Multidisciplinary approach to assess hydrology of karst vadose zone: from Han-sur-Lesse cave to the Rochefort Cave Laboratory (Belgium).

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Abstract

The role of the vadose zone in karst aquifers is under the scope of the multidisciplinary project KARAG (www.karag.be). This paper shortly describes an innovative methodology to highlight transfer and storage characteristics of the unsaturated zone. This long term and multi-scale methodology was applied in two karstic areas in southern Belgium.

First of all, stalactite drip-water discharges were recorded continuously since 2008 in the cave of Han-sur-Lesse. Data coming from 3 monitoring sites give valuable information about the hydrogeological behavior of the vadose zone in this folded Devonian limestone aquifer. A first descriptive approach allows to identify the existence of temporary epikarst storage in the vadose zone as well as the regularity of this storage with time. Dye tracing experiment in the unsaturated zone also precise the transfer and storage dynamic of infiltration water (Poulain et al. 2015).

Secondly, a new experimental site has been installed in a nearby cave (Rochefort Cave Laboratory). Drip discharge, vadose zone dye tracing and stable isotopes analysis have been carried out in 2015 and 2016.

Finally, the comparison of the two experimental sites highlights major differences in the behavior of infiltration and recharge. Storage is important and clearly evidenced in Han-sur-Lesse, with recharge attenuation and retardation and stalactite feeding through the year. In Rochefort, the role of the epikarst is less clear. Perched water bodies are also identified but their impact on water transfer, recharge and storage is limited.

Introduction

The KARAG project aims at understand the role of the unsaturated zone in karst aquifers. To reach this objective, a multidisciplinary research is ongoing in southern Belgium, mainly in the Han-sur-Lesse cave and the Rochefort Cave Laboratory (RCL). The purpose of this underground lab is to support hydrogeophysical measurements aiming at monitor the vadose zone hydrology (gravimetry, ERT and groundwater monitoring) in Rochefort.

Besides geophysical approach, hydrogeological methods are employed in order to characterize the vadose zone. Long term drip-water monitoring, surface-to-cave dye tracing and stable isotopes (surface and cave) analysis were used simultaneously. The combination of these methodologies gives a comprehensive view of the unsaturated zone and allowed to test and refine hypothesis.

Study sites

Both study sites are located in the Variscan fold-an-thrust belt in southern Belgium (Figure 1). The karst systems are developed in Devonian limestone (Givetian in age). Han-sur-Lesse and Rochefort caves are part of two major active systems of Belgium. The two systems are 5 kilometers apart and they are developed in the exact same geological unit.

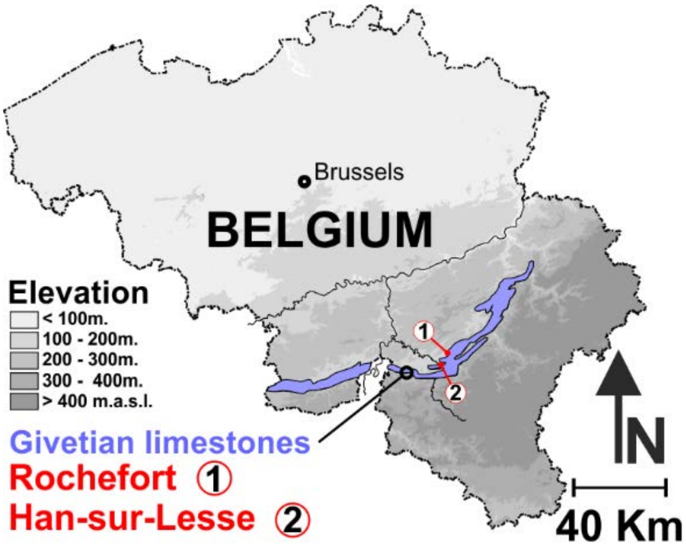

Figure 1: The two study sites in southern Belgium.

Three undergrounds stations were studied in the Han-sur-Lesse system: the Père Noël station, the Salle d'Armes station and the Grande Fontaine station. Stalactite drip monitoring was recorded with an experimental device since 2008 in those 3 points. Descriptive analysis of hydrographs already allow to draw the seasonal scheme and main characteristics of the dripping and to make hypothesis about the unsaturated zone functioning.

An additional underground station has been installed in the Rochefort Cave Laboratory since 2016. Drip-water, dye tracing and isotopes analysis were performed on this site in order to compare the results with the Han-sur-Lesse site.

Methodology

Stalactite drip-monitoring is based on self-siphoning devices coupled to pressure sensors. The absence of mechanical parts ensure the durability of the device regarding calcification and humidity.

Surface-to-cave dye tracing was performed with uranine above the Père Noël station of Han-sur-Lesse and above the Rochefort Cave Laboratory. Two different field fluorimeters were used at the drip point: a GGUN field fluorometer in Han-sur-Lesse and a Fluo-G fluorometer in the RCL. Combining drip-rate and tracer concentration measurement allow to calculate tracer recovery.

Oxygen stable isotope monitoring was performed in the RCL. Water sample were taken on a weekly or 2-weeks basis in the cave (stalactite drip-water) and at the surface (rainwater). Sample were analyzed using a PICARRO L2130-i Cavity Ring-Down Spectrometer at the Vrije Universiteit Brussels (VUB).

Results

8 years of drip-rate are available for the 3 stations of the Han-sur-Lesse cave. The analysis of the flow rate variations already leads to important observations as described by Poulain et al. (2015). An epikarstic aquifer was identified and the storage capacity of this perched water body was estimated for each station. This capacity is similar from one year to another for each site. This demonstrate the well-established dynamic of the unsaturated zone. Differences in drip-rates between stations leads to the identification of variable behavior regarding recharge through the year (Figure 2).

The surface-to-cave dye tracing allow to determine an infiltration velocity of 6.5 m/h in the unsaturated zone (Figure 3). Transfer is fast and most of the tracer arrives quickly. Nevertheless, restitution of the tracer lasts for months and the final recovery mass was less than 1%. This illustrate the duality of the unsaturated zone with a fast transmissive behavior coupled to a high storage capacity.

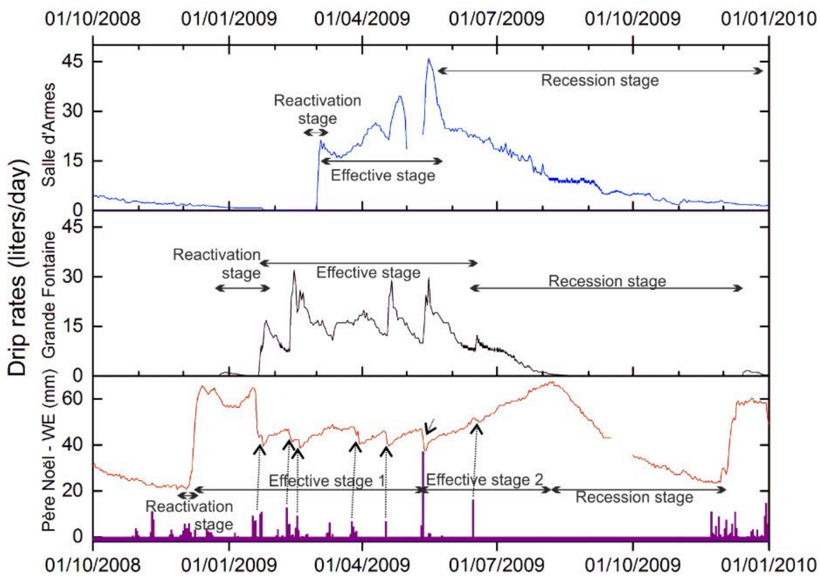

Figure 2 : Drip-water monitoring in three stations of the Han-sur-Lesse cave and daily water excess at the surface of the cave (Poulain et al. 2015)

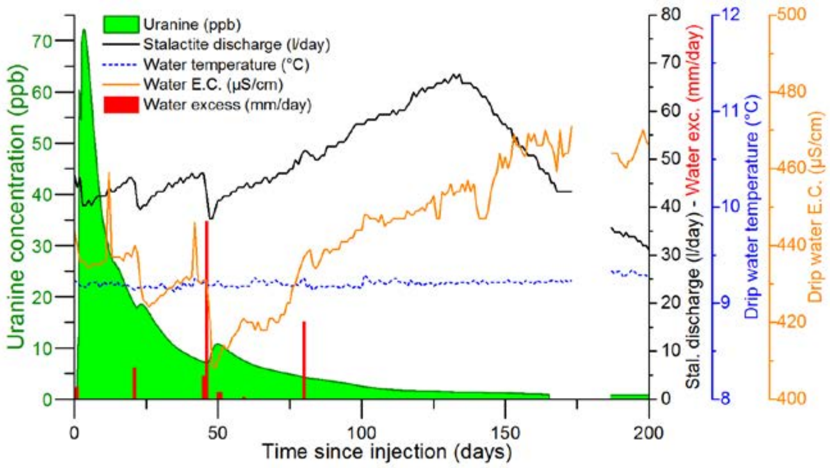

Figure 3: Surface-to-cave dye tracing above the Père Noël station of the Han-sur-Lesse cave. Monitoring has been performed with a GGUN field fluorometer (Poulain et al. 2015)

In the Rochefort Cave Laboratory, the drip-rate responds quickly to the surface precipitations. The decrease of drip rate after a rainfall event is quick. This indicate a less developed storage system that could feed the stalactites during dry periods. Analysis of the temperatures variations of water and surface air indicate a very fast damping of the water temperature during its fast transfert in the unsaturated zone. Nevertheless, daily variability is still observable, which confirms the fast transit of water in the vadose zone.

Surface-to-cave dye tracing show a very quick transit of water and an extended period of restitution, enhanced by infiltration that remobilizes uranine. This results indicates that a storage capacity is present and holds the water during long time periods. The release of uranine is slow, which indicate mixing processes inside the vadose zone.

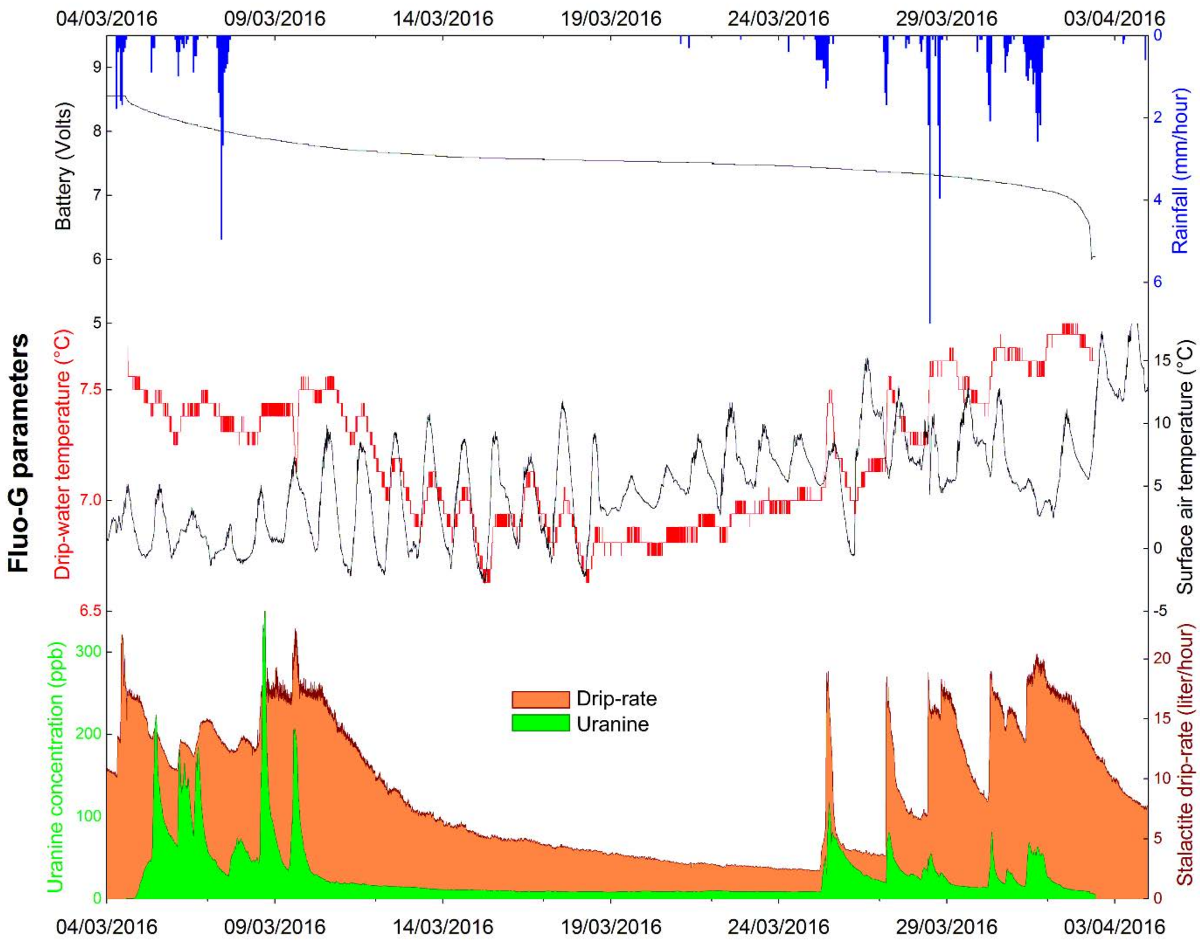

Figure 4: Drip-water monitoring and surface to cave dye tracing in the Rochefort cave laboratory.

Conclusions

Multidisciplinary project to assess vadose zone hydrology gives valuable results and allow a comprehensive approach of this research topic. Long term stalactite drip-water monitoring is the basis tool to highlight transfer and storage processes. Surface-to-cave dye tracing can bring valuable additional information regarding infiltration and transit dynamics. Such tracing experiment require long-term monitoring with adapted material. Stable isotopes are easy to measure and highlight the storage and mixing effect inside epikarst. This combined methodology bring local information that could be combined with integrative approaches such ERT and gravimetry in a further multi-scale study.

Poulain et al. (2015) Stalactite drip-water monitoring and tracer tests approach to assess hydrogeologic behavior of karst vadose zone: case study of Han-sur-Lesse (Belgium). Environ Earth Sci. DOI 10.1007/s12665-051-4696-9.