of unique and anabranching channels, with frequent slope changes, overlapped on frequent narrowing and widening of the floodplain. The main cause for this spatial behavior is attributed to the local geological (structural, tectonic) conditions

The impact of direct human interventions before 1970's is maintained at local scale, without evident correspondences in the general patterns of the considered morphometric parameters. There are no yet good understanding on the impact of the land use politics from the last decades of the XIXth century and the first decades of the XXth century on sediment discharges along the main collector. However, the existing synthesis on sediment budgets and rate of soil erosion on Romanian territory, suggest that the maximum impacts were recorded in the hilly domains and the resulting sediment supplies were

preferentially preserved along the small tributaries draining these areas (Dumitriu et al., 2017).

Starting with AD 1977, the human induced changes in the channel morphologies became dominant between Gilău and Apahida: two lakes (Gilău, Florești) and the artificial channel between them replaced the previous channel reaches, anabranching reaches disappeared, and the river was straightened through meander cutoffs and bank protection measures. Further downstream (e.g. Jucu, Iclod, Ghela, Mănăstirea, Figs. 1, 3), these interventions were smaller, the natural aspect of the channel being preserved.

On this background, the slight tendency to meandering recorded during AD 1977 – AD 2005 reflects local meander developments along non-adjusted channel reaches susceptible to meandering, a process sustained also by the complete elimination of floods after AD 1983. The bankfull channel width followed a similar decreasing trend, generalized along the entire length of the river. This tendency is confirmed by the successive measurements on channel cross sections at the four gauging stations distributed along the river (Șerban, 2007). However, these data support a limited impact of dams on channel incision, with attenuation in the first 30 km downstream from Gilău Reservoir (Șerban, 2007).

The channel planform dynamics of the past 100 years detailed above was limited compared to those occurring during the previous 100 years (AD 1764 vs. AD 1860 reference years, qualitative estimates) (Fig. 4). These differences suggest a dominating centennial scale climate control on channel platform behavior. According to Perșoiu and Rădoane (2011) and Perșoiu and Perșoiu (2019), the cold and humid decades of the late XVIIIth century (the end of the Little Ice Age), characterized by an increased frequency and magnitude of flood events during AD 1764 – AD 1860, are probably responsible for local avulsions/channel repositioning and cutoffs of previous well-developed meanders, while the ensuing warmer and drier period, with less frequent flood events, favored the development of new generations of meanders along the AD 1860 configured channels.

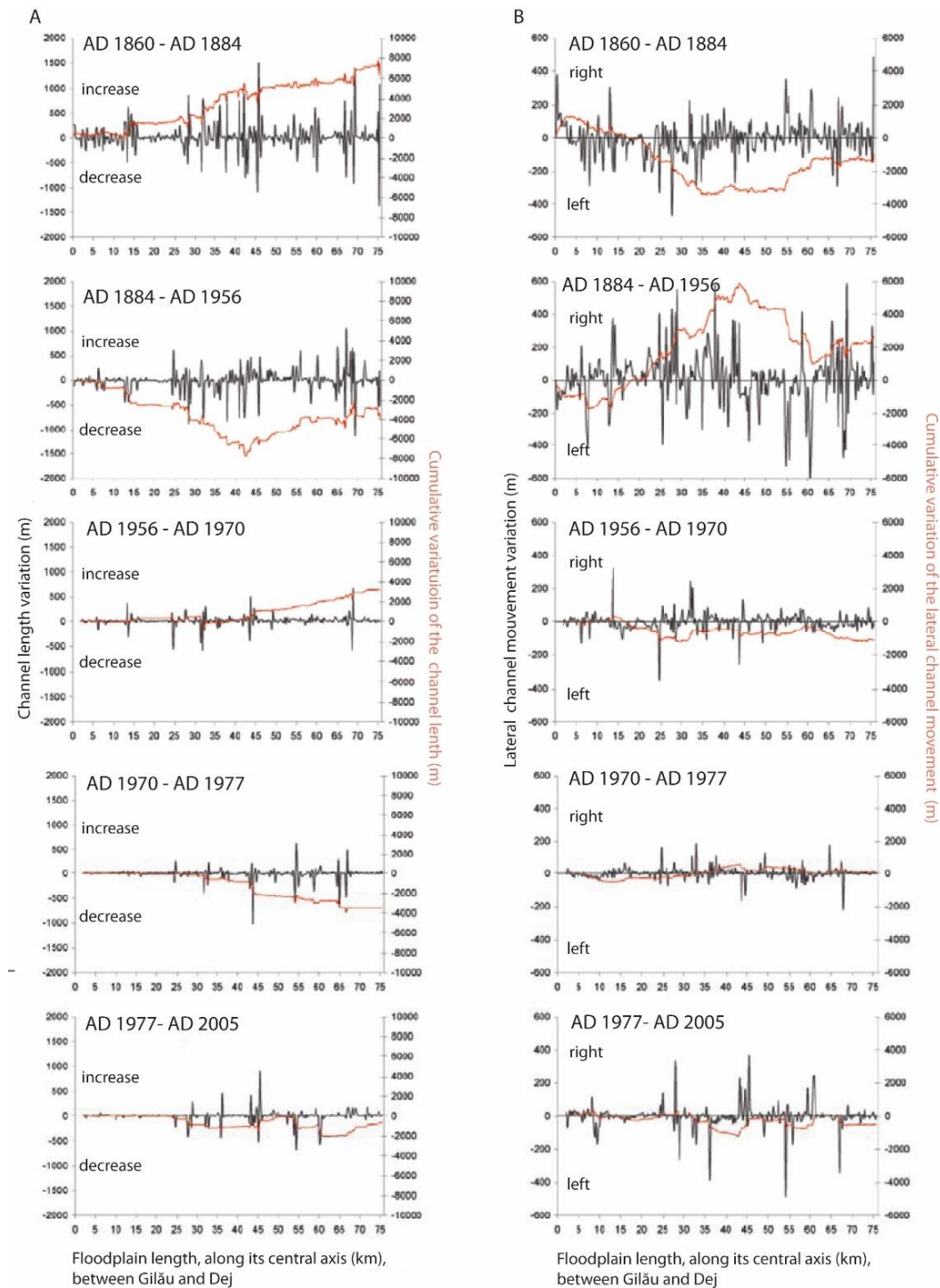


Figure 3 A – Channel length variation and **B** – Lateral channel movement in successive, 250 m spaced, cross sections on the floodplain central axis, and their cumulative variations in the longitudinal profile. The two parameters were measured along the central axis of the unique/main channel. Between AD 1860 and AD 1884, the channel length increased, associated with development of meanders along the downstream half of the river. The following phase mark an opposite tendency, up to AD 1970, and reflect mainly the channel shortening along the meandering reaches, both as consequences of natural and artificial cutoffs. The increased channel planform stability after AD 1970 is mainly caused by human interventions along the channel. Local meanders, developed during AD 1977 – AD 2005, are visible in the small scale variations of the two morphometric parameters, subordinated to the general tendencies

Based on these observations, in the absence of evidences regarding important human induced changes on sedimentary budgets and load regimes during the last ca. 150 years, *the main control on general temporal channel planform trends is climate, through its centennial – decadal scale variations in magnitudes and amplitudes of flood events.* Most relevant at local scale, conditioning the channel typologies and associated mechanisms of planform and vertical channel adjustments to changes, *the local geological conditions and hydro technical works have subordinate effects, translated in preferential locations of meandering and cutoffs, avulsion nodes and associated multichannel flows, or long term stability along natural or artificially induces sinuous channels.*

4.3 Reference condition, boundary condition, and channel sensitivity vs. channel resilience to disturbances

The local geological conditions were found responsible for the complexity of channel typologies, being identified 42 relatively short (hundreds of meter – kilometers long) channel reaches of different typologies, translated in long profile variety of alluvial and mixed channel types, with sinuous, meandering or anabranching planform patterns. *At historical scale, this geological conditioning is further reflected in preferential locations of meandering and cutoffs, avulsion nodes and associated multichannel flows, or long term stability along sinuous channel reaches* (Figs. 2, 5, 6).

The obtained sSP estimates for natural flow regime are considered here as a rough guide of river energy and its long profile variations. They most probably reflect minimum values for mixed/"in rock" channel reaches, or the anabranching ones. Further improvements should be obtained based on the data provided by detailed hydrological measurements and morphological field surveys before the human induced flow regime.

With these known shortcomings, the long profile distribution of sSP is interpreted to reflect the local geologic conditioning on flow organization, with lower values associated to the alluvial reaches along local scale subsidence basins (here the floodplain vertical aggradation is the dominant process), and

increased values along reaches where the valley bottom rocks are exposed in the river bed and its banks, as the river sectioned the entire sedimentary sequence of the floodplain, or intersect uplifting tectonic structures.

The quantitative relations between a series of hydro-morphometric parameters (bankfull slope, specific stream power, sinuosity, anabranching index), highlight several aspects of the spatial organization of flow along this particular river: (a) decreases of slope and specific stream power in the downstream direction and from 'bedrock' to mixed and alluvial reaches; (b) normal relation between slope and single-thread channel planform behavior, even if the alluvial and mixed types evolves at different energetic levels; (c) a good "memory" of the initial planform configurations, even if the historical planform configuration could indicate different channel types (e.g. a previous meandering channel, imposed on a diapiric anticline, appears now as a sinuous reach, a state reflecting the advanced phase of reach evolution in the local geological context); (d) superposition of anabranching reaches on the sinuous-meandering ranges, as responses of the river to local conditions; (e) for the mixed type reaches, the rock-alluvium proportion in the channel cross-section seems to be the main control for the channel type (a higher proportion of rock will impose sinuous or sinuous anabranching reaches and an increase of alluvium will favor lateral meandering along the single-thread channel reaches as well as the anabranching ones) (Perșoiu and Rădoane, 2011).

The post 1970's human induced artificial flow regimes and changes in local slopes, as the anabranching and part of meandering reaches were replaced by sinuous ones, together with the continuing tendency of channel narrowing and incision, are expected to be reflected in different values of specific stream power, especially along the first 30 km of the river, with possible translations in the above mentioned boundary conditions. Therefore, the reference period for assessing the present-day morphological state of the river is considered to be the interval AD 1860 – AD 1970, with AD 1970 as reference period for estimating the boundary conditions in "natural" context, as it reflects the last

morphological channel configurations before the large scale hydrotechnical works along the rivers and in the catchment areas for which are available detailed morphometric (topographic maps, scale 1:5000) and flow regime estimates (decadal scale measurements at gauging stations). As many local interventions were already reported along the river starting with the XVIIIth century, it is evident that the considered reference interval in assessing the present-day state of the river is not a real natural one. A more proper definition of *the proposed reference condition is a river state in which the human impacts are maintained below the river sensitivity to disturbances*.

5. Present day morphological state of the river

The Morphological Quality Index (MQI) is a tool designed to assess, classify and monitor the current morphological state of the rivers (Rinaldi et al., 2013a, Rinaldi et al., 2017). The procedure is a quali-

tative one, consisting in 28 indicators selected to assess the longitudinal and lateral channel continuity, its planform pattern, cross section configuration, bed structure and substrate, and vegetation in the riparian corridor. They are grouped in three distinct categories: geomorphological functionality, artificiality and channel adjustments. The resulting scoring, based on expert judgment, leads in the end to the definition of the MQI. The obtained values of this index are in the range of 1 to 0. According to Rinaldi (2013), MQI = 1 should reflect river morphological state defined by „ i) full functionality of geomorphic processes along the reach; ii) the absence or negligible presence of artificial elements along the reach and to some extent (in terms of flow and sediment fluxes) in the catchment; iii) and the absence of significant channel adjustments (configuration, width, bed elevation) over a temporal frame of about 100 years”, while MQI = 0 corresponds to minimum quality.



Figure 4 Examples of channel planform changes between AD 1764 and AD 1884: Florești: from a previous sinuous configuration, the channel became meandering; Someșeni (Cluj–Napoca): planform reconfiguration of the anabranching channel reach

In the case of Someșul Mic River, the process of channel segmentation for assessing its present-day morphologic state (reference period: AD 2015 – 2019) has considered the distribution of human induces structures along the longitudinal profile (lake, artificial channel, bank protections, meander cutoffs, levees), or, by contrast, their absence and dominance of a more „natural” pattern. We distinguished 17 distinct channel reaches (Table 2 and Fig. 1, Fig. 5). The reference conditions reflect here the channel planform typology as defined at historical scale (AD 1860 – AD 1970) and the boundary conditions indi-

cated by specific stream power estimates at AD 1970.

The MQI values (Fig. 7) indicate the high geomorphic degradation of the river induced by the last decadal hydrotechnical interventions along the channel. This finding is in agreement with the poor condition attributed to the river in the National Plan of Water Management 2016 – 2021. The new emerging image attests a further more complex situation in the longitudinal profile. Very poor conditions are concentrated mainly along the first ca. 30 km, while further downstream the river is in a dominating moderate deterioration state.

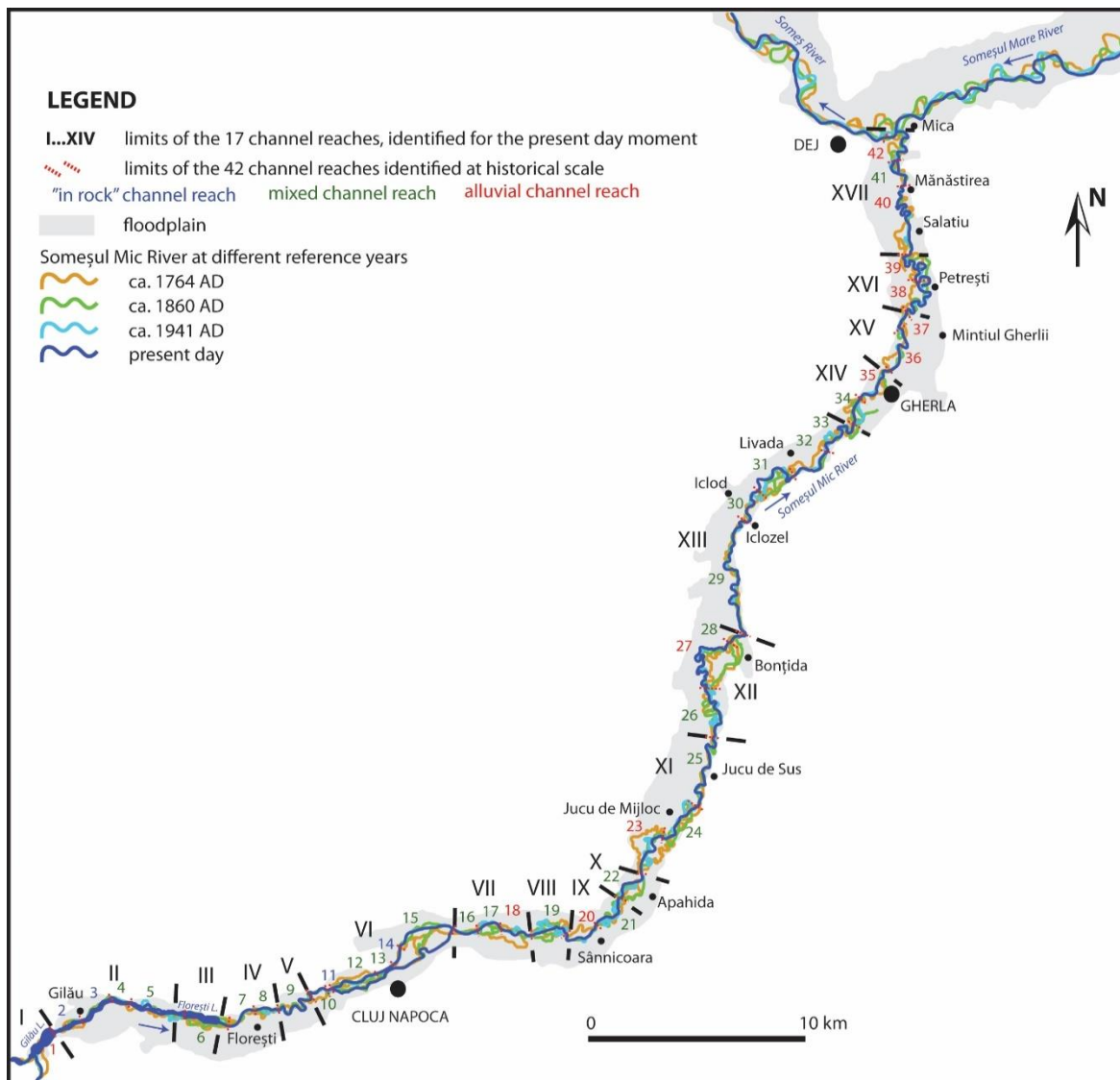


Figure 5 Long profile distribution of the 42 distinct channel reaches identified at historical scale (reference period: AD 1860 – AD 1970), and the corresponding 17 channel reaches reflecting the present-day river state, in terms of the degree of human impact on hydro-morphological conditions of the river

Table 2 Channel typologies before large scale human interventions vs. present-day channel types and their Morphological Quality Index (MQI)

Reference locality	Channel reaches at historical scale (AD 1860 – AD 1970)			Present day channel reaches (AD 1977... AD 2019)		
	Code	Channel typology	sSP (W/m ²)	Code	Channel typology	MQI assessment
Gilău	R1	S, alluvial	?	R I	<i>Gilău Lake</i>	0
	R2	S, mixed	31.12	R II	S, mixed	0.2
	R3	As, mixed	57.34			
	R4	S, mixed	29.04			
	R5	M, mixed	31.61			
Florești	R6	As, mixed	30.04	R III	<i>Florești Lake</i>	0
	R7	S, mixed	40.27	R IV	S, mixed	0.37
	R8	M, mixed	46.66			
	R9	M, alluvial	43.02	R V	M, alluvial	0.45
Cluj–Napoca	R10	S, mixed	50.51	R VI	S, mixed	0.09
	R11	S, mixed	64.18			
	R12	As, mixed	44.35			
	R13	S, mixed	35.58			
	R14	S, mixed	102.89			
	R15	S, mixed	31.09			
Someșeni (Cluj–Napoca)	R16	S, mixed	68.79	R VII	S, mixed	0.25
	R17	Am, mixed	45.32			
	R18	M, alluvial	31.01			
The International Aeroport	R19	Am, mixed	20.03	R VIII	S, mixed	0.14
Sânnicoara Apahida	R20	S, alluvial	6.39	R IX	S, mixed	0.40
	R21	M, mixed	19.95			
	R22	Am, mixed	76.97	R X	S, mixed	0.29
Jucu de Mijloc	R23	M (Am), alluvial	37.31	R IX	S with local meanders, mixed	0.62
	R24	As, mixed	43.34			
	R25	S, mixed	33.21			
Bonțida	R26	M, mixed	46.32	R XII	Unchanged	0.30
	R27	Am, alluvial	29.21			
	R28	As, mixed?	17.73			
	R29	S, mixed	24.17	R XIII	S with local meanders, mixed	0.62
Iclod	R30	M, mixed	50.49			
	R31	Am, mixed	20.69			
	R32	S, mixed	17.69			
Gherla	R33	M, mixed	37.20			
	R34	Am, mixed	37.76	R XIV	S, mixed	0.17
	R35	M (Am), alluvial	46.38			
Petrești	R36	M, alluvial	30.01	R XV	Unchanged	0.50
	R37	S, alluvial	24.82			
	R38	M, alluvial	11.89			
	R39	Am, alluvial	15.41	R XVI	S, alluvial	0.64
Salatiu	R40	M, alluvial	15.58	R XVII	Unchanged	0.37
	R41	S, mixed	50.18			
Dej	R42	M, alluvial	17.72			

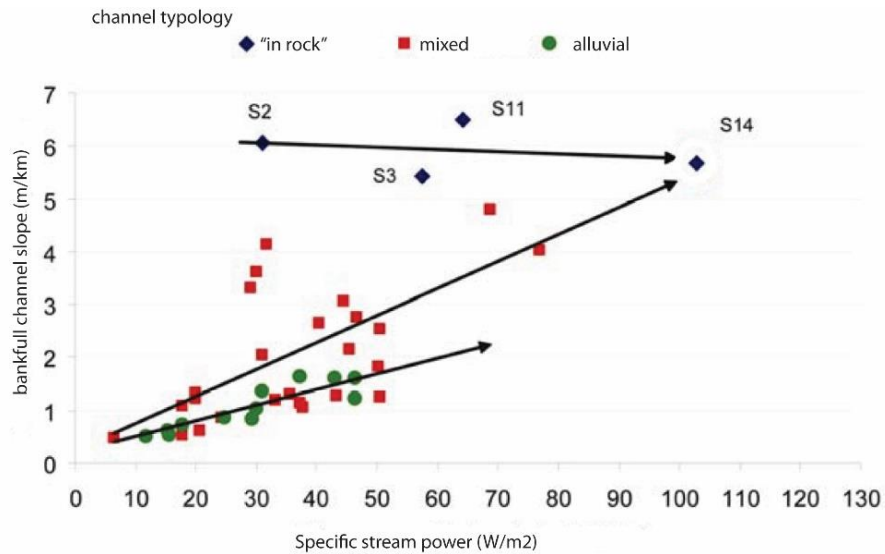


Figure 6 Bankfull slope vs. specific stream power along 42 distinct channel reaches identified at historical scale, before large scale human interventions (reference year: AD 1970, estimates along the unique/main channel)

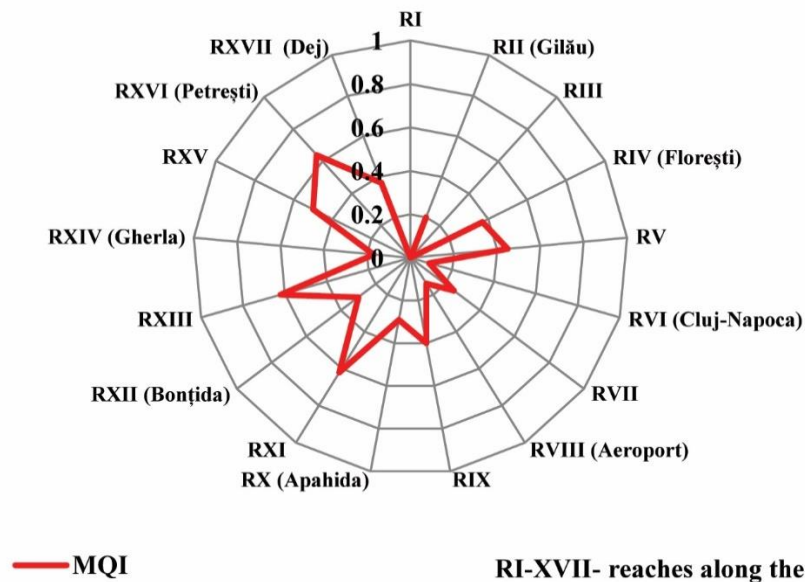


Figure 7 The Morphological Quality Index (MQI) in 17 distinct channel reaches along Someșul Mic River, reflecting long profile distribution of present-day human induces structures (lake, artificial channel, bank protections, meander cutoffs, levees), or, by contrast, their absence and dominance of a more „natural” pattern. MQI interpretation: 0–0.3: bad; 0.3–0.5: poor; 0.5 – 0.7: moderate; 0.7 / 0.85: good; 0.85 – 1: high

The main causes of disturbances vary from case to case. In the upper reaches of the river, between Gilău and Florești, the artificial diversion of flow and the presence of the two lakes highly influenced the flow regime along Reach II (R II). The decrease of water and sediment discharges downstream of the dams favored the development of riparian vegetation. A deltaic formation is present at the entrance

of the river in Florești Lake. Gravel extractions and bank consolidations are responsible for local scale changes in the channel morphology. Downstream from Florești Lake, after an artificially channelized portion (R II), the river passes a short reach where the historical pattern is conserved (R IV), and where human interventions are reduced to levees along the two banks. The next portion corresponds with

the most deteriorated part of the river, both in terms of aggressiveness (channel straightening, bank consolidations, crossing structures, levees) and affected channel length, and is superimposed on the most developed urban area along the valley, between Cluj-Napoca and Apahida. Intercalated small scale reaches (R VII, R IX) show tendencies of returning to a natural state, few decades after the local hydrotechnical works and gravel extractions, reflected in the development of riparian vegetation, development of mid-channel islands, and local meandering. Downstream from Apahida (R IX – XVII) the hydrotechnical interventions are further more dispersed and of lower impact. A series of artificial cutoffs and levees are meant to protect local villages at Jucu, Iclod, Petrești, and Gherla city, with the most extensive ones along R XIV (Fig. 7). They are responsible for the elimination of anabranching reaches recorded in the past at Iclod, Gherla and Petrești, and of some of the well-developed meander bents active before 1970's, but as in general, with the exception of Gherla, they do not impose river segmentation and dramatic changes in the historical river typologies. More visible impacts are related to the gravel extraction sites (some of them already abandoned), located both along the channel and in the near vicinity and associated with local changes in planform/cross-section channel morphologies, and floodplain land use practices, responsible for narrowing and deterioration of the riverine vegetation belt.

6. Conclusions

The goal of this paper was to demonstrate the usefulness of systematic historic and present-day geomorphic analysis along channel reaches with distinct typologies, part of a multi-scalar, hierarchical, process based hydro-morphological framework focused on understanding river functioning and evolution in interpreting current conditions, as an alternative to physical survey procedures promoted today in the evaluation and classification of the Romanian rivers.

It brings to attention the better perspective on processes, mechanisms and controls acting on a river obtained through a systematic investigation of channel historical behavior, in particular for periods

of time when human interventions were more isolated and of lower intensities that in the present, with relevant insights on aspects as channel evolutionary trajectories, previous boundary conditions, sensitivities and resilience, at different scales of space and time. All these elements will further permit to establish a relevant interval of time for reference conditions, together with its meanings in terms of river naturalness, needed to assess the present-day geomorphic state of the river.

In this context, the historical perspective on channel planform dynamics of Someșul Mic River highlights the main role played by centennial and decadal flood patterns (their magnitudes, frequencies) in the ca. 250 years temporal trends of channel behavior. On this background, the local geological conditions are responsible for a complex long profile succession of channel typologies, which further on sustain local tendencies to stability, meandering or avulsion.

In terms of recent human impact, the hydro-technical interventions along the river are concentrated along the first ca. 30 km of it, leading to channel straightening, narrowing and incision and more localized further downstream. By comparison, gravel extractions activities are more frequent along the lower half of it (the downstream part of it), and impose significant local changes in the spatial and cross section morphology of the channel, even long time after their abandonments. Agricultural practices in the floodplain perimeter are the third important disturbing elements, responsible for deterioration of the riparian vegetation belt, in terms of size and structure, and is frequently associated with local active bank erosion processes. The cumulative effects of these local scale human disturbances impose the present morphological state of the river, when compared with a reference condition defined as reflecting channel hydro-morphological characteristics between AD 1860 and AD 1970: dominant bad to poor conditions between Gilău and Apahida, and some moderate ones between Apahida and Dej.

The resulted image, characterized by an increased resolution when compared with the existing ones, has the potential to better identify the critical reaches along this river, and the main disturbing

elements acting on them in order to support and increase in the quality of projections on possible channel trajectories, and of the proposed river management actions.

Acknowledgments

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References

- Amăriucăi M. 2000. *Șesul Moldovei extracarpatică dintre Păltinoasa și Roman. Studiu geomorfologic și hidrologic*. Carson Press, Iași (in Romanian).
- Armencea G, Marinescu G, Stoicescu H, Lup I. 1980. Aspects of the channel incision prognosis downstream of dams. *Hidrotehnica*, **25**(2): 11–15 (in Romanian).
- Anițan I. 1974. *Maximum discharge in the Someș drainage basin*, unpublished PhD Thesis. "Babeș-Bolyai" University, Cluj-Napoca (in Romanian).
- Armaș I, Gogoșe-Nistoran DE, Osaci-Costache G, Brașoveanu L. 2012. Morphodynamic evolution patterns of Subcarpathian Prahova River (Romania). *Catena*, **100**: 83–99.
- Belletti B, Rinaldi M, Gurnell AM, Buijse AD, Mosselman E. 2015. A review of assessment methods for river hydromorphology. *Environ. Earth Sci.*, **73**: 2079–2100.
- Brierley GJ, Fryirs KA. 2005. *Geomorphology and River Management: Applications of the River Style Framework*. Blackwell, Oxford, UK, p. 398.
- Brierley GJ, Fryirs KA, Boulton A, Cullum C. 2008. Working with change: the importance of evolutionary perspectives in framing the trajectory of river adjustment. In: Brierley G, Fryirs KA. (eds.): *River Futures: an Integrative Scientific Approach to River Repair*. Society for Ecological Restoration, International Island Press, Washington, DC, USA, pp. 65–84.
- Brierley GJ, Fryirs K, Cullum C, Tadaki M, Huang HQ, Blue B. 2013. Reading the landscape: integrating the theory and practice of geomorphology to develop place-based understandings of river systems. *Prog. Phys. Geog.*, **37**: 601–621.
- Chiriță C. –(ed). 1981. *Pădurile României. Studiu monografic*. Edit. Academiei RSR, București. Romania.
- Ciomac IL, Popa-Necșa V. 1936. *Munții Apuseni. Cercetări asupra stărilor economice*. Tipografia ziarului „Universul”, București, Romania. 310p.
- Ciupagea D et al. 1970. *Geologia Depresiunii Transilvaniei*. Ed. Acad. RSR, București, Romania. 256 p.
- Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Off. J. L 327, 73, 22/12/2000, Brussels, Belgium.
- Dufour S, Piégay H. 2009. From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits. *River Res. Appl.*, **25**: 568–581.
- Dumitriu D, Rădoane M, Rădoane N. 2017. Sediment Sources and Deliver. In: Rădoane M, Vespremeanu-Stroe A. (eds.): *Landform Dynamics and Evolution in Romania*. Springer, 629–654.
- Dumitriu D. 2007. *Sistemul aluviunilor din bazinul râului Trotuș*. Universității Suceava Press, Suceava.
- Feurdean A, Tanțău I. 2017. The evolution of vegetation from the Last Glacial Maximum until the Present. In: Rădoane M, Vespremeanu-Stroe A. (eds.): *Landform Dynamics and Evolution in Romania*. Springer, 67–86.
- Feurdean A, Parr CL, Tanțău I, Fărcaș S, Marinova E, Perșoiu I. 2013a. Biodiversity variability across elevations in the Carpathians: parallel change with landscape openness and land use. *Holocene*, **23**(6): 869–881.
- Feurdean A, Liakka J, Vanniere B, Marinova E, Mossbrugger V, Hickler T. 2013b. Holocene fire regime drivers in the lowlands of Transylvania (Central–Eastern Europe): a data–model approach. *Quat Sci Rev*, **81**: 48–61.
- Feurdean A, Astaloș C. 2005. The impact of human activities in the Gutâiului Mountains, Romania. *Studia UBB Geologia*, **50**(1–2): 63–72.
- Ficheux R. 1996. *Les monts Apuseni (Bihor) – Vallées et aplanissements*. Ed. Academiei, Cluj-Napoca, Romania. 535 p.
- Giurgiu V. 2010. Considerații asupra stării pădurilor României. *Revista pădurilor*, anul 125, nr.2/2010, București.
- Griffiths P, Kuemmerle T, Baumann M, Radeloff WC, Abrudan IV, Lieskovsky J, Munteanu C, Ostapowicz K, Hostert P. 2014. Forest disturbances, forest recovery, and changes in forest types across the Carpathian ecoregion from 1985 to 2010 based on Landsat image composites. *Remote Sensing of Environment*, **151**: 72–88.
- Gurnell AM, Rinaldi M, Buijse AD, Brierley G, Piégay H. 2016a. Hydromorphological frameworks: emerging trajectories. *Aquat. Sci.*, **78**: 135–138.
- Gurnell AM, Belletti B, Bizzi S, Blamauer B, Braca G, Buijse AD, Bussetini M, Camenen B, Comiti F, Demarchi L, Garcia De Jalon D, Gonzalez Del Tanago M, Grabowski RC, Gunn IDM, Habersack H, Hendriks D, Henshaw A, Kleosch M, Lastoria B, Latapie A, Marcinkowski P, Martinez-Fernandez V, Mosselman E, Mountford JO, Nardi L, Okruszko T, O'Hare MT, Palma M, Percopo C, Rinaldi

- M, Surian N, van de Bund W, Weissteiner C, Ziliani L. 2016b. A multi-scale hierarchical framework for developing understanding of river behaviour. *Aquat. Sci.*, **78**: 1–16.
- Hoffmann T, Lang A, Dikau R. 2008. Holocene river activity: analysing 14C-dated fluvial and colluvial sediments from Germany, *Quaternary Science Reviews*, **27**: 2031–2040.
- Knighton D. 1998. *Fluvial Forms & Processes – a new perspective*. Oxford University Press Inc., 400 p.
- Krezsek C, Bally AW. 2006. The Transylvanian Basin (Romania) and its relation to the Carpathian fold and thrust belt: Insights in gravitational salt tectonics. *Marine and Petroleum Geology*, **23**: 405–442.
- Kondolf M, Piegay H. (eds.) 2016. *Tools in fluvial geomorphology*. John Wiley & Sons, Ltd. 560 p.
- Liébault F, Piégay H. 2001. Assessment of channel changes due to long-term bedload supply decrease, Roubion River, France. *Geomorphology*, **36**: 167–186.
- Liébault F, Piégay H. 2002. Causes of 20th century channel narrowing in mountain and piedmont rivers of south-eastern France. *Earth Surf Proc Land*, **27**: 425–444.
- Leopold LB, Wolman MG, Miller JP. 1964. *Fluvial Processes in Geomorphology*. San Francisco: WH Freeman. 522p.
- Munteanu C, Kuemmerle T, Boltziar M, Butsic V, Gimmi U, Haladad L, Kaimh D, Királyi G, Konkoly-Gyuró E, Kozakh J, Lieskovsky J, Moyses M, Müller D, Ostafin K, Ostapowicz K, Shandra O, Stych P, Walker S, Radeloff WC. 2014. Forest and agricultural land change in the Carpathian region – A meta-analysis of long-term patterns and drivers of change. *Land Use Policy*, **38**: 685–697.
- Pandi G. 1997. *Concepția energetică a formării și transportului aluviunilor în suspensie – Aplicație în NV României*. Presa Universitară Clujeană.
- Perșoiu I, Perșoiu A. 2018. Flood events in Transylvania during the Medieval Warm Period and the Little Ice Age. *The Holocene*, **29**(1): 85–96. <https://doi.org/10.1177/0959683618804632>.
- Perșoiu I, Feurdean A, Perșoiu A, Rădoane M, Robu D, Tanțău I. 2016. Late Quaternary floodplain evolution in the Transylvanian tablelands, Romania. *Carpatho-Balkan-Dinaric Geomorphological Commission*, Conference Proceedings.
- Perșoiu I, Rădoane M. 2011. Spatial and temporal controls on historical channel responses – study of an atypical case: Someșul Mic River, Romania. *Earth Surf Land Proc*, **36**(10): 1391–1409.
- Perșoiu I. 2010. *Reconstruction of Holocene geomorphological evolution of Someșul Mic Valley*. Unpublished PhD thesis “A. I. Cuza” University, Iași, Romania (in Romanian).
- Pop GP. 1996. *România – geografie hidroenergetică*. Ed. Presa Universitară Clujeană, Cluj-Napoca.
- Posea G. 1962. Aspecte de relief din jurul Clujului. *Analele Universității din București, Seria Geografie*, **32**: 119–139.
- Posea G, Popescu N, Ielenicz M. 1974. *Relieful României*. Ed. Științifică, București. 483 p.
- Rădoane M, Perșoiu I, Chiriloaei F, Cristea I, Robu D. 2017. Styles of Channel Adjustments in the Last 150 Years. In: Rădoane M, Vespremeanu-Stroe A. (eds.): *Landform Dynamics and Evolution in Romania*. Springer, 489–518.
- Rădoane M, Obreja F, Cristea I, Mihailă D. 2013a. Changes in the channel-bed level of the eastern Carpathian Rivers: climatic vs. human control over the last 50 years. *Geomorphology*, **193**: 91–111.
- Rădoane M, Perșoiu I, Cristea I, Chiriloaei F. 2013b. River channel plan channel planform change based on successive cartographic data. A methodological form change based on successive cartographic data. *Revista de Geomorfologie*, **15**: 69–88.
- Rădoane M, Pandi G, Rădoane N. 2010. Contemporary bed elevation changes from the Eastern Carpathians. *Carpathian J Earth Environ Sci*, **5**: 49–60.
- Rădoane M, Rădoane N. 2009. Monitoring of the Moldova River channel changes in the Preutești – Timișești gravel extractions area. In: Irimuş IA (ed.): *Geografia în contextul dezvoltării contemporane*. Presa Universitară Clujeană: Cluj-Napoca; 160–175 (in Romanian).
- Rădoane M, Rădoane N. 2005. Dams, sediment sources and reservoir silting in Romania. *Geomorphology*, **71**: 217–226.
- Rinaldi M, Belletti B, Bussettini M, Comiti F, Golfieri B, Lastoria B, Marchese E, Nardi L, Surian N. 2017. New tools for the hydromorphological assessment and monitoring of European streams. *Journal of Environmental Management*, **202**: 363–378.
- Rinaldi M, Bussettini M, Surian N, Comiti F, Gurnell AM. 2016. *Guidebook for the Evaluation of Stream Morphological Conditions by the Morphological Quality Index (MQI)*. Version 2. Istituto Superiore per la Protezione e la Ricerca Ambientale. <http://www.isprambiente.gov.it/it/pubblicazioni/manuali-e-lineeguida/guidebook-for-the-evaluation-of-stream>.
- Rinaldi M, Surian N, Comiti F, Bussettini M. 2013a. A method for the assessment and analysis of the hydromorphological condition of Italian streams: the Morphological Quality Index (MQI). *Geomorphology*, **180–181**: 96–108.
- Rinaldi M, Wyzga B, Dufour S, Bertoldi W, Gurnell A. 2013b. River Processes and Implications for Fluvial Ecogeomorphology: A European Perspective. In: Shroder J. (editor in chief), Butler DR, Hupp CR. (eds.):

- Treatise on Geomorphology*. Academic Press, San Diego, CA, vol. **12**, Ecogeomorphology, 37–52.
- Rinaldi M. 2003. Recent channel adjustments in alluvial rivers of Tuscany, Central Italy. *Earth Surf Proc Land*, **28**: 587–608.
- Robu D. 2018. *Evolution of the river network in the Lower Someș Plain*. Unpublished PhD thesis, "Ștefan cel Mare" University, Suceava, Romania (in Romanian).
- Savu A. 1964. *Someșan Plateau – geomorphological study*. Unpublished PhD thesis, "Babeș – Bolyai" University, Cluj–Napoca, Romania (in Romanian).
- Sümeğy P. 1999. Reconstruction of flora, vegetation and landscape evolution, and human impact on the Bereg Plain from late–glacial up to the present, based on palaeoecological analysis. *The Upper Tisza valley*, 171–203.
- Surian N, Rinaldi M. 2003. Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology*, **50**: 307–326.
- Șerban G. 2007. *Lacurile de acumulare din bazinul hidrografic superior al Someșului Mic – studiu hidrogeografic*. Presa Universitară Clujeană.
- Ioana–Toroimac G, Dobre R, Grecu F, Zaharia L. 2010. A 2D active–channel's evolution of the Upper Prahova River (Romania) during the last 150 years. *Geomorphol–Relief Processus Environ*, **3**: 275–286.
- Zugrăvescu D, Polonic G, Horomcea M, Dragomir V. 1998. Recent vertical crustal movements on the Romanian territory, major tectonic compartments and their relative dynamics. *Revue Romaine de Geophysique*, **42**: 3–14.
- Winterbottom SJ. 2000. Medium and short–term channel planform changes on the rivers Tay and Tummel, Scotland. *Geomorphology*, **34**: 195–208.
- *** *National Plan of Water Management 2016–2021 – Plan de Management actualizat al spațiului hidrografic Someș – Tisa, 2016–2021*, Ministerul Mediului, Apelor și Pădurilor & Administrația Națională "Apele Române" (<http://www.rowater.ro>)

Detection of the piping processes analyzed through the Self Potential method, in the peripheral area of the Dognecei Mountains

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ABSTRACT

The water movement in the soil contributes to entrainment of particles of varying sizes and, over time, some tendency for the orientation of this flow may occur. In the areas with particular soil characteristics, an internal discrete drainage network appears, that manifests differently depending on the causative factors. The aim of the recording and monitoring of this concentrated water flow movement that contributes to soil erosion as a discrete pipe network through a geophysical method is that of understanding his evolution. Using a method such as the Self Potential (SP) allows the study of the piping processes in a quantitative manner. In the peripheral area of the Dognecei Mountains, specifically near Doclin village, it was analyzed one such area in which this process occurs. It was analyzed the evolution of a site in periods with different climatic parameters which are the ones that function as the active elements. The amplitude of the SP values (mV) differs depending on the causative environmental factors, with negative values in the dry period and positive values when the soil is wet, the values having fluctuation up to 15 mV. The piping processes contribute to soil degradation and the knowledge of the areas affected by these processes and particularly of the factors that influence its occurrence, with good results, by using the Self Potential method can be achieved.

KEYWORDS

Self Potential; piping; soil erosion; water movement; Dognecei Mountains; Romania

1. Introduction

The soil erosion depends on many factors, and this can occur both at the soil surface and internally, in the form of piping processes caused by water movement in soil as a linear network (Anthony and

Jones, 2004), contributing to the creation of an underground pipe network.

Piping is a subterranean erosion – a kind of subcutaneous erosion – defined as a process initiated by percolating waters which remove solid particles from clastic (fragmental) rocks to produce tubular

underground conduits (Mears, 1968). Soil piping depends on numerous factors including soils and lithology, topography, climatic conditions, vegetation and land management. Due to the discrete manifestation of the subsurface nature of this process, piping morphological effects cannot be easily detected.

The piping processes appear mostly in the areas with steeper gradients through internal stress, but their presence is proved in the areas where the slope gradient is up to 12° (Bernatek, 2015). Our interest about this hidden, discreetly geomorphological phenomenon is connected to the fact that the detection and evaluation of piping potential are currently limited (Richard and Raddy, 2007).

An important component of soil erosion is related to the land use in mountainous areas where the vegetative associations are predominant (Anțilă, 2012; Rusu, 2013). In the areas with low gradient are mentioned agricultural practices of the XVIIIth century, practices that widened since 1962, when forced socialization of agriculture is imposed (Medeleț, 2005). In the contact area between the mountain area and the Doclin Hills, the soil surveys emphasized the pedogeographical characteristics, aspects structured in the studies of Ianoș and Pușcă (1998). The mining impact on water quality in the mountain area was presented by Marinică and Borza (2010).

All these anthropogenic changes in the landscape are essential and favor the soil erosion in various forms. This area was included in a study that had as a goal "The identification and delineation of natural hazards (earthquakes, landslides and floods)" in the territory of the county, and the study had as beneficiary the Ministry of Regional Development and Tourism. In this study it was determined that the Doclin area corresponds to a medium to large risk of landslides occurrence.

In the specialized literature the relations between the land erosion as a process and the factors that contribute to its accelerating or cessation are discussed, so that Nunes et al. (2011) address how different plant associations and ways of land use influence soil erosion and surface runoff. Similar studies were conducted by Alewell et al. (2008) and Warsta et al. (2013), these aimed at describing and predicting the soil erosion in mountainous areas.

Faulkner (2013), studied the scattering of the soils and the subsurface erosion and analyzed the stages of occurrence of the piping processes; the analysis of the factors that lead to soil erosion due to piping process and the emergence of the rills surface was made by Flores–Berones et al. (2011), Verachtert et al. (2011), Schuppener (2013) or Jacobson (2013) considering that the slope gradient, the drainage area, the curvature, the surface aspect, the soil type and the lithology, to which are added the mechanical and chemical action of the water, have a major role. Other factors associated with the piping processes are the soil erosion coefficient, internal stress, or the time (Bonelli and Benahmed, 2010).

By knowing the factors that might influence the internal soil erosion, we can establish to a certain measure that there might be the areas susceptible to these processes, but individual treating of the factors or implementation of a mathematical model gives only a simplified image of what actually happens in a certain area. It is therefore a need for a validation of the simulation carried out on various environments and this validation may be performed by a geophysical method, used by TehSaufia et al. (2012) in studying the effects of piping and the erosion. For this study, we chose to carry out investigations with the Self Potential method.

This is a non-intrusive method that contributes to achieve, through subsequent methods, of an image of what is happening in the basement at a time (Reville and Jardani, 2013). It has direct applications in the mapping of the fluid leaking into the soil (Wishart et al., 2009; Moore et al., 2011; Boleve et al., 2011; Singarinbum et al., 2012). On the other hand, the physic–chemical approach of the method was performed by Linde et al. (2007), Boleve (2009), Reville et al. (2009), or Peksen et al., (2011).

The work of Jardani's et al. (2009) must also be specified, studying the level of phreatic water by this method, and the study of Giano et al. (2000) as well, which is focused on the analysis of sedimentary deposits through Self Potential method, the same type of deposits being found in the transition zone between the Dognecei Mountains and the Doclin Hills. This technique can be used in determining of the areas with susceptibility to erosion, even if in the first instance there are no visible elements. The

representation of these processes can be made on a continuous structure like interpolating the values obtained from the field (Buhmann, 2000; Morse, 2005; Henglet al., 2008; Lu and Wong, 2008; Kleijnen, 2011) each interpolation method presenting some advantages and disadvantages.

The objective of this study is the analysis of the piping processes through a non-invasive geophysical method, at different time intervals and the correlation of these processes with the environmental factors.

2. The study area

The area in which investigations were conducted is located in northwestern of Caraș – Severin County, in the transition area between the Dognecei Mountains and the Doclin Hills at an altitude of 290 m

(Fig. 1.), within the administrative boundary of the Doclin village, in the area of interfluvial „Dealul Între Văi”, at a distance about 2 km from the village. The investigations were carried out as a grid made in an area that has as lithology micaschists and paragneiss with biotite having the intercalations of micaceous quartzites or feldspathic quartzites from Proterozoic (Năstăseanu and Savu, 1968), lithological formations covered with pedological material.

The slope derived from a digital elevation model obtained from the interpolation of the contour lines on a topographic map with the scale 1:25.000 (Torok, 2001) is low, the area of interest being included in the class values below 10°, as attested and validated in the field, using a SUUNTO tandem compass. The declivity values were between 3 and 7° in this case.

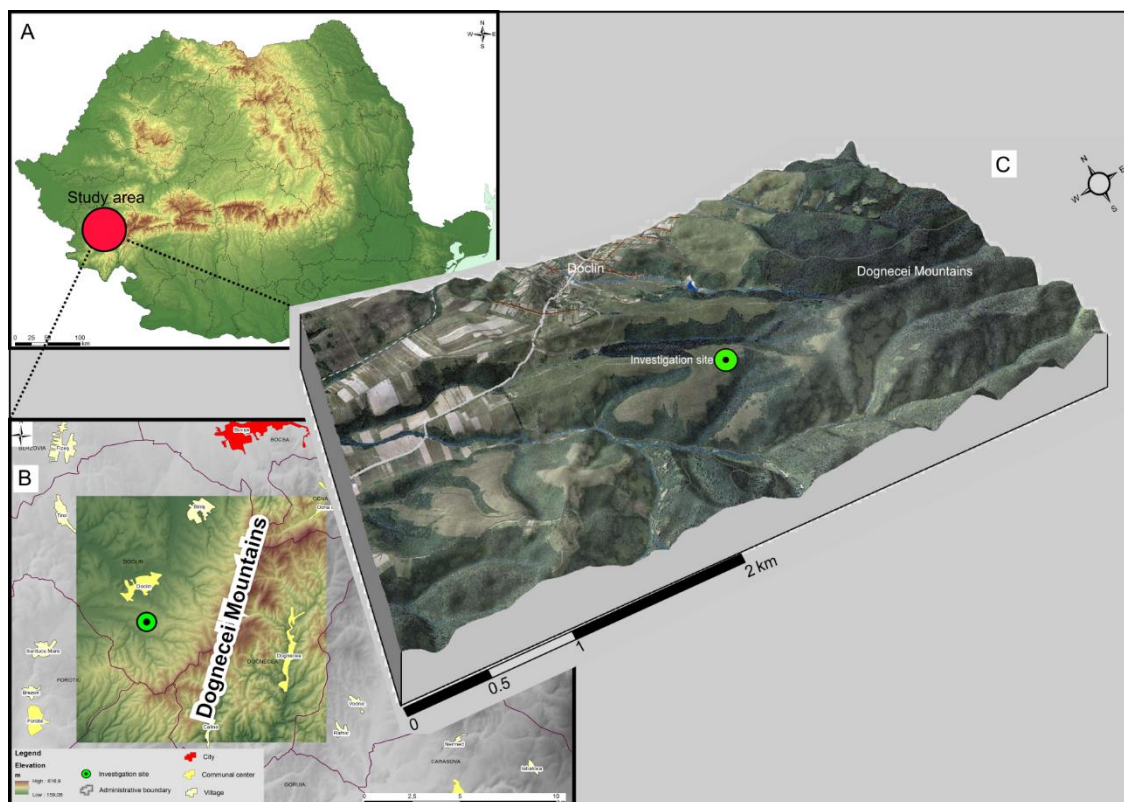


Figure 1 Location of the study area

The aspect of the area where investigations were made is SW and in some places west. This aspect influence the values obtained by the Self Potential method as a result of varying levels of reception of solar radiation.

The relief fragmentation depth is relatively low, of 57 m, this value contributing to a reduced amount of water draining from the soil surface. In the north of "Dealul Între Văi" site, the gullies appear in the form of a bulb with variable lengths that can reach up to 150 meters, and in the mountain

area, because of forestry practices, gullies and rills occurred, located predominantly near the forest roads.

The diversified climatic episodes contribute to shaping of the land surface by the intensity and the alternation of the rainfall (Rădoane et al., 2001), and by the average temperature and the amount of solar radiation at ground level that influence the process of evapotranspiration (Warsta et al., 2013). These factors contribute both directly and indirectly to the transport of the water and thus of the sediments at pore level, involving the erosion of sub-surface (Warsta et al., 2013).

In this area there is no nearby weather station which can provide dates, and for knowing what kind of values appear here, we used the models of the annual average temperature and precipitation that were made based on specific values, yielding a linear regression equation, which is correlated with a DEM. The annual average temperatures, derived from this modeling, for the entire area, are included in the range from 11.2°C in areas with lower elevations and 8.6°C in the peak areas. The rainfall has values of about 750 mm in the lowlands and where the relief fragmentation is high, and about 900 mm in the central–northeastern area.

The model of the received radiation was derived based on the DEM with a spatial resolution of 10 m and is a tool for checking the amplitude of evapotranspiration phenomenon existing in different periods. It can be seen, therefore, that early autumn (15.09.2013, more precisely) (Fig. 2A), the amount of solar radiation was about 3274.9 Wh/m²/day in the concerned area, compared to the solar radiation recorded in November, on 03.11.2013 (Fig. 2B), when the maximum is 1028 Wh/m²/day. Basically, the solar radiation received by the ground during the late autumn days drops to 31% compared to the initial period. These differences contribute to the existence of different regimes of water movement in the soil, which influences the varied development of the erosion. The situation in the spring season shows a significant increase in the radiation received by the ground, with a maximum of 2268.8 Wh/m²/day, increasing by over 45 percent compared with 03.11 when measurements were made before the winter season. The main course of water

from this area is Ciornovăț creek, which is supplied by several springs, but predominantly from precipitation. In this area, a number of temporary water courses are active during periods of heavy rainfall, these contributing to increase of the soil erosion on slopes. The drainage of the volume of water resulting from the liquid and solid precipitation influence both surface erosion by moving unconsolidated fragments as well as the internal erosion through sustained action on the pores level. The woody species – especially *Quercus* sp. – are located around the area of investigation and sometimes meet shrub species such as hawthorn (*Crataegus monogyna*), rosehip (*Rosa canina*) or blackberry bush (*Rubus fruticosus*) (Anțilă, 2012), all occurring in the transition zone from the forest environment to that of the hills. The entire area comprises small grass associations (*Poa nemoralis*, *Festuca ovina*, *Dactylis glomerata*, *Bromus secalinus*) that contribute in a modest way to stabilize the soil because of the intense pastoral activity.

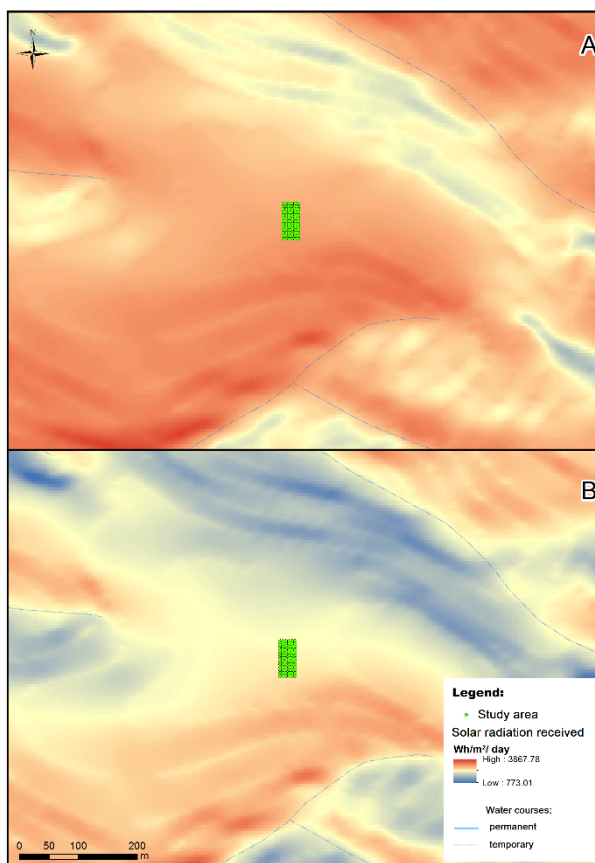


Figure 2 Simulated solar radiation in the interest area: (A) 15.09.2013, (B) 03.11.2013

The characteristics of the pedological material are important in the evolution of various forms of erosion, and therefore for the results obtained through Self Potential method as well due to the differentiated leakage of water through heterogeneous environments. A high proportion in the soil categories have it the districambosols arranged in the eastern zone, which it corresponds to the mountain area, and being at the same time the area with the largest forest area expansion. For a more detailed analysis of the diagnostic properties of the soils in areas where investigations were conducted, we chose maps with the 50,000 scale of Ianoş and Puşcă, 1998. On large areas Luvisols can be found (pseudogley, local pseudogley, typical, eroded). In the eastern part of the Doclin village, the interfluvies are composed from multiple types of alluvial-clay, presenting surface erosion caused by the water eroding in the "Dealul Între Văi" area and of the pastures located between the village and the forest area. In all these categories of soils, the piping is an active process (Bernatek-Jakiela, Poesen, 2018). The rock takes the form of middle fine-textured clays and the groundwater depth is over 10 meters.

The instrumental investigated area (Fig. 3) has a size of 25 m on the north and south sides – the grid has a NS orientation –, and 60 m on the east and west sides. The interval between sample points was 5 m, with a fixed electrode placement to 3 m outdoors. The investigations were conducted on 09.15.2013, 03.11.2013 and 08.03.2014. If in the first period the horizon of soil was quite dry, in the last stage of investigation the soil was supersaturated and in the flat areas, the water is stagnating.

The analysis of the piping process involves the establishment of an investigation area in a place whose local gradient is lower. The woody vegetation must be reduced or non-existent because it serves to stabilize the soil and the amount of moisture in the soil must be high in some periods of the year. At those, the soil characteristics and his thickness are adding, because in some conditions, the response of the local lithology can be highlighted in the form of the cracks or the morphology, aspect that requires the knowledge of the local landscape for differentiation of the results. Based on these characteristics, we chose the location of the investiga-

tion site within the upper area of the "Dealul Între Văi", where the land use is as meadows for grazing and the slope gradient is less than 10°. In the interval when the investigations were carried out, the amount of water in soil varied considerably, fact that emphasized the stress on soil.



Figure 3 The investigation site „Dealul Între Văi”, Doclin

3. Methodological aspects

3.1 The Self Potential method

The Self Potential Method is a non-invasive geophysical method of inquiry that allows obtaining natural values of the electric potential from the soil as a result of the chemical, physical and biological interaction of generating factors. Knowing the internal mechanisms that generate this electrical natural current can lead to a better interpretation of the results obtained, so that these processes will be presented in the following paragraphs.

The Self Potential is defined as "*the passive measure in surface or in the drilling of the distribution of the electric natural potential created by the mechanisms of polarization of the electric loads in porous media (electro-infiltration related to water leakage, oxidation related to the redox phenomena)*" (Jardani, 2007, p. 46).

The current recorded through the Self Potential method is regarded as having a source in the electrical double layer present as the contact area between a solid and a liquid state. This electric double layer implies that there is an area near the solids, called "compact Stern layer", from which they take loads of the mineral surface, and a concentration of

mobile charges located in close proximity to mineral element (Fig. 4), called "Gouy–Chapman diffuse layer" (Boleve, 2009). The movement of the fluid in the pores of the soil contributes to movement of existing mobile ions, and when there is contact between the free colloids and the mobile part of the mineral layer, the latter is detached, helping to create convection current and another opposite called the conduction current. The potential associated with the conduction current is the one that can be measured at ground level (Moore et al., 2011).

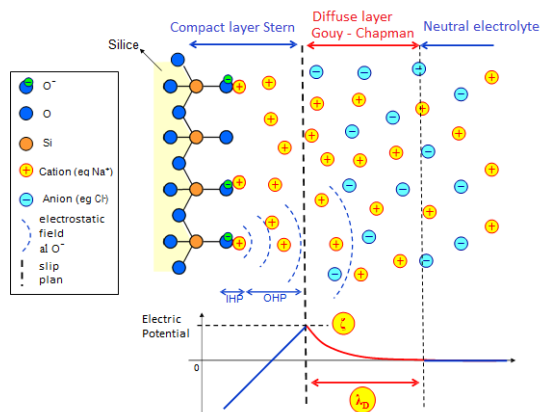


Figure 4 The ionic distribution diagram of the electric double layer in the case of a silicon surface (after Darnet, 2003)

It has been observed that the excess of charges existing in the diffuse layer moves toward the end of the sample, in the case of fluid displacement in the poral environment. The movement of electric charge is called the electric current source (convection current) and generates an electric field that can be recorded by the devices (Boleve, 2009). It occurs complementary a conduction current generated by charges induced by electro-infiltration, opposite in the sense of the convection current. The intensity of conduction current depends mainly on the electrical conductivity of the environment under which the process is carried out (Boleve, 2009), the poral environments contributing to the generation of an electric conduction current more important. The electric potential difference between the terminals of electrodes is called the electro-infiltration potential.

Equally important is how the electric potential distribution is segmented, appearing two aspects like: one refers to a primary source associated with

the difference in charges of the natural current density, this source is responsible for the appearance of the electric field measurable in the area around a location and, the second, refers to the secondary sources, which appear in addition to electric fields associated with the primary source, where heterogeneity of the electrical resistivity is responsible for the disruption of the distribution of electric potential; this disturbance can be represented as an accumulation of electric charges in the heterogeneous areas (Jardani, 2007). Due to delineation in the soil of the processes through which the electro-infiltration current is generated, the characteristics of the pedological material are influenced by many factors (geology, plant associations (even if the radicular system is limited to the first centimeters of the upper horizon of the soil, these plants compensated by density, so it is recommended to conduct investigations in periods when their development is minimal), climatic influences, moisture found in soil; geomorphometry and the Self Potential values obtained can be influenced by all these factors. In addition to the electro-infiltration current itself there are also associated a range of parameters that influence positive or negative values recorded.

Although it has a multitude of applications, this method does not present a great interest for some researchers because of the electrical noise and difficulties of interpretation. Such noise sources come in the form of telluric currents, the movement of the electrodes, of the topographic effect associated to the potential difference, of the photovoltaic potential or of the changes incurred in the composition and the moisture of the soil and of its plant cover (Nyquist and Corry, 2002). The noise sources can have both natural character (Sheffer, 2007; Jardani, 2007; Guichet, 2007) and anthropogenic (Nyquist and Corry, 2002). The latter can occur in the form of terrestrial power grids or underground, of the buried metal objects or even of the devices used by an analyst (some influences may occur due to the cables between the electrode and the voltmeter, for example). If the anthropogenic noise generating sources can be identified and possibly avoided, the same cannot be said about the natural sources. Jardani (2007) identified as being responsible for producing of the noise the following two sources,

namely the magneto-telluric induction and the bio-electric potential. This effect is well highlighted in the forest areas and those with pastures and meadows, due to the plant roots which drain water from the soil thus helping to create an additional electric potential, but this effect can be diminished and/or eliminated by using bentonite for the homogenization of the moisture in the sample points. According to the company that produces the SDEC electrodes (electrodes used in this study) the temperature – electro-infiltration current ratio is $0.21 \text{ mV}/^{\circ}\text{C}$, so that during the day, the thermal amplitude should also be considered and off-setting from the final values. A difference of 10°C is considered to be responsible for the amplitude of Self Potential values of about 2mV, an aspect which should be corrected (Jardani et al., 2009).

In addition to the noise sources listed, changes in Self Potential values are influenced by the effect of pH, the more alkaline it is, the recorded values are higher on the negative scale (Ishido and Mizutani, 1981, quoted by Guichet, 2007). The rock mineralogy also imposes certain issues, depending on their composition the electro-infiltration differentiated values are obtained. Equally important are the influence of the permeability, partial saturation of the electrolyte or the soil electrical conductivity (Darnet, 2003). Knowledge of these parameters allows an objective distinction between current source itself and those that are redundant and contribute to a misinterpretation of results (Urdea and Țambriș, 2014).

3.2 The data acquisition

The Self Potential investigations were carried out using the non-polarized electrodes connected to a voltmeter (Fig. 5). A non-polarized electrode is composed of a metal in contact with a saline solution (Reville, Jardani, 2013), in this case the Petiau electrodes Pb/Cl₂ in tandem are used: one used as a fixed electrode (placed outside the site investigation), and a second movable electrode displaced at different sample points. At the point where the fixed electrode was placed, bentonite mixed with water was inserted for better conductivity and for avoid reducing of the salinity from the poral water due to the evapotranspiration occurred at the soil level as a

result of the changes made by the analyst (Reville, Jardani, 2013).

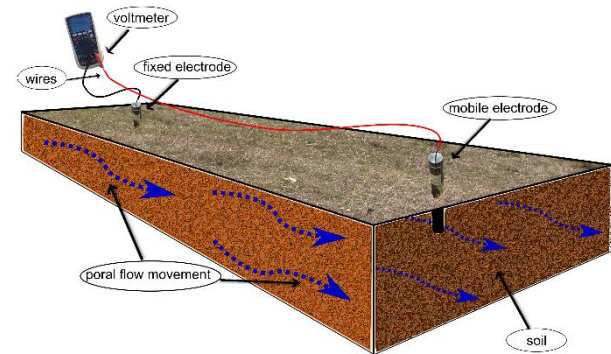


Figure 5 The model of data acquisition of Self Potential values

The voltmeter used was a Voltcraft VC850 which allows the recording of the voltage of the electric current in the range of $0.1 \text{ mV} - 1000 \text{ V}$, thus providing high accuracy values. The instrument can also be used for the acquisition of the temperature values and the intensity and frequency of the current out of the soil. With these tools available, we chose to obtain values from a rectangular network, practice that allowed the resumption of investigations in the same point after a period of time.

3.3 The interpolation of values obtained by Self Potential method

The next step of data acquisition was to use them in a way that allows continuous analysis of the values obtained in the grids made and their modeling as objective to obtain patterns of erosion and water infiltration into the soil (Urdea and Țambriș, 2014). This operation was carried out by integrating those values in the interpolation methods implemented in the software ArcMap 10.1. Within ArcMap 10.1 software, there were implemented several interpolation methods, both deterministic, such as Inverse Distance Weighting, Global Polynomial Interpolation, Radial Basis Functions and Local Polynomial Interpolation, as well as stochastic called geostatistical methods (A quick tour of Geostatistical Analyst, ArcMap 10.1). However, in both categories of interpolation methods, there are interpolations that return results that take into account the values entered previously with an intersection between the

result and the sample values, these being of accurate type. On the other hand, there are also interpolations that simulate the result starting from the initial values and applying a smoothing over them, the latter being known as inaccurate methods (Urdea and Țambrîș, 2014).

For this study, we chose the use of accurate interpolations, given that it operates directly with the values resulting from investigations in small areas. The study was based on the use of the Radial Basis Functions (RBF) Interpolation (Fig. 6.), but other interpolation models can be used. In this method, the resulting surface must pass through every sample point, the spaces between the points being constructed on the basis of some variables selected by analyst: Thin-plate Spline, Spline with tension, Completely regularized Spline, Multiquadric function and Inverse multiquadric function, the last function resulting in a much lower prediction error

compared to the others. This method was used in this study also because of the favorable response to all data sets, compared with other models that returned the artifacts to some integrated data sets. Another interpolation methods which presents potential for use are Inverse Distance Weighted (IDW) (Childs, 2004), (Fig. 6.) or Kriging. Under these conditions, it was necessary to use a method in which the analyst intervened as little as possible to not significantly influence the results. Also, the method used had to take into account the values entered, since there may be cases when isolated values can explain certain particularities of the environment, values that return the least square mean error.

Thus we choose to use in this study Radial Basis Functions interpolation method, which offers standardization for all data sets included in the returned raster data.

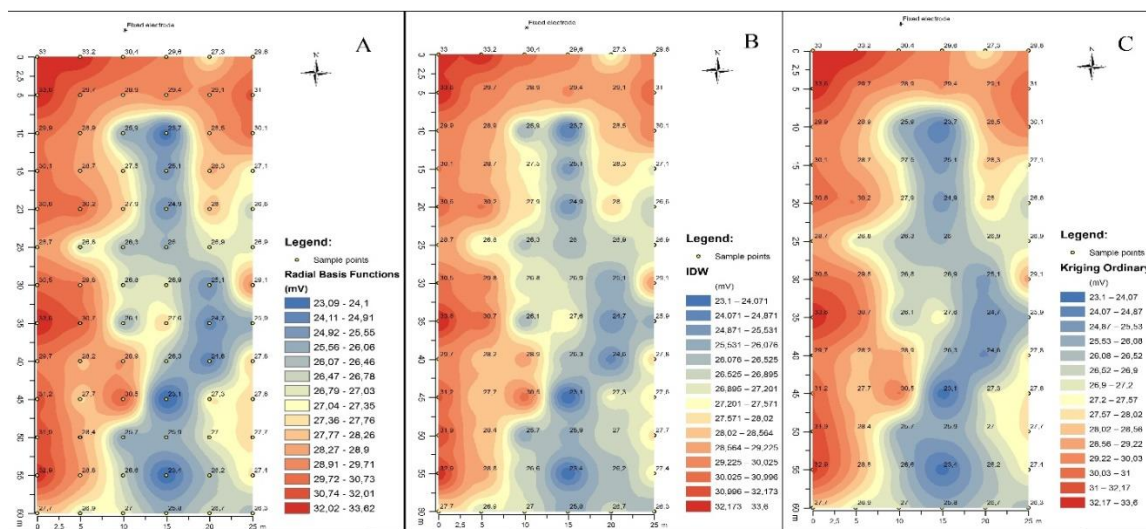


Figure 6 The SP values interpolation for investigation site „Dealul Între Văi” – stage III. A. the IDW method; B. the RBF method; C. the Kriging Ordinary method

3.3.1 Defining the parameters used in the interpolation method

In the Radial Basis Functions method there are some parameters which must be defined to obtain a reduced mean square error (RMSE), (Table 1). We defined some parameters for all the data sets with some exceptions when we let the custom settings. These parameters were determined after testing of multiple combinations. In Geostatistical Analyst module, in the first phase, the selection of the data

set and of the values that were to be used was made and after, the parameters were defined in the "Method Properties" section (Fig. 7). In the section "General properties", we choose the function that is to be used and, based on this a different RMS was returned, based on the algorithm implemented in the tool.

Based on the data set obtained in the investigation site „Dealul Între Văi”, in the first stage of measurements, without changing the other parameters, it resulted the following mean square error

(Table 1) and from these models, it can be seen that the Inverse Multiquadric method returned the lowest mean square error. When a function is chosen, below the row of choice of the function it appears a parameter which acts as weight and is directly influenced by the selected function and of the characteristics of the data set. After these steps, it is established the way of finding the neighbors based on which will be realized and the return of the intermediate values.

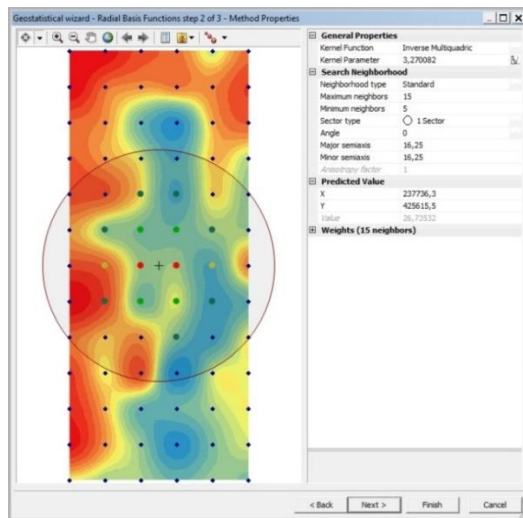


Figure 7 Defining the parameters of the interpolation model in the Geostatistical Analyst module

Table 1 The comparison of the RMS for the interpolation models used

Function	RMS
CompletelyRegularizes Spline	1.55
Spline withTension	1.56
Multiquadric	1.57
Inverse Multiquadric	1.54
Thin Plate Spline	1.69

Each different setting of the interpolations parameters affects the final result, but it should be kept in mind that these settings should be implemented in each of the data sets, and they must be chosen in such a way that they do not differ.

4. Results

The investigation was carried out in the form of three periods of analysis on the area of interest, so that the geomorphological features under study, namely the piping phenomenon, to be observed.

Thus, in the first stage of investigation, performed on 15.09.2013 (Fig. 8), grid made after a period with low rainfall, the soil was quite dry on the first centimeters of the profile due to the significant evapotranspiration in the higher temperatures conditions. However, the existing soil moisture was sufficient to report negative values mostly, associated with a sufficient fluid mobility. The areas with the largest displacement of water in the soil can be seen in the eastern part of the grid, an area characterized by an increase in the slope gradient of up to 7°. It should be mentioned that in the southern part of the study area, at a distance that varies between 25 and 40 m, depending on the corners of the grid, the forest area begins, aspect that can contribute to the modification of the obtained values.

Isolated, distinct portions appear in which a localized movement of water in soil results, as is the case of portions between the points of 10 to 15 m on the vertical axis and 10 m on the horizontal axis. Even under these conditions, a drainage trace can be observed on the eastern side, over 45 m long. There, the values recorded at that time were between -8.9 mV and -18.2 mV (Fig. 8).

The sections with higher values (above 4 mV), are located mainly in the N, NW and SW area, corresponding to the lower slope areas. This time, the amplitude of returning values is higher (23.97 mV) compared to other periods in which investigations were conducted. The lack of a regular flow of water in the soil is highlighted from the model obtained by interpolation of the Self Potential values as well, and there is not, at this time, outlined a well-defined linear sub-cutaneous flow of drainage.

In the second stage of the investigation, on 03.11.2013 (Fig. 8.), the soil moisture was higher, and although the values obtained were all positive – between 8.4 mV and 19.2 mV –, associated with a lack of mobility of water, this can be attributed to the saturation of soil with pore water. Even if the values returned are higher (positive) than in the first stage of investigation, it is not about a significant changing of the values in the positive interval, usually associated with the stability of the fluid. Also, in this case, higher values are located in the NE, NW and E of the grid, being the portions that appear to be most stable in terms of fluid dynamics.

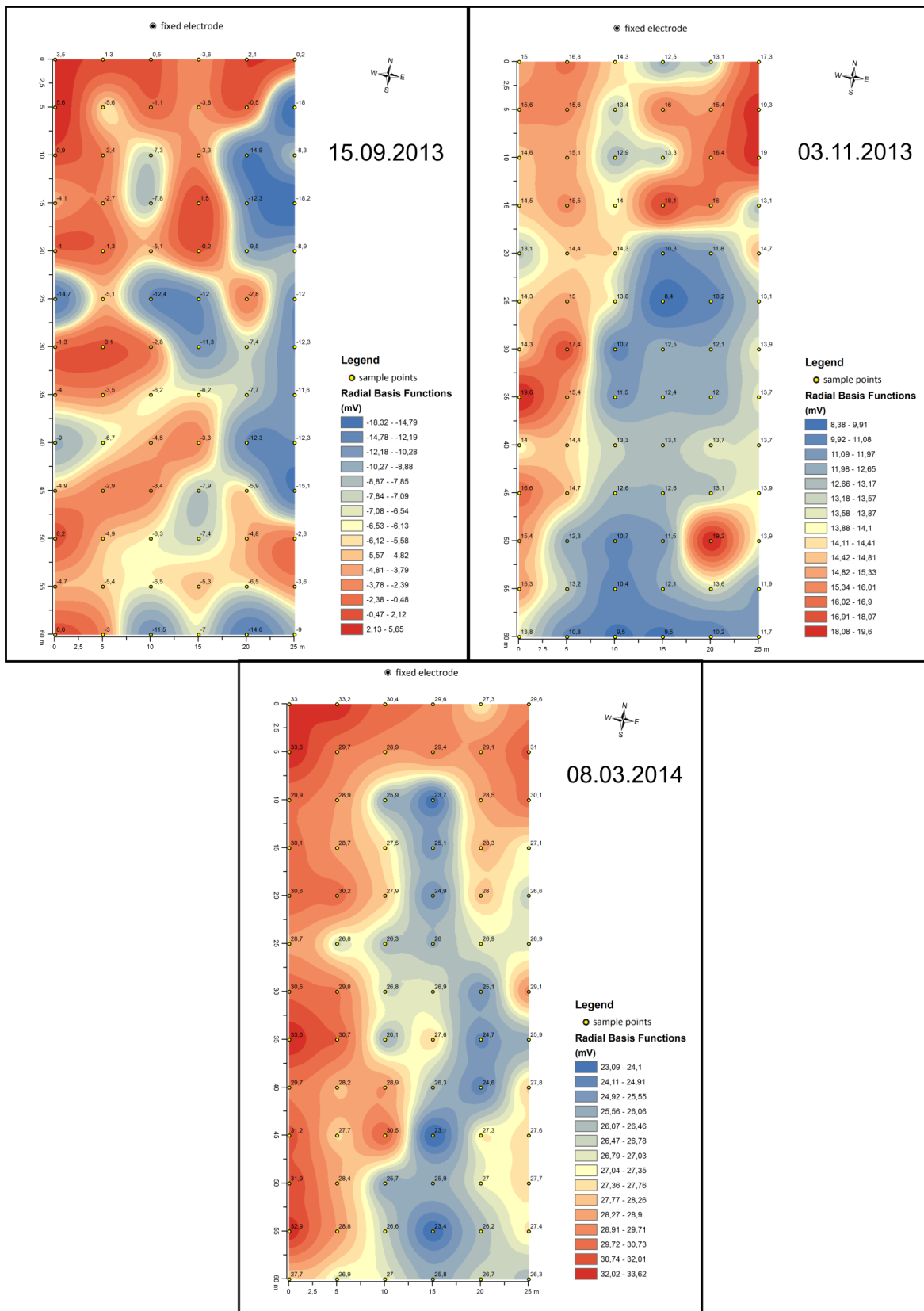


Figure 8 The SP model on the site „Dealul Între Văi”

Although the values recorded were higher than in the previous stage, their spatial distribution outlines better the existence of an underground drainage discrete channels network. It is oriented N–E, between the sample points from 5 and 20 m on the horizontal axis and the 20 and 60 m on the vertical axis. Given the fact that the soil layer is relatively consistent, with no rock fragments on the surface, the entire area having the flat features, this drainage channel could, mapped through the Self Potential method, to be tied to lithologic substrate as well, thus contributing to the manifestation of subsurface erosion.

The third stage of the investigation was conducted in early spring, on 08.03.2014. This time, although the solid winter precipitation were reduced quantitatively in the context of southern orientation of the area of analysis, with an amount of solar radiation by up to 2500 Wh/m²/day, due to the characteristics of the flat topography, the soil moisture was raised. The poor drainage of surface water due to low gradient led to its super-saturation in some sampling locations and the water stagnation occurred. For these reasons, the peripheral areas of the grid, except for the south of it, present high levels of Self Potential values, up to 33.6 mV (Fig. 8.), much higher than in the previous stage of measurements, when the maximum was 19.6 mV. The presence of the positive values confirms the sustained reduction in fluid flow mobility, and the lack of the shrub and tree vegetation favors the registration of values consistent with what was happening at that time in the soil layer.

The cause of this difference between the positive values perceived by the voltmeter and the shape of drainage channel from the interpolation of these values is represented by the slope that is low, but in the conditions of soil saturation in the sides of the grid, the pore water is concentrated in the middle of it, having a slope a few degrees higher than the rest of the site of interest.

In terms of topographical uniformity, the identification of a linear drainage network would indicate, in our opinion, a differentiation in horizons of the deeper soil texture or a discontinuity in crystalline

schists microfabrics, which is the parental material, or even a major schistosity plan or a hidden discrete fault.

In all three stages of investigation, at the level of column 4 (points located on the vertical axis at 15 m from the west side of the grid), higher values were obtained in the upper zone (Fig. 9) and lower values in the lower part of the grid, the tendency of displacement of the water within the drainage channel being affirmed.

Analyzing the Self Potential data, we can observe well-defined fluid flow on the N–S direction, confirming its existence during the three stages of investigation, meaning that this area is prone to piping process.

5. Discussions

The Self Potential method, through the simplicity it offers to create the prerequisites to achieving a model of water movement in soil under the action of various endogenous and exogenous factors, it has the role to highlight the fluid mobility in the first phase. Even if the Self Potential value returns were influenced by a variety of factors, each of them has different weights in the resulting values, so it is difficult to quantify their importance in the absence of objective studies on them. The main problem is related to the lack of climatic data, to which are added the characteristics of soils and geology, which are the most important for this analysis. For example, it requires knowledge of soil moisture, this being one of the factors that directly affects the fluid mobility, or the physics of movement processes of the sedimentary materials in the regolith basement. The processes and factors from soil surface are easier to interpret, having an important role in erosion processes. However, a degree of uncertainty occurs related to assessing the extent to which some changes in the obtained values are generated. The degree of detail requires consideration of additional factors, so at a small scale of detail some indicators will be lost from analysis while, at a greater detail scale, the correlation with overall factors is more difficult.

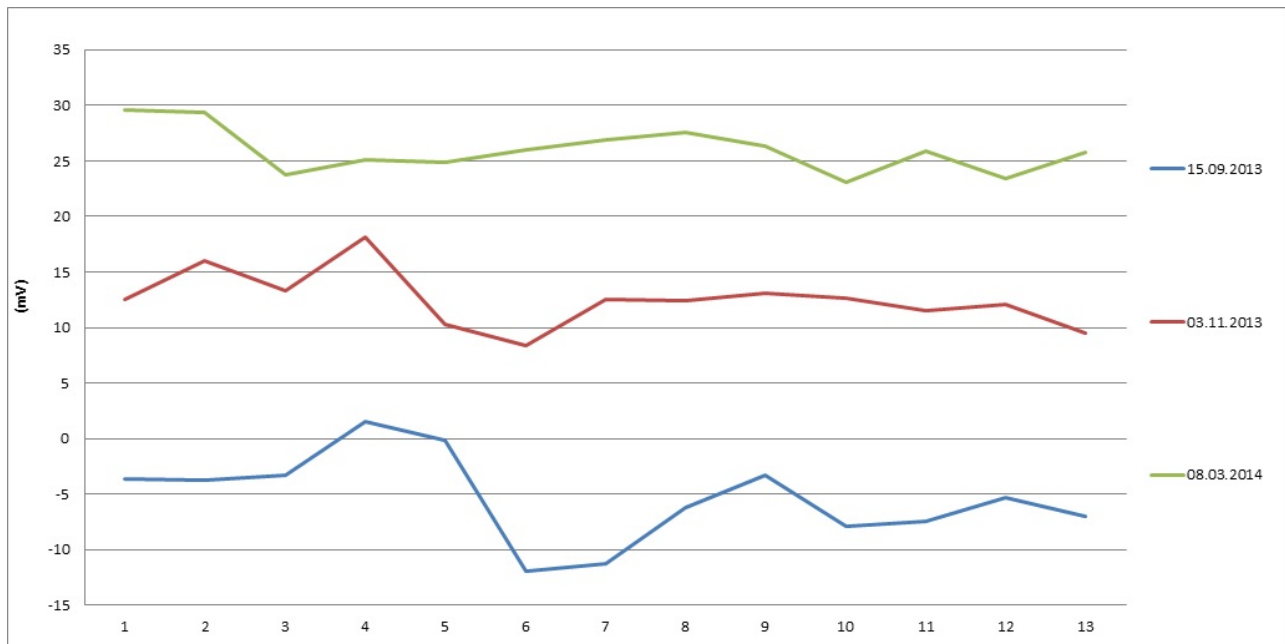


Figure 9 The SP profile – column 4, site „Dealul Între Văi”, periods: a.15.09.2014; b. 03.11.2013; c. 08.03.2014

For observing the behavior of the analyzed process, the multi temporal analysis of the study area was used. The resulting Self Potential model in a certain period can be influenced by local factors which can occur only in that interval of time, as it happened on this study area. The increasing of the amount of soil water contributed to the formation of internal drainage channel, and decrease of the pores water minimizes the footprint of the linear voids formed by the piping process. In addition to changes related to the influence of natural and anthropogenic factors on the ground, changes due to the modeling of the analyst were imposed, most often related to the representation of the model results.

The sampled values can remain the same, but the types of classification condition the type of interpretation performed by the analyst, especially that, by making models at different time intervals, it may contribute to the preservation of the Self Potential values in certain conditions, but with a different distribution of these values. The thinking of a uniform methodology for achieving all the models through interpolation methods will have two different effects: on the one hand, the same settings will be applied to all models, which will reduce the bias in their creation, but on the other hand, it will contribute at increase the mean square error for some

models built and at these it will need to apply specific modifications. The multitude of factors causing influences of any kind imposed a detailed knowledge of themselves, although the technique used in some circumstances contributed to the generation of artifacts, particularly from the cables by which electrical current was transmitted between electrodes and voltmeter. However, these problems have been correctable, and some influences, like those caused by thermal amplitude in a day or those induced by vegetation can be deduced and corrected.

The accurate establishing of the soil moisture, the quantification of the vegetation impact on the results, the reduction of the influence caused by bioelectricity, and climatic gradient within a day by mathematical methods, the knowledge of the soil layer depth, this can be achieved through GPR and/or ERT techniques, or analyses under laboratory conditions of some models to be applied in the natural environment could be some of the next trends for the results optimization and the modeling of Self Potential values.

Equally important it would be an extension of the recording technology of the values in question by using several electrodes that provide real-time information about what is happening in the soil. On the side of the computer analysis, it is required the

thinking of the integration and modeling some parameters to return a high degree of accuracy and to suit various conditions as to exclude certain anomalies.

6. Conclusions

The applying of Self Potential method to the knowledge of the piping phenomenon is, according to our information, a premiere for the geomorphological literature. Considering the specificity of the method but also the characteristics of the test area, we consider the results to be promising. The analysis of the results was correlated with the analysis of the methods of interpolation and graphical representation, so that, in our opinion, the method that best expresses the territorial differences of the subcutaneous drainage and the manifestation of the piping phenomenon is the Radial Basis Function method. The fact that the results were obtained through investigations carried out in three distinct periods, each of them having an "own imprint", constitutes as a validation of the application of the method to this phenomenon. We consider that the application, in parallel, with other complementary geophysical methods, such as electric tomography (ERT), along with the knowledge of soil characteristics and the geological substrate, as well as meteorological and topoclimatic parameters would lead to a better understanding of this phenomenon.

References

- Alewell C, Meusburger K, Brodbeck M, Bänninger D. 2008. Methods to describe and predict soil erosion in mountain regions. *Landscape and Urban Planning*, **88**: 46–53.
- Anthony J, Jones A. 2004. Pipe and piping. *Encyclopedia of Geomorphology*, Vol. 2. Routledge Ltd., New York, 784–788.
- Anțilă O. 2012. Cercetări privind condițiile de producere și conducere a regenerării arboretelor din șleaurile de deal cu gorun și cer din Masivul Dognecea. *Centrul de cercetare: Managementul durabil al Resurselor Forestiere și Cinegetice*, Brașov, 22 p.
- Bernatek–Jakiela A, Poesen J. 2018. Subsurface erosion by soil piping: significance and research needs. *Earth–Science Reviews*, **185**: 1107–1128.
- Boleve A. 2009. *Localisation et quantification des zones de fuites dans les digues et les barrages par la méthode du potentiel spontané*. PhThesis, Université de Savoie, Savoie, 223 p.
- Boleve A, Janod F, Revil A, Lafon A, Fry J. 2011. Localization and quantification of leakages in dams using time–lapse self–potential measurements associated with salt tracer injection. *Journal of Hydrology*, **403**: 242–252.
- Bonelli S, Benahmed N. 2010. Piping flow erosion in water retaining structures: inferring erosion rates from whole erosion tests and quantifying the failure time. *IECS 2010, 8th ICOLD European Club Symposium Dam Safety – Sustainability in a Changing Environment*, Innsbruck: Austria, 6 p. fhal-00555648f.
- Buhmann MD. 2000. *Radial Basis Functions*. Cambridge University Press, 38 p.
- Colangelo G, Lapenna V, Peronne A, Piscitelli S, Telesca L. 2006. 2D Self–Potential tomographies for study in groundwater flows in the Varco d'Izzo landslide (Basilicata, southern Italy). *Engineering Geology*, **88**: 274–286.
- Darnet M. 2003. *Caractérisation et suivi de circulation des fluides par la mesure de Potentielles Spontanées (PS)*. PhD Thesis, l'Université Louis Pasteur, Strasbourg I, 205 p.
- Flores–Berrones R, Lopez–Acosta N. 2011. Internal erosion due to water flow through earth dams and Earth Structures. *InTech, Rijeka*, 283–307.
- Giano S, Lapenna V, Piscitelli S, Schiattarella M. 2000. Electrical imaging and self–potential surveys to study the geological setting of the Quaternary slope deposits in the Agri high valley (Southern Italy). *Annali di Geofisica*, **43(2)**: 409–419.
- Golse F. 2011. From the Boltzmann equation to hydrodynamic equation in thin layers. *Bolettino delle Unione Matematica Italiana*, 163–186.
- Guichet X. 2002. *Etudes expérimentales des propriétés électriques des roches potentielles d'électro–infiltration, suivi des mouvements de fluides en zones hydrothermales*. PhD Thesis, Université Paris 7, Paris, 199 p.
- Ianoș G, Pușcă I. 1998. *Solurile Banatului*. Edit. Mirton, Timișoara, 106 p.
- Jacobson T. 2013. An analysis on soil properties on predicting critical hydraulic gradients for piping progression in sandy soils. *Utah State University, All Graduate Plan B and other Reports. Paper 336*, 38 p.
- Jardani A. 2007. *Nouvelles approches géophysiques pour l'identification des dolines et des cavités souterraines dans un contexte karstique*. PhD Thesis, Université de Rouen, Rouen, 225 p.
- Jardani A, Revil A, Barrash W, Crespy A, Rizzo E, Straface S, Malama B, Cardiff M, Miller C, Johnson T. 2009. Recon-

- struction of the Water Table from Self-Potential Data: A Bayesian Approach. *Ground Water*, **47**(2): 213–227.
- Linde N, Revil A, Boleve A, Dage C, Castermant J, Suski B, Voltz M. 2007. Estimation of the water table throughout a catchment using self-potential and piezometric data in a Bayesian framework. *Journal of Hydrology*, **334**: 88–98.
- Maineult A. 2004. *Application de la méthode du potentiel spontané à l'hydrogéologie: expérimentation sur modèle réduit d'aquifère*. PhD Thesis, Université de Savoie, Savoie, 216 p.
- Marinică I, Borza I. 2010. Impactul exploatărilor de zăcăminte metalifere asupra calității apei în județul Caraș Severin. *Instit. Naț. de Hidrologie și Gospodăria Apelor, Conf. Șt. Jubiliară* 256–267.
- Mears BJr. 1968. Piping, in Fairbridge RW (editor) – *The Encyclopedia of Geomorphology*, Ed. Reinhold, New York, 849–450.
- Medeleț F. 2005. Date din istoria comunei Doclin. *Analele Banatului*, **XII–XIII**: 513–522.
- Mehanee S. 2014. An efficient regularized inversion approach for self-potential data interpretation of ore exploration using a mix of logarithmic and non-logarithmic model parameters. *Ore Geology Reviews*, **57**: 87–115.
- Moore JR, Boleve A, Sanders JW, Glaser SD. 2011. Self-potential investigation of moraine dam seepage. *Journal of Applied Geophysics*, **74**: 277–286.
- Năstăseanu S, Savu H. 1968. Notă explicativă Harta Geologică, Scara 1:200.000, foaia L-34-XXVIII, Institutul Geologic, București.
- Nunes A, De Almeida AC, Coelho C. 2011. Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. *Applied Geography*, **31**: 687–699.
- Nyquist J, Corry C. 2002. Self-potential: the ugly duckling of environmental geophysics. *The Leading Edge (Society of Exploration Geophysicists)*, 446–451.
- Peksen E, Yas T, Kayman AY, Ozkan C. 2011. Application of particle swarm optimization on self-potential data. *Journal of Applied Geophysics*, **75**: 305–318.
- Rădoane M, Dumitru D, Ichim I. 2001. *Geomorfologie*. Edit. Universității Suceava, 394 p.
- Revil A, Jardani A. 2013. *The Self-Potential Method: Theory and Applications in Environmental Geosciences*. Cambridge University Press, Cambridge, 369 p.
- Revil A, Trolard F, Bourrie G, Castermant J, Jardani A, Mendonca CA. 2009. Ionic contribution to the self-potential signals associated with a redox front. *Journal of Contaminant Hydrology*, **09**: 27–39.
- Richard KS, Raddy KR. 2007. Critical appraisal of piping phenomena in earth dams. *Bull. Eng., Geol., Environ.*, **66**: 381–402.
- Roudasari M, Beitollahi A. 2013. Forward modeling and inversion of self-potential anomalies caused by 2D inclined sheets. *Exploration Geophysics*, **44**: 176–184.
- Schuppener B. 2013. Hydraulic failure. *Geotechnical Design*, Dublin, 37 p.
- Sencu V, Ianoș I. 1987. Munții Dognecei, în *Geografia României*, **III**. Edit. Academiei Române, București, 392–393.
- Sheffer M. 2007. *Forward modelling and inversion of streaming potential for the interpretation of hydraulic conditions from self-potential*. PhD Thesis, The University of British Columbia, Vancouver, 224 p.
- Singarimbun A, Djamal M, Meilawati F. 2012. Fluid Flow Direction Beneath Geothermal Area Based on Self-Potential Data (A Case Study at Mount Patuha, West Java, Indonesia). *International Journal of Geology*, **1/6**: 26–35.
- Straface S, De Biase M. 2013. Estimation of longitudinal dispersivity in a porous medium using self-potential signals. *Journal of Hydrology*, **505**: 163–171.
- TehSaufia A, Saad R, Nordiana M. 2012. Integration of Electrical Imaging Methods in Detecting Engineering Problems. *Intern. Conf. on Geological and Environmental Sciences IPCBEE*, **3/6**, IACSIT Press, Singapore.
- Torok–Oance M. 2001–2002. Aplicații ale SIG în geomorfologie (I). Realizarea modelului numeric al terenului și calcularea unor elemente de morfometrie. *An. Universității de Vest din Timișoara, GEOGRAFIE*, **XI–XII**: 17–30.
- Verachtert E, Van Den Eeckhaut M, Poesen J, Govers G, Deckers J. 2011. Prediction of spatial patterns of collapsed pipes in loess-derived soils in a temperate humid climate using logistic regression. *Geomorphology*, **130**: 185–196.
- Urdea P, Țambrîș A. 2014. Spontaneous Potential investigations in Semenic Mountains. *STUDIA UBB GEOGRAPHIA*, **LIX**, **2**: 25–46.
- Warsta L, Taskinen A, Koivusalo H, Paasonen–Kivekas M, Karvonen T. 2013. Modelling soil erosion in a clayey, subsurface-drained agricultural field with a three-dimensional FLUSH model. *Journal of Hydrology*, **498**: 132–143.
- Wishart DN, Slater LD, Schnell DL, Herman GC. 2009. Hydraulic anisotropy characterization of pneumatic fractured sediments using azimuthal self-potential gradient. *Journal of Contaminant Hydrology*, **103**: 134–144.
- *** A quick tour of Geostatistical Analyst, ArcMap 10.1.
- *** ANCPI – Ortofotograme – 2005
- *** ArcGis 10.1 Help.
- *** Soil Map of Romania 1:200.000, (1989), (sheet Reșița), Research Institute for Pedology and Agrochemistry.
- *** Topographic Map 1:25.000, sheet L-34-104-A-b.

- *** Institute of Geology and Geophysics – Geologic Map 1:200.000, sheet L-34-XXVIII.
- *** The Annual Report concerning status of environmental factors from Region 5 West in 2010;
<http://rezervatii.exploratorii.ro/rez11.php>.
- <http://www.sdec-france.com/soil-science-equipment-sensor-pms9000.html>.
- <http://www.conrad.com/ce/en/product/124602/VOLT-CRAFT-VC850-Digital-Multimeter-with-Software-included-6000-counts-CAT-IV-600V-CAT-III-1000V>.
- <http://individual.utoronto.ca/lackner/ggr272/DataClassificationMethods.pdf>.
- <http://blogs.esri.com/esri/arcgis/2007/10/18/about-the-geometrical-interval-classification-method>.

Miscellanea

Symposium

National Symposium on Geomorphology, 35th Edition, Timișoara, Romania, May 23-26, 2019

The 35th edition of Romanian Geomorphology Symposium was held in Timișoara, between 23 and 26 May 2019, organized by the Department of Geography of West University of Timișoara. The symposium represented a new opportunity for Romanian geomorphologists and geomorphologists from abroad, to present and to debate the results of their scientific work in the last years.

For the first time, this national symposium had three distinct sequences, each with its own significance, a sequence dedicated to the young geomorphologist's day, the symposium works themselves, and the field trip application.

The **Young Geomorphologists Workshop** took place on May 23, and the specific activities were structured on two distinct modules.



The first module was a theoretical–methodological one, by the presentation of recognized specialists of new methods and techniques in geomorphological practice, such as „*Object-oriented analysis for landform mapping*” (Drăguț L, West University of Timișoara), „*To date or not to date? Practical guidelines for the application of Optically Stimulated Luminescence (OSL) in geomorphological studies*”

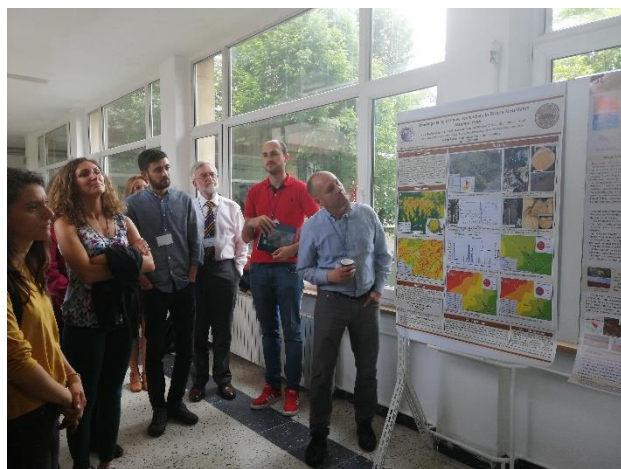
(Sipos, G., University of Szeged, Hungary), „*Ultra mobile 3D scanning solutions for generating a digital terrain model*” (Toma, C., Blacklight S.R.L. Timișoara), „*IAG opportunities and events for young geomorphologists*” (Micu, M., Institute of Geography, Romanian Academy of Science) and „*Geoscience methods for archaeological research*” (Hegyi, A., West University of Timișoara). The second module was a practical one, for the field, intended for demonstrations of some technical methods applied in the research of „Șanțul Turcilor” Mașloc archaeological site, like Scanner laser 3D mobile GeoSLAM ZEB Horizon, Ground Penetrating Radar and Electrical Tomography.



The 24 oral papers of the Symposium were presented during two days, May 24th and 25th, in 6 different time modules, each module's works being opened by a keynote presentation by the brand's scientific personalities: Ian Evans (Durham University, UK) – *The erosion of glaciated mountains*, György Sipos (Szeged University, Hungary) – *Late Pleistocene linkages between glacial, fluvial and aeolian processes in the SE Carpathian Basin*, Lucian Drăguț (West University of Timișoara) – *Semi-auto-*

mated mapping of landslides, Daniel Germain (Université du Québec à Montréal, Canada) – *Improving climate change adaptation and disaster risk* and Andreas Kellerer–Pirklbauer (University of Graz, Austria) – *Crumbling Alps? Permafrost and periglacial dynamics in Austria under the influence of climate change reduction through geomorphology*.

With more than 50 participants from many Romanian's academic centers (Bucharest, Cluj–Napoca, Iași, Craiova, Timișoara) and from abroad (Austria, Canada, Hungary, United Kingdom), the presented works covered a very varied subject area – regional geomorphology, fluvial and coastal geomorphology, slope processes and landslides, hazards and associated risks, glacial and periglacial geomorphology, geomorphometry and remote sensing, Pleistocene paleogeomorphology, dendrogeomorphology, geomorphosites, which often led to a passionate debate on scientific topics. The 13 works presented in poster format were the subject of a special session held on Saturday May 25th afternoon.



An important event included in the agenda of the symposium, according to the Statute of Romanian Association of Geomorphologists, was the presentation of the activity report of the AGR for the last two years and the election of the new president and the steering committee.

The new leading structure of Romanian Association of Geomorphologists is: president – Mihai Micu (Institute of Geography, Romanian Academy), general secretary – Nicușor Necula (A.I. Cuza Iassy University), treasurer – Florin Tătui (Bucharest University), vice-presidents: Petru Urdea (West Univer-

sity of Timișoara; national and international scientific relations portfolio), Mircea Voiculescu (West University of Timișoara; financing portfolio), Ciprian Mihai Mărgărint (A.I. Cuza Iassy University; communication/visibility/popularization portfolio), Sandu Boengiu (Craiova University; publications portfolio), Olimpiu Traian Pop (Babeș–Bolyai Cluj–Napoca University; young geomorphologists portfolio), and members: Alexandru Onaca (West University of Timișoara; young geomorphologists portfolio), Sanda Roșca (Babeș–Bolyai Cluj–Napoca University; financing portfolio), Mirela Vasile (Bucharest University; publications portfolio), Răzvan Popescu (Bucharest University; national and international scientific relations), Florin Zăinescu (Bucharest University; website / communication / visibility / publicity portfolio).

The field trip application had as the target the Muntele Mic Massif (1801 m a.s.l.), a distinct unit of the Țarcu Mountains. The geomorphological landscape dominated by the presence of the peneplained relief within the Borăscu sculptural complex, some glacial forms not very expressive (cirques, moraines, erratics), but with many detail forms due to the periglacial morphogenesis (nivation niches and hollows, altiplanation terraces, rock streams, blocks fields, tors, ploughing blocks, earth hummocks) incited interesting discussions.



Some of these discussions took place in the monitoring perimeters by the West University team, of some periglacial processes (frost heaving, soil and rocks creep, nivation, freezing–thaw cycles).

The program of this national scientific manifestation, the summaries of the works and the guide of

the field application were included in a booklet entitled „*Current status and new challenges in geomorphological research*”, Urdea P, Ardelean F. (edi-

tors), Edit. Universităţii de Vest, ISBN 978-973-125-688-7, 83 p.



Petru URDEA, *West University of Timișoara*

International conference

Regional Conference on Geomorphology of the International Association of Geomorphologists

Athens, Greece, September 19–21, 2019

During September 19–21, 2019, the Regional Conference on Geomorphology of the International Association of Geomorphologists (IAG) took place in Athens, Greece. Entitled *Geomorphology of Climatically and Tectonically Sensitive Areas* and organized by the Greek Committee for Geomorphology & Environment of the Geological Association of Greece in collaboration with the National and Kapodistrian University of Athens, Aristotle University of Thessaloniki, University of Patras, Hellenic Centre of Marine Research and Harokopio University. The Conference included a pre-Conference field trip (four days, Santorini Island, Cyclades, and Aegean Sea), a post-Conference field trip (four days, Rhodes island, Aegean Sea and dedicated to the memory of Paolo Pirazzoli) and an intensive course for young geomorphologists.



The latter, organized under the joined auspices of IAG–EGU was entitled *Coastal Geomorphology of Climatically and Tectonically Sensitive Areas* and

took place during September 22–27, 2019. The event was hosted by Harokopio University and the Hellenic Centre for Marine Research, and 19 participants from 7 countries (Brazil, Colombia, Croatia, Greece, India, Indonesia and Italy) participated to numerous laboratories and field works.

The conference was attended by 252 participants from 36 countries (12 from Romania). It consisted out of 14 scientific sessions (Advancing theory and modelling of river systems, Anthropocene, Geoarchaeology and Society, Coastal geomorphology and Morphodynamics, Denudation in the Mediterranean Zone, Geodiversity of landforms in the Mediterranean Zone, Geomorphological Hazards and Risks, Glacial and Periglacial Geomorphology, Human Impacts on Geomorphic Systems, Karst Geomorphology, Quantifying land surface processes with high-resolution topography and terrain analysis, Seismic Geomorphology, Submarine Geomorphology, Tectonic Geomorphology, UNESCO Global Geoparks: geoheritage assessment and management – geotourism development) which gathered 125 oral presentations and 89 posters. Four keynote lectures focused on the heritage value of Geomorphology (Emmanuel Reynard), the imprint of river capture on continental topography and biodiversity (Taylor Peron), tsunami signatures in ancient harbor deposits (Andreas Vott) and sandstone and conglomerate landforms (Piotr Migon).

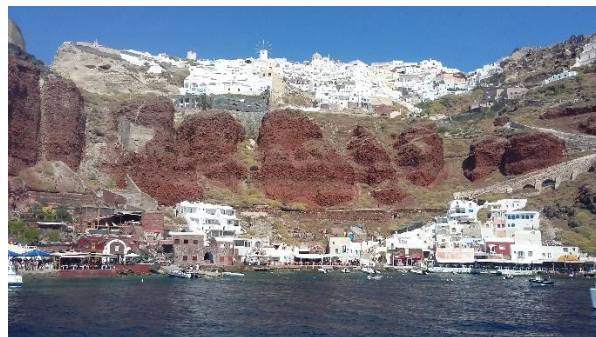
During the conference, a Council Meeting of the IAG took place (the Romanian Association of Geomorphologists was represented by Petru Urdea, Vice-President responsible for international relationships and collaborations). Among the most important issues discussed (and approved) during the meeting were: the milestone in the history of the IAG represented by the obtaining of its legal status, making thus IAG a registered international non-profit organization, with an official address and fi-

nancial personality (4th of March 2019, under Spanish Law, the IAG was formally recognized as a legal institution); approval of the new IAG Constitution and Bylaws; travelling grants will be offered as well for countries not considered "less favoured" (provided that the National Scientific Members are having the IAG membership fees paid up-to-date); a new definition for Young Geomorphologists: *Undergraduate or postgraduate – Masters/PhD students or scientists who has received their highest degree, i.e. BSc, MSc, or PhD, within the past seven years. Provided parental leave fell into that period, up to one year of parental leave time may be added per child, where appropriate*, approval of new IAG Working Groups and new National Scientific Members.

The Romanian Association of Geomorphologists was represented by 10 of its members (Bucharest University, West University of Timisoara, Institute of Geography), which gave oral and poster presentations on glacial geomorphology (the rock glaciers on the Bulgarian highest mountains and Retezat mountains: a comparative analysis), coastal geomorphology (coastal evolution of the two natural reserves of the tideless Black Sea and Baltic sea: similarities, discordances and cyclic alternating evolutionary trends; paleoecological tracers of marine–freshwater transitions during the Early to Mid-Holocene Danube Delta build-up; using satellite images to detect underwater features along Danube Delta upper shoreface), applied geomorphology for geoarcheology (new contributions to the analysis of the geomorphological and geological vulnerability of

the roman edifice with mosaic site, Constanta) and slope processes (national-scale landslide susceptibility map in Romania).

The next Regional Conference on Geomorphology will be organized in October 2020 in Iran (Mashhad University), under the title *Desert and arid environments: opening opportunities for geomorphologists to share research experiences*.



Symposium

VIII Italian Young Geomorphologists' Days

Milan and Veny Valley, Italy, June 26–28, 2019

The event „VIII Italian Young Geomorphologist's Days" gathered together early career geomorphologists from Italy, Switzerland, France, Romania, Russia, Austria, Greece, Poland, Costa Rica, Brazil and India. The conference lasted for three days and took place in Milano, at Palazzo Greppi of the University of Milan. During the first two days, the participants presented their work while on the third day a fieldtrip was organized in the Veny Valley (Mont Blanc Massif, Italy). The large number of contributions, either oral or poster presentations, covered a wide variety of geomorphological processes such as glacial, periglacial, coastal, fluvial, mass movements, etc. and techniques used for the hazard assessment and conservation of geoheritage.

The second day of the event was marked by the meeting of the young geomorphologists' national delegates. The public discussion with the representatives of the groups from Italy, Switzerland, Poland, France, Greece, Costa Rica and Romania was chaired the President of International Association of Geomorphologists (IAG), prof. Mauro Soldati, and Vice-President of IAG, dr. Susan Conway. Its main aim was to bring together the national groups of young

geomorphologists to talk over the development of the international group of young geo-morphologists. The discussion agenda included a brief presentation of each group, ideas on how we can improve the networking and collaboration between groups, expectations of this project, a small debate regarding the definition of Early Career Scientists (ECS) and the possibility of organizing these meetings every year.

The last day fieldtrip to the Veny Valley was a great chance to enrich our knowledge of glacial geomorphology thanks to the expertise of Philip Deline and Marco Giardino that presented the geological, geomorphological and climatic context of the area and its significance in the evolution of the Miage Glacier. More than that, we enriched our knowledge about the landforms on Mars through a very interesting presentation by Susan Conway. Moreover, the beautiful landscape, the nice walk between unique landforms, the lively topic related discussions, the good vibes and the sunburns have completed this great trip, out of which, I suppose, interesting collaborations will come out.



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