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Investigation of spatial and temporal changes of cave climate in different karst areas of Hungary

Theses of dissertation

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1. Introduction

"Cave climate is defined as the characteristic climate of a hole formed naturally in solid rocks of the Earth's crust" (Fodor, 1981). Cave air temperature usually approaches the surface mean annual temperature and although there are seasonal air exchanges between cave air and surface air with varying intensities, these airflows do not hinder the formation of a characteristic cave climate. Cave microclimate is also influenced by the features of cave entrances: height above sea level, size, location (at valley bottom, hillside or hilltop), exposure and number. Furthermore, passage morphology also affects cave microclimate, as passages of different sizes and forms react differently to the cave air circulation (Stieber, 2014). Vegetation cover also influences cave air temperature conditions, as due to shading under dense forests cave air temperature is more balanced compared to open karsts (Zelinka, Stieber, 2014). Cave air temperature varies in a cave system spatially, since the halls and corridors are not at the same elevation, thus, an internal air circulation can start (Fodor, 1981). Apart from these differences the cave is characterised by a more balanced climate compared to the surface.

Cave air is continously exchanging with surface air due to the differencies in their warming up, however, each cave has a different air circulation resulting in a characteristic cave microclimate. The cave climate measurements and investigations significantly advance the knowledge on cave environments.

Due to climate change, being one of the most important environmental problems, increasing climate extremities are current challenges on the surface (drought years are followed by extreme humid years) and an important question is how they influence the cave climate conditions.

The research on cave climate has a long history in Hungary. The first measurements on the temperature of Stryx Creek were recorded in the Cave

Baradla (Townson, 1797). In the report of Keresztély Raisz to Gömör County on the Baradla Cave the temperature of the creek was also mentioned (Kessler, 1941). For the end of the 19th century an increasing number of researchers investigated the formation, the development, the description and the classification of caves, and there were growing number of studies including periodic temperature measurements.

Based on the climate characteristics of cave entrance sections a general classification was set up (Kordos, 1970): the first zone nearest to the entrance is the cooling section in winter and the warming section in summer; the second and the third ones are the turbulence and the warming sections, respectively.

In the book of István Fodor (1981) on cave climatology based on cave climate investigations of Hungarian and foreign study areas, he classifies caves considering human comfort. He analyses the climate conditions of the Baradla, Abaliget, Tapolca and Telkibánya Caves, furthermore the Dobsina Ice Cave. His complex cave climate investigations considerably advanced the development of cave therapy as well. He grouped caves into 4 climate types in the aspect of cave therapy considering human comfort as cold, cool, comfort and warm. There are several other grouping possibilities of caves. Apart from the classification speleometeorology demonstrated that as many caves exist, as many different sub-surface microclimate can develop.

2. Aims

The research addressed the following aims:

1. There has been an increasing attention on the preservation of cave environments nowadays. To reach a more efficient prevention in the case of Rózsadomb thermal karst a complex monitoring system was set up in 1995 in the Pál-völgyi Cave (in the framework of the PHARE program), and climate measurements were also

planned to include. The arrangement of the cables was time-consuming and difficult with the given technical conditions (Bekey, 1995), and the system could not operate due to the high humidity. By the technical development such automatic wireless data recording systems were created, which can be placed in the cave easily and can provide continuous data on the changes of cave climate. In my doctoral research the applicability of a wireless sensor network (UC Mote Mini) in cave environment, as methodological novelty, was tested.

2. The research addressed the mapping and the comparison of microclimate features in caves of different genetics and morphology. Caves situated on three karst areas were chosen as study areas: caves of hypogenic origin (the Pálvölgy Cave, the Hideg-lyuk and the Harcsaszájú Cave in the Pálvölgyi cave system in Buda Hills), a near-surface cave (the Hajnóczy Cave in Bükk Mountains) and a swallow cave (the Trió Cave in Mecsek Mountains). In the investigated caves only periodic cave climate and radon measurements were carried out, but temperature monitoring networks were not set up.
3. The relationship between the elevation and the air temperature layering was also investigated during my doctoral research (Muladi, Mucsi, 2013). Microclimatic conditions were investigated on a cliff located at the entrance of Macocha Cave on Moravian Karst in 2008 by Litschmann et al. (2012). The winter-summer temperature profiles of the 138.4 m cliff showed seasonal temperature layering and demonstrated how variable the temperature is depending on the height above sea level. The air temperature rises with the rising elevation also in the caves, however, the rate of increase is different (Fodor, 1981). Fodor investigated the temperature layering in the Baradla-Domica Cave and found that the highest vertical difference is at the entrance (0.4 °C in 140 cm). Bandino (2010) assessed Italian caves and determined that the relationship is not linear between the elevation and the temperature.
4. Three different sections can be separated in caves based on the distance from the entrance: 0–2 m: cooling section in winter and warming section in summer;

2–14 m: turbulence section; 6–14 m warming section, where cave air circulation dominates (Kordos, 1970). The precise measurements allow this approach to be reversed. Sections can be delineated based on the daily and annual temperature fluctuation, and depending on the temperature variability, zones can be allocated in distances from the entrance for each cave separately.

5. In my doctoral research the investigation of the temporal changes of cave air temperature and the description of its long term (seasonal) changes were addressed. Cave air temperature follows the periodical changes of surface temperature in a different rate. The microclimate of the different cave sections reacts to the changes of surface temperature differently on daily, seasonal and annual levels, thus it informs about the temporal changes of air temperature (Kordos 1970).
6. The favorable microclimate of caves allowed several utilization (Keveiné, 2009). The measurement of cave climate parameters is important in the aspect of use as well, as the visitors in caves, opened for tourists, influence cave climate (Smith et al., 2013). The climate measurements can support tourism at National Parks, as by their assessment optimal group size can be identified and surplus heat can be avoided, which harms troglobion species. In actively explored caves for research purposes the cavers can cause temperature anomalies due to the intensive physical work for several hours. My aim was to determine the rate of aperiodical changes in the studied caves, namely the rate of the anthropogenic influence due to tourist groups visiting the cave and the rate of heat surplus caused by the research activity of cavers. The assessment of the time, necessary for temperature and humidity values to be restored to the original state following the cave visits, allows the determination of the rate of cave ventilation. These data can be valuable for the cave research, as they can also contribute to better understand the features of air circulation of complex cave systems.

3. Applied methods

In parallel with the developing technology of wireless sensor network the number of related applications was also increasing. The general features of the sensor network are the short-range operation, the low cost and the low power consumption. The nodes in the network are generally of small size and the processor and the memory are limited. In case of wireless sensor networks the application of expensive wired devices can be avoided, the devices can be easily set up in the field and they communicate using radio communication. Extra sensors can be integrated to the devices, thus more parameters can be measured parallel (Lengyel, 2007).

The radio module of the UC Mote (using the IEEE 802.15.4/ZigBee wireless communication protocol) can operate at a data rate of 250 Kbps in ISM 2.4 Ghz band. The control is regulated by 16 MHz Atmel ATmega128RFA1 microprocessor with 128 kB RAM. Several types of sensors are integrated as default into the device: temperature, humidity and air pressure sensors. SHT21 measures temperature and humidity, and MS5607-02BA03 records air pressure (Muladi et al., 2012). The accuracy and the scale of SHT21 temperature and the humidity sensor are ± 0.3 °C, 0.01 °C and ± 2.0% RH, 0.04% RH, respectively (Sensiron, 2011).

In the initial phase of the research the devices were tested in laboratory environment, and the tests demonstrated that with adequate calibration the 0.3 °C deviation between the devices can be eliminated. Preliminary measurements were carried out in a climate chamber to provide exact calibration constants for each sensor. Before the continuous measurements in the caves the sensors were tested in the Hajnóczy Cave in the Bükk Mountains in December 2011 (the parameters were measured in a 10-minute interval). During the research the number of study areas was continuously increasing. From April 2012 and April 2013 there were continuous measurements in the Hideg-lyuk Cave and in the Pál-völgyi Cave (in Buda Hills), respectively, and there were temporary measurements in the Harcsaszájú Cave (being the member of the Pál-völgyi cave system) and in the Trió Cave (in Western Mecsek karst area, Szuadó valley). 10 devices were placed in both the Hideg-lyuk and the Hajnóczy Caves, where data were recorded in a 10 minute-interval, thus altogether 61.934 and 94.533 data from the two caves were used for the assessment, respectively. 27 devices recorded 32.216 data from the Pál-völgyi Cave providing information on caves closed from tourists. In case of the Harcsaszájú and Trió Caves, 4.000 data were analysed.

The measured surface data were compared to the data of the nearest meteorological stations in all cases. The recorded data at the Hajnóczy Cave was compared to Szentlélek meteorological station. In the case of the Pál-völgyi, Harcsaszájú and Hideg-lyuk caves the measured parameters of the meteorological station at the Quarry were used. For the comparison in the case of the Trio Cave the data of Pécs meteorological station were applied.

Polygon software was used for the spatial assessment of the caves and it helped the planning and determination of device locations. The spatial distances of the devices from the entrance were determined using this software as well.

The layout drawings of the caves were georeferred using ArcGIS software. An overview 3D model was built using Therion software based on cave polygon data and layout maps, and the model was clarified with cross sections.

4. Results

1. A new method was developed to investigate cave climate using UC Mote Mini wireless sensor network.

Before the continuous temperature measurements in caves the applicability of the devices was proved in both laboratory and cave environments. The 0.01 °C scale of the sensors allowed the detection of slight temperature changes of natural and anthropogenic origin. The 0.3 °C difference in accuracy was eliminated by calibration of the devices before the measurements. The devices can be easily and rapidly installed and transported in the caves. High humidity was not problematic for the sensors. Extreme underwater conditions in the caves resulted in data gaps, however, these events did not cause damages in the devices. Using the new type of wireless sensor network I successfully performed continuous data collection in caves.

2. Based on the measured mean temperature the vertical cross section of temperature distribution in the cave passages was performed.

The measured data confirmed that at the cave entrance sections temperature layering can be observed due to the vertical differences. For example 10 °C temperature difference was detected between the pit entrance and the deepest explored point at the Áron Gábor 25 m long pit entrance in the case of the Hideg-lyuk Cave. Independently from height above sea level an increasing temperature can be observed from the entrance towards the interior of the cave. Using the measured mean temperature data of cave passages it was detected that the distance from the entrance has higher influence on the temperature distribution than the height above sea level.

3. Entrance, turbulence and cave air circulation sections were delimited using the daily, seasonal and annual fluctuation of the temperature and the distance from the entrance.

Due to the convection air flow, cooling is observed in winter, while in summer the air flows out from the investigated caves. The impact of surface conditions on the caves are diverse, and the resulted changes in the cave passages have different intensity. The categorization of the cave sections was carried out based on long-term temperature measurements and seasonal observations. Different intervals were given for each caves, as their entrances, the fracture system connecting the surface, and the passage morphology caused different impacts.

Long-term measurements were carried out in two caves. In the Hajnóczy Cave the entrance section is 14 m (ΔT=3.3–9.7 °C), the turbulence section is between 14 m and 64 m (ΔT=0.8–1 °C), than it is followed by the cave section (ΔT=0.1–0.3 °C). In the Hideg-lyuk Cave the entrance section is 19 m (ΔT=4,4–13,6 °C), the turbulence section is observed between 19 m and 48 m (ΔT=1,9–2,7 °C), and it is followed by the cave section (ΔT=0,5–0,9 °C). The maximum temperature of the airflow from the cave was also determined during summer air circulation, which resulted in different values for the investigated caves (8.3 °C for the Hajnóczy Cave and 9.4 °C for the Hideg-lyuk Cave). In the Pál-völgyi and Harcsaszájú Caves the entrance zone was further classified according to the rate of surface influence.

4. The rate of seasonal and daily temperature fluctuations was determined in different cave sections.

The seasonal temperature fluctuation assessments revealed the changes of the airflow direction. Spring and autumn air circulations were short transitional periods, when the temperature fluctuation is low in all section of the caves.

The assessment of the daily temperature fluctuation revealed what are the atmospheric reasons for the temperature changes in the caves. I could allocate such points in the caves where the air circulation is not through the entrance. The thickness of soil and limestone layers above the passages was assessed to reveal if the given fissure or fracture is permeable or not. The allocation of these points or passage sections is of high importance for cave exploration. The cave measurements allowed the detection of an airflow in a section of the Hideg-lyuk Cave, where researchers explored a new 20 m long section of the cave in summer 2014 at a formerly researched point.

5. The rate of anthropogenic influence was determined based on group and passage sizes.

The former measurements of anthropogenic influence were carried out mainly in show caves according to the literature. In the passages of the Hajnóczy Cave characterized by diverse cross sections, the daily visitor groups of a summer research camp were tracked by the measured temperature values. Based on these, the heat surplus caused by the visitors in the different passage sections were identified. My results highlighted that not only in narrow passages, but in wider halls the positive temperature anomaly due to the visiting groups can be detected. Beside the resulted temperature rise the relaxation time was also determined for all passages. The heat surplus due to different visitor group sizes was investigated in certain sections of the Trió Cave that is used only for overall cave visits.

6. Complex air convection models were set up for all investigated caves based on the impacts on the cave sections.

The assessment of the seasonal mean temperature and its fluctuation in the different passage sections revealed that in what distance the inflowing air through the entrance can modify the cave climate seasonally or where local temperature anomalies can develop which cause specific air circulation. During summer air circulation it was shown that air was flowing out of the caves through the entrance, however, there were other cave sections where air inflow was detected (in the Lapos Hall of the Hajnóczy Cave and in the sections of Medvecsapda and Guillotine in the Hideg-lyuk Cave). These influences were indicated on the 3D models and the heat maps of the caves.

Publications in relation with the dissertation:

Muladi B., Csépe Z., Mucsi L., Puskás I. (2012): Application of wireless sensor networks in Mecsek mountain's caves In: Stünzi H.(Ed.): Proceedings of the 13th National Congress of Speleology Zürich, Druckzentrum ETH-Zentrum, 131–136.

Muladi B., Csépe Z. (2013): Vezeték nélküli szenzorhálózatok egy barlangi alkalmazási lehetősége *Karszt és barlang* 2011, **I-II**, 29–39.

Muladi B., Csépe Z., Mucsi L., Puskás I., Koltai G., Bauer M. (2013): Climatic features of different karst caves in Hungary In: Michal Filippi, Pavel Bosák (Eds.) 16th International Congress of Speleology: Proceedings, Prague, Czech Speleological Society, **2**, 432–438.

Muladi B., Csépe Z., Mucsi L. (2013): Barlangklimatológiai mérések két különböző karsztterületen elhelyezkedő magyarországi barlangban In: Veress M. (ed.): Karsztfejlődés, **18**, 127–136.

Muladi B., Mucsi L. (2013): Látogató csoportok hatása a Trió-barlangban In: Galbács Z. (ed.): The 19th International Simposium on Analytical and Environmental Problems, 72–75.

Muladi B., Mucsi L. (2013): Investigation of Daily Natural and Rapid Human Effects on the Air Temperature of The Hajnóczy Cave in Bükk Mountains *Journal of Environmental Geography,* **6 (3-4)**,21–29.

Muladi B., Mucsi L. (2014): Investigation of the spatial and temporal trends of the air temperature of the Hajnóczy cave in the Bükk mountains *Geographica Pannonica,* **18 (3).** 51–61.