

A complex approach in the interdisciplinary field of karst geomorphology. The case study of Anina karst area (Banat Mountains, Romania)

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Abstract

Karst regions are characterized by discontinuity and even by the lack of surface water drainage due to the fissured and porous rocks, but the rivers are often flowing in the underground. Our study area is represented by the Anina karst area, a karst region that is situated in the largest and most compact carbonate area in Romania, the Reșița - Moldova Nouă Synclinal. This study aims to analyse a mature karst area using a complex approach in karst geomorphology. To achieve this assessment, we intended (i) to get an overall description of the morphology of the area using digital data and GIS methods; (ii) to obtain detailed data regarding cost evolution using geophysics, hydrogeology and speleology, and (iii) to correlate all the data to evaluate the karst terrain from the geomorphology perspective.

Our research is still in progress, and yet we have results that are leading to a complex approach in karst topography research from a geomorphological perspective, using different fields of study as geology, speleology, spontaneous potential as geophysical method and computer science (GIS). Based on our field measurements we were able to correlate those features that are extremely important in karst solution processes, as water circulation, underground conduits, slope, soil properties, water properties in order to have a better understanding regarding the actual landscape in the Anina karst area and also in order to develop hypotheses regarding the possible evolution of karst landforms in the studied territory.

Interdisciplinarity in karst topography studies is very important. Only by involving scientists, and techniques belonging to different scientific domains, we may understand in detail the karst topography. This complex approach is useful for stakeholders and local authorities in their feasibility studies and strategies for local development due to the fact that our study enriches the knowledge regarding karst environment "behaviour" in Anina region.

Keywords: karst, geomorphology, complex approach, interdisciplinarity, Anina Mountains

Rezumat. Abordarea complexă în domeniul interdisciplinar al geomorfologiei carstice. Studiul de caz al zonei carstice Anina (Munții Banatului, România)

Regiunile carstice sunt caracterizate de către discontinuitatea și chiar lipsa apelor de suprafață ca urmare a rocilor poroase și fisurate, dar râurile cel mai adesea au curgerea în subteran. Zona de studiu este reprezentată de zona carstică Anina, o regiune carstică situată în cea mai întinsă și compactă suprafață de roci carbonatice din România, Sinclinalul Reșița - Moldova Nouă. Scopul studiului este de a analiza un areal carstic matur folosind o abordare complexă în ramura geomorfologiei carstice. Pentru atingerea acestei evaluări am intenționat (i) să obținem o imagine de ansamblu a morfologiei arealului studiat folosind date digitale și aplicând metode SIG; (ii) să obținem date de detaliu privind evoluția carstică folosind metode geofizice, hidrogeologia și speologia, și (iii) să corelăm toate aceste date pentru a evalua arealul carstic din perspectivă geomorfologică.

Chiar dacă cercetarea de față este în derulare, am obținut rezultate ce ne conduc spre o abordare complexă în cercetarea reliefului carstic din perspectivă geomorfologică, folosind diferite domenii de studiu precum geologia, speologia, potențialul spontan ca metodă geofizică și tehnica computațională (SIG). Pe baza măsurătorilor din teren am reușit corelarea factorilor importanți în procesele de disoluție carstică, precum circulația apei, canale carstice, proprietățile solului și ale apei, panta, toate acestea pentru a avea o mai bună înțelegere a carstului din Câmpul Minier Anina și pentru a putea ridica ipoteze privind posibila evoluție ulterioară a teritoriului studiat.

Interdisciplinaritatea în studiile regiunilor carstice este foarte importantă. Doar implicând cercetători și tehnici aparținând diferitelor domenii științifice, suntem capabili să înțelegem în detaliu relieful carstic. Această abordare complexă este utilă părților interesate și autorităților locale în studiile de fezabilitate și strategiile pentru dezvoltarea locală datorită faptului că acest studiu îmbogățește cunoștințele privind "comportamentul" mediului carstic în zona Anina.

Cuvinte-cheie: carst, geomorfologie, abordare complexă, interdisciplinaritate, Munții Aninei

Introduction

Karst regions are characterized by discontinuity and even by the lack of surface water drainage due to the fissured and porous rocks, but the rivers are often flowing in the underground (Ford & Williams, 2007, 2011). In Romania, almost 2% of its surface, it's occupied by limestone (Sencu, 1978), meaning almost 4,500 km² (Orghidan et al., 1972). Karst geomorphology includes both surface and underground landforms research, landforms that develop on soluble rocks by solution and associated processes. Typical karst landforms develop best on

pure, dense and thick limestones and marbles, and in consequence, it is very important to obtain various data regarding these two submediums. We consider that karst geomorphology is an interdisciplinary scientific field because the research in a karst area from a geomorphological perspective involves different studies, belonging to many scientific fields: geology, hydrogeology, biogeography, pedology, geophysics, speleology, computer science.

This interdisciplinary approach is widely used to study karst areas in Spain (Gutiérrez et al., 2011; Anchuela et al., 2013), Croatia (Telbisz et al.,

2009), Saudi Arabia (Youssef et al., 2012) and Italy (Ercoli et al., 2012).

This study aims to analyse a mature karst area using a complex approach in the interdisciplinary field of karst geomorphology. To achieve this assessment, we intended (i) to get an overall description of the morphology of the area using digital data and GIS methods; (ii) to obtain detailed data regarding cost evolution using geophysics, hydrogeology and speleology, and (iii) to correlate all the data to evaluate the karst terrain from geomorphological perspective.

Theoretical background

A concern regarding interdisciplinarity is “how” different perspectives, belonging to different sources are situated, selected and after that used in any field of science (Payne, 1999). Another paper regarding interdisciplinarity in geography belongs to Baerwald (2010). In this paper the author tries to point out the relationship of geography with other disciplines and also the perspectives of geography as an interdisciplinary domain. Baerwald (2010) considers that geography is a “big tent” having three major areas that encourage communication and interaction, two factors extremely important in interdisciplinarity. These three major areas focus on spatial analysis, human–environment interaction, and place-based and regional analyses.

Geomorphology is the area of study leading to an understanding of landforms and appreciation for landforms and landscapes, including those on continents and islands, those beneath oceans, lakes, rivers, glaciers and other water bodies, as well as those on the terrestrial planets and moons of our Solar System (Bauer, 2004). Considered to be a composite science (Osterkamp, 2008), geomorphology is claimed by the geographers and by geologists.

The modern-day geomorphologist has a deep appreciation for the importance of slowly acting processes in concert with large-magnitude, low frequency events in leaving imprints on the landscape, for the utility of detailed process, mechanical studies as well as historical reconstructions of landform assemblages in unravelling the complexities of the present-day surface. Besides these, the geomorphologist deals with the interconnectivity between the various subspecializations of geomorphology and allied Earth and engineering sciences, and for the complementarities among twenty-first century technological capacities (Bauer, 2004).

Being connected to the ever-growing influence of the socioeconomic domain on the natural environment and, implicitly, on the relief and its evolution, geomorphology is simultaneously developing in diverse directions: on one hand, it is becoming a more rigorous geophysical science — a significant part of a

larger earth science discipline; on the other hand, it is becoming more concerned with human social and economic values, with environmental change, conservation ethics, with the human impact on the environment, and with issues of social justice and equity (Church, 2010).

Karst geomorphology is represented by the study of both surface and underground landforms that are developed on soluble rocks as the consequence of dissolution and associate processes (De Waele et al., 2009).

Below are defined the main scientific domains that are used in the interdisciplinary field of karst geomorphology and there are also mentioned several references in order to emphasize the importance of each of those fields in karst terrains research.

Geology is the scientific study of the origin, structure, composition, and history of the Earth, together with the processes which have led to its present state (Whittow, 1984).

Geophysics is the science concerned with all aspects of the physical properties and processes of the Earth and planetary bodies and their interpretation, including, for example seismology, gravity, magnetism, heat flow, geochronology (Allaby, 2008).

Application of geophysical methods – GPR, DC electrical tomography, self potential – enable the knowledge of the structure of karstifiable masses, to identify karst cavities and morphology of karst landforms and, of course, water circulation in karst structures. The proof of these research directions is those many papers that present investigations in karst topography that are using geophysics techniques: Chamberlain et al. (2000); Zhou et al. (2000; 2002); Gibson et al. (2004); El-Qady et al. (2005); Rozycki et al. (2006); Jouniaux et al. (2009); Cardarelli et al. (2010); Anchuela et al. (2008; 2009; 2010; 2013); Moore et al. (2011); Coskun (2012); Mihevc & Stepišnik (2012) and Łyskowski et al. (2014). Karst geophysical approaches In Romanian are sporadic: Maftciu (1991) and Mitrofan et al. (2008), studies that are using resistivity methods in the Padiș Plateau and respectively in the Cerna Valley.

Hydrogeology is the scientific study of the occurrence and flow of groundwater and its effects on earth materials (Allaby, 2008). It is closely related to karst geomorphology due to its information regarding the water circulation in karst massifs, giving important data about the evolution of the endokarst. This field of study is the link between the exokarst geomorphological investigations and the underground investigations in karst topography. There are many papers dealing with hydrogeology in karst terrain around the world: Bakalowicz (2005); Goldscheider et al. (2008); Williams (2008); Jeannin et al. (2012); and also in Romania, Orășeanu & Iurkiewicz (2010); Povară & Ponta (2010).

Pedology - science that has as object for its study the soils as natural units, from the perspective of their genesis, morphological characters, physical, chemical and biological properties, their classification and distribution, and general principles of use, amelioration and control their fertility (Conea et al., 1977).

Soil is the layer that separates the exokarst from the endokarst. Its presence or absence is decisive in the development of karst landforms and in karst environment pollution. There is a strong relationship between the formation of landforms, soils and vegetation on karst terrains. There are different approaches that are studying soil related with karst environment: karst aquifer investigations (Tooth & Fairchild, 2003); cave drips studies (Baldini et al., 2006; Fairchild et al., 2006); infiltration processes (Arbel et al., 2010); human influence on karst soils (Canora et al., 2005); soil formation and distribution in Yucatan, Mexico (Bautista et al., 2011); role of soil cover in groundwater recharge (Jeannin et al., 2013), the relation between vegetation formation and soil properties (Efe, 2014).

Speleology is the scientific study of the origin of caves and cave life (Whittow, 1984).

In the scientific literature, there are a large number of papers where speleology is used to present some important aspects for different karst areas, as for e.g. Kambesis (2007); Goldscheider et al. (2008); Klimchouk (2009); Debevec et al. (2012); Ballesteros et al. (2015).

Land Use/Land Cover (LU/LC) - Land use is represented by the socioeconomic inputs to land. It describes an activity with an input, a process, and also the results of this human activity. Land cover is defined as the vegetation cover on the Earth's

surface. It includes also man-made features, but also bare rock, bare soil and inland water surfaces (Herold et al., 2007).

Geographical Information Science (GIS) is the system based on using electronic techniques for calculation, for acquisition, to store, analyse and display geographic data. It is an information system that is able to organize the information based on spatial criteria (geographical criteria) (Donisă, Donisă, 1998).

Remote Sensing (RS) - a system that is based on remote capturing, recording and analysis of electromagnetic or sound signals that are sent by objects and processes as emissions or reflections (Donisă, Donisă, 1998).

GIS and RS as methods in karst studies were used in different papers. In Romania, Torok-Oance et al. (2009) used DEM for the identification of the planation surfaces in Mehedinți Mountains and Torok-Oance & Ardelean (2012) used Object-Oriented Image Analysis (OBIA) for detection of barren karst areas in Mehedinți Mountains. Around the world, there are several approaches that are using GIS and RS as tools in karst terrains investigations: Orndorff et al. (2000); Hung et al. (2002); Ohms & Reece (2002); Tagil & Jenness (2008), Telbisz et al. (2009), Pardo-Igúzquiza et al. (2013), Zylshal & Haryono (2013).

In order to get a brief image regarding the domains that we mentioned above as fields that we used in our complex approach in the interdisciplinary field of karst geomorphology, we propose a schematic representation of those scientific domains and the connections/correlations that could be made between them (Fig. 1).

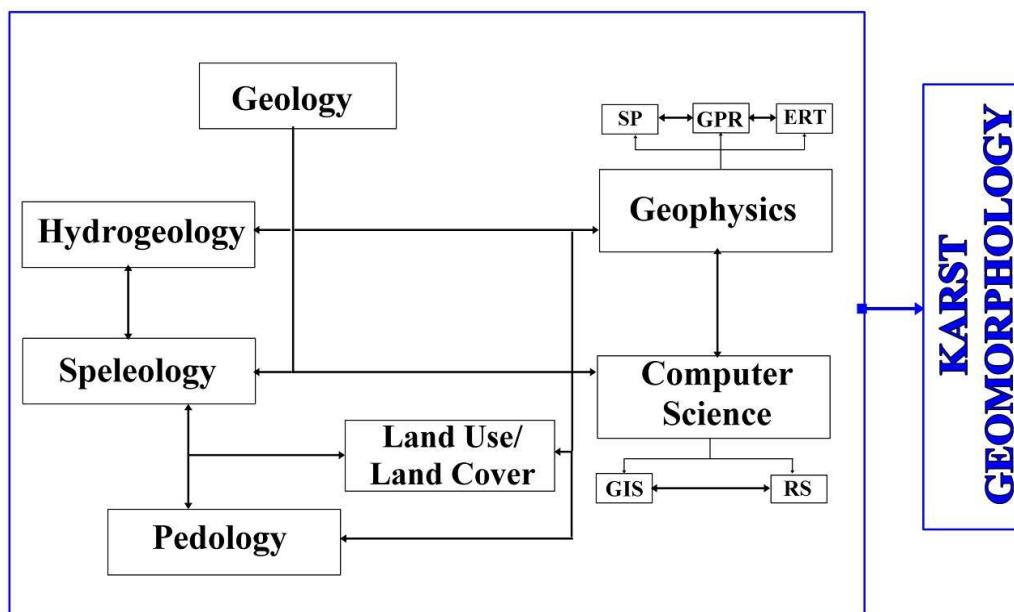


Fig. 1: Scientific domains that we used in our complex approach in the interdisciplinary field of karst geomorphology

Case study. Methodology and results

This section of our paper explains briefly our field measurements and parts of our results in the study area which is represented by Anina karst area, a karst region that is situated in the largest and most compact carbonate area in Romania, the Reșița - Moldova Nouă Synclinorium. Anina karst area was defined by Sencu (1977) as the area that surrounded Anina town and it may be exploited by mining activities. Using the 1:25000 topographic maps and taking into account the main geomorphological landscape characteristics, we established the geomorphological limits for this region (Fig. 2).

The lithology of the study area is formed by many types of limestone (Anina Valley's limestone, Brădet limestone, Marila limestone, Gumpina limestone, Miniș limestone) and different types of marl. We should also mention the presence of clays and noncarbonated materials that occupy smaller areas, such as granite, gravel and sandstones (Bucur, 1997).

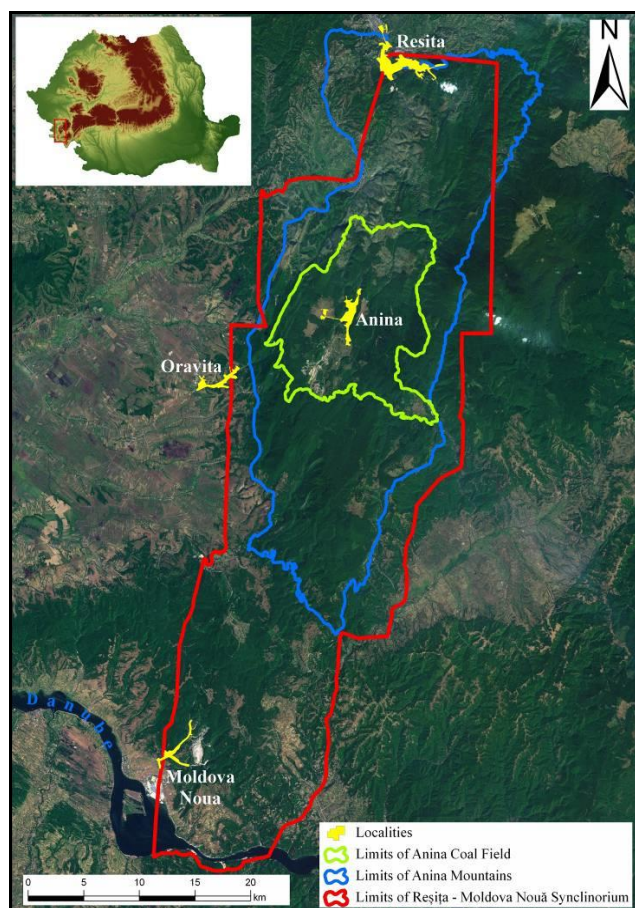


Fig. 2: The location of Anina karst area (Source of background satellite image: http://goto.arcgisonline.com/maps/World_Imagery)

Embracing an interdisciplinary perspective, we carried out several measurements in our study area. First of all, we used GIS techniques and methods to obtain an overall perspective regarding the study

area analysing morphometric parameters of the study area. Hypsometry is a very important parameter, indicating that the altitude is similar on the suspended karst plateaus and the importance of faults direction in morphology (Fig. 3 - left). The slope is also extremely important in the dissolution processes due to the water and snow retention on low slopes and correlating with sinkholes, we emphasized the contribution of slope in karst terrain evolution (Fig. 3 - right).

Another approach of our study is one of the geophysical methods, naming here spontaneous potential for a preliminary approach in our area (Artugyan & Urdea, 2014). This method involves using a digital voltmeter and two non-polarising electrodes (Fig. 4 - left). We developed measurements in many sinkholes (Fig. 4 - right) and we obtained results as grids (Fig. 5 - left) and as profiles (Fig. 5 - right). The grid results were obtained in ArcMap 10 using Kriging interpolation method, using 5 meters between measurement points, as we used in the field. The profiles were obtained in Microsoft Excel, based on the field measurement distance between points, of 3 meters.

Moreover, we developed karst water analysis. We gathered data on calcium, magnesium, water pH and hardness, and also thermal conductivity (Fig. 6 - left). For soil cover we studied soil pH and soil moisture (Fig. 6 - right). Soil moisture is an important element in Spontaneous Potential values and we intended to join SP data with this parameter for a better understanding of water drainage using SP.

Another field that we have used belongs to the speleology domain. Thus, we have visited 8 caves: Buhui Cave - the largest cave with more than 6 km development and which is draining the homonymous creek, the longest underground stream in Banat Mountains with more than 3 km, Cuptoare Cave (135 meters length), Mărghițaș Cave (115 meters length), Cârneală Cave, The Cave from Caraș Spring, The Cave with Water from Gârliște Gorges, The Vertical Shaft under Black Peak, Salamanders' Cave. Buhui Cave is the largest active cave in Banat and Cuptoare Cave was in the past a gallery of Buhui Cave. In Cuptoare Cave and Mărghițaș Cave we repeated our visits to observe the level of water (for those active caves) and to observe that the drip water is different based on the season when we were there. Cârneală Cave is retaining snow for many months of the year, having a negative development and acting as snow/ice trap. The Vertical Shaft under Black Peak is quite a new discovery in the study area, having more than 200 meters' depth with further exploring potential. All these caves are indicating the level of karstification.

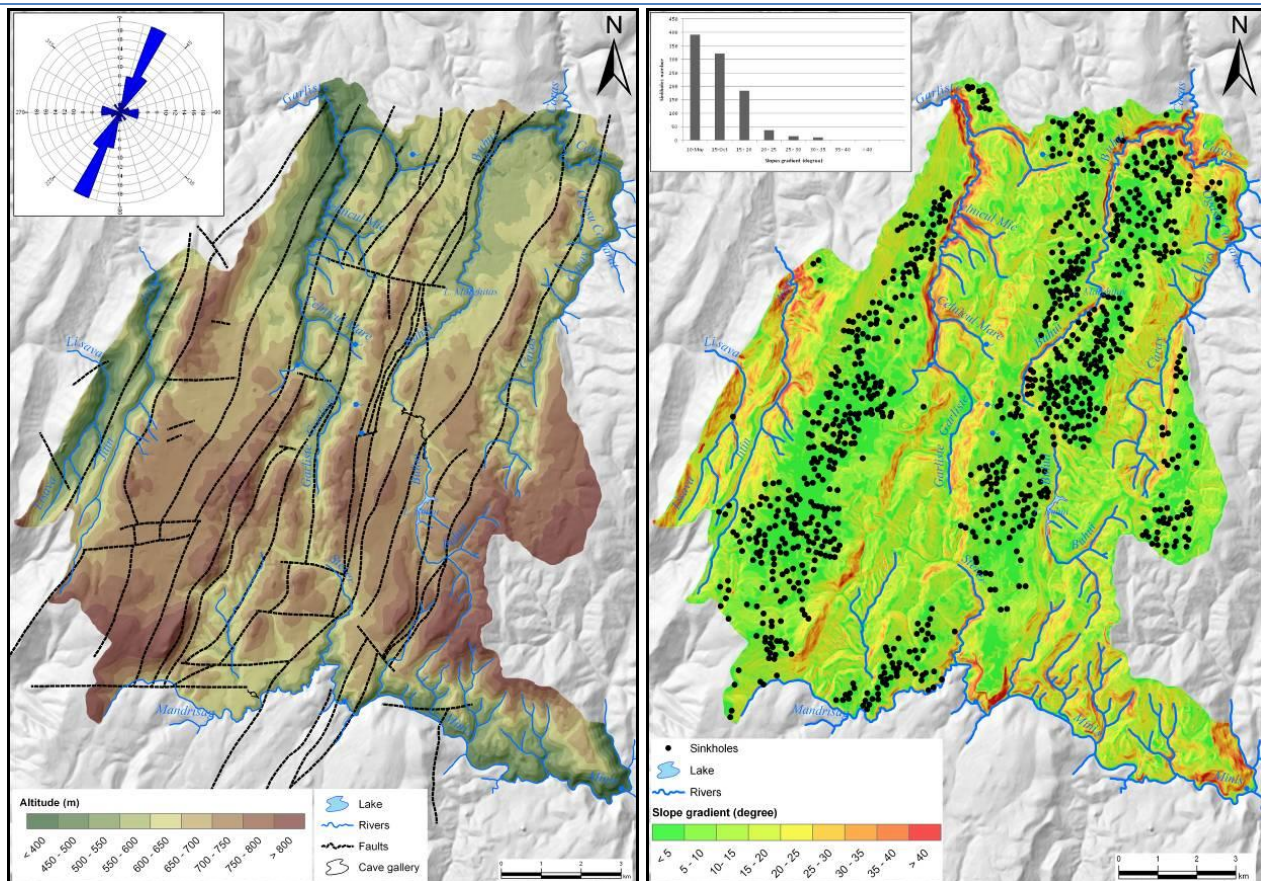


Fig. 3: The morphology and the importance of faults directions in morphology; the main faults directions (upper left corner) (left); slopes and sinkholes in slope classes (upper left corner) (right) in Anina karst area



Fig. 4: The SP measurements - the digital voltmeter (left) and one of our sinkholes study cases (right)

Based on the morphometric analysis, we were able to point out the importance of morphometric parameters for the other fields of studies (speleology or geophysics for example). The slope is indicating those areas with water stagnation and slow snow melting process as a consequence of low values of slope parameter. In those areas sinkholes are well developed, with a high density, surface

water is missing, indicating the presence of the underground flowing water system. Drainage density parameter points out those areas without surface drainage, highlighting karstic suspended plateaus. The morphometric approach indicates those areas with favourable conditions for underground conduit development where we should focus our geophysical investigations and

speleological research. Then, based on the geophysics we were able to observe the structure of the underground and to get a model based on SP measurements on the drainage direction into the sinkholes on the surface water. Using this geophysical method, we were able to identify the karst conduits orientation based on surface water drainage direction, that in most of the cases matches with fault orientation. Using speleology, we observed the orientation of geologic features, of

fractures and the water circulation directions based on bedrock fissures.

Based on our field measurements we were able to correlate those features that are extremely important in karst solution processes, as water circulation, underground conduits, slope, soil properties, water properties in order to have a better understanding regarding the actual landscape in the Anina coast area and also in order to develop hypothesis regarding the possible evolution of karst landforms in the studied territory.

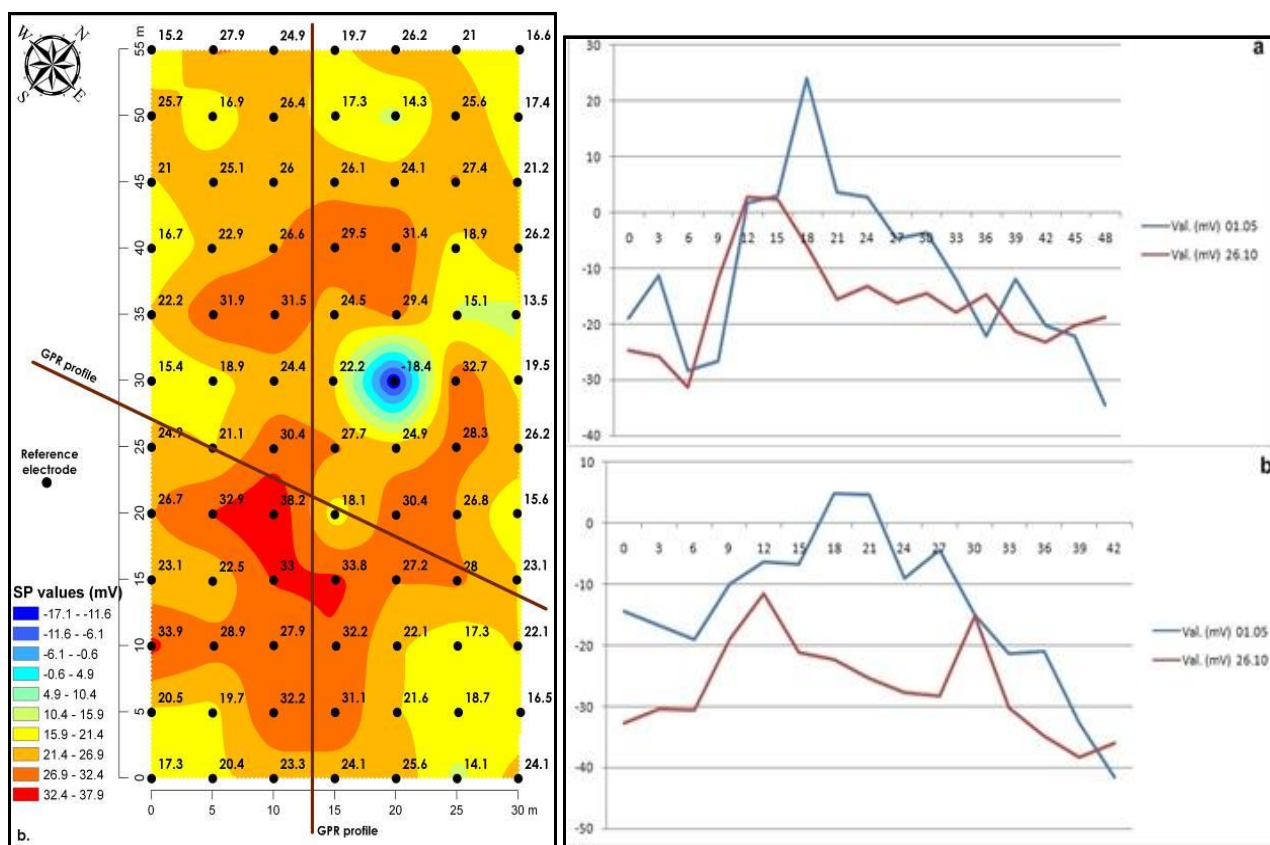


Fig. 5: The results based on SP measurements - a grid (left) and 2 profiles (right) (Artugyan & Urdea, 2014)



Fig. 6: The water chemistry analysis downstream Caraș Spring (left) and soil properties (pH and moisture) studies in a sinkhole in the Anina's neighbouring New Town (Orașul Nou) (right)

Discussions

First of all, for the karst geomorphology, we need to know the geology because we should speak about limestone, regarded as a rock with specific mineralogy and, on the other hand, the masses of rock with some certain structure and tectonics. Then, to get the morphometric characteristics we should use computational techniques associated with GIS and geomorphometry. Because karst terrain presents both surface and underground, for the underground studies, we should use speleology to study caves and their landforms, and also SP as a geophysical method in drainage water investigations. Recognizing the essential role of groundwater in karst landscape genesis, hydrogeological approach is required to know the karst water circulation and their chemical composition. For karst geomorphology, it is very important to have information regarding the soil cover and vegetation cover, in order to understand better the duration of surface water reaching the underground.

Our research is still in progress, and yet we have results that are leading to a complex approach in karst topography research from a geomorphological perspective, using different fields of study as geology, speleology, spontaneous potential as geophysical method and computer science (GIS).

Such a complex approach, involving several scientific fields and methods, is quite a new one in the karst geomorphology. For Romanian karst terrains, this kind of research is the first one. Around the world, there are several studies having a complex approach: De Waele et al. (2009); Ercoli et al (2012); Anchuela et al. (2013). These studies were the scientific references of our research and the results have similar aspects, but there are also differences given by the geological and geomorphological characteristics of the study areas.

As De Waele et al. (2011) said, only having a better knowledge of karst geomorphology and karst hydrogeology we are able to live "together" with karst environment in order to have a sustainable development of karst resources, and not just to live in karst terrains.

Conclusions

Using many fields of study in the Anina karst area, we were able to exemplify that the karst geomorphology may be considered as an interdisciplinary field of study. If we would use only field observations and morphometric analysis, it would be difficult to have a real perspective regarding karst morphology in our study area. But combining with geophysics, water chemistry, soil

properties (as moisture and pH) and speleology, we obtained different data that give us a larger perspective regarding karst topography in the Anina karst area. Our results indicate the role played by the structural features in the terrain morphology, show up the importance of slope in dissolution processes and the role played by the sinkholes in disorganising the surface hydrography. Moreover, based on our approach we were able to correlate soil pH and moisture with SP results, SP measurements that is correlated with rock stratigraphy and orientation. Also, we could identify several underground conduits that are draining the surface water into the underground.

Interdisciplinarity in karst topography studies is very important. Only by involving scientists or techniques belonging to different scientific domains, we may understand in detail the karst topography.

In our future work we intend to complete our data and to enlarge the number of our sites in the study area because a large number of data is very important for a complete perspective regarding karst geomorphology.

In the near future, we intend to use also hydrogeology and other geophysics methods as GPR and DC electrical tomography, and also to continue with the acquisition for spontaneous potential data and speleological data.

This complex approach is useful for stakeholders and local authorities in their feasibility studies and strategies for local development due to the fact that our study enriches the knowledge regarding karst terrain "behaviour" in the Anina region.

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