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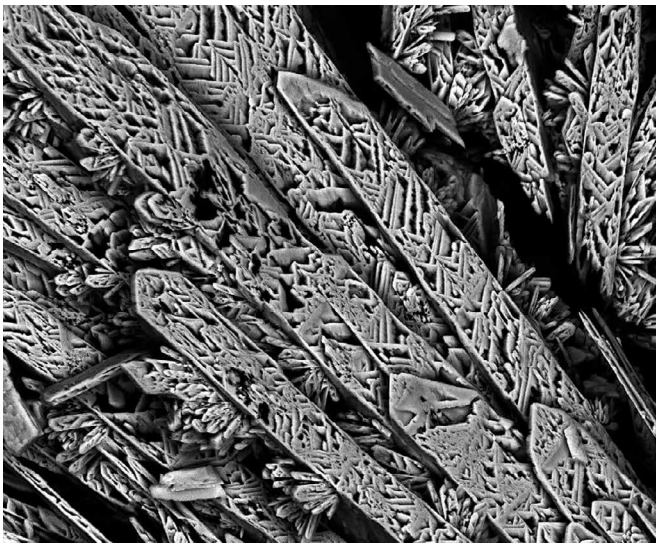

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# KARST HYDROGEOLOGICAL OBSERVATIONS IN CAO BANG PROVINCE (VIETNAM): THE TRA LINH-THANG HEN LAKE AREA

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In March 2012, the "Geokarst Adventure" Association under the auspices of the French Speleological Federation and the Romanian Speleological Federation along with the Vietnam Institute of Geoscience and Mineral Resource organized an expedition to explore the karst systems located in the Cao Bang Province, Northeastern Vietnam. The results include karst geological and hydrogeological observations and preliminary geochemical data based on 14 water samples. The values measured for the specific conductance are typical for caves waters (between 232.6 and 371 µS/cm). Total alkalinity as $CaCO_3$ ranges between 92.5 and 186 mg/l (gour 68), and the total hardness as $CaCO_3$ varies between 85 and 326 mg/l. The highest pH value (8.29), specific conductance (371 µS/cm) and concentration of calcium (97.93 mg/l) were recorded at Thang Hen Lake. The lowest temperature of 16.4 ºC, specific conductivity of 166.9 µS/cm, and total alkalinity as $CaCO_3$ of 68 mg/l were recorded in the water sample collected in the gour of Bang Ga T09 cave. The waters are calcium bicarbonate type. The local meteoric water line (LMWL) for the investigated region is $\delta D = 7.83\delta^{18}O + 14.694$ and shows a higher intercept and slope value than the global meteoric water line (GMWL), suggesting major changes in the origin of precipitation during the seasonal rain cycles.

## 1. Geographical Settings

The Socialist Republic of Vietnam is situated in the easternmost part of the Indochinese Peninsula (Fig. 1a). It covers a total area of 331,210 km$^2$ of which 40% is represented by mountains, mostly forested. Carbonate rocks are exposed over 60,000 km$^2$, representing 18.12% of countries' surface (Clements 2006).

The Province of Cao Bằng is located in the northeastern Vietnam, 270 kilometers from Hanoi, on the border with China. It has a surface of 6,724.6 km$^2$ and a population of 632,450 (Fig. 1a). The topography of the region is characterized by mountain ranges with elevation over 900 m above sea level (a.s.l.), and karstic plateaus developed between 500 and 700 m a.s.l. Tropical climate is characteristic to the area. The temperature varies from 5 °C in December and January to 37 °C in July and August.

The karst of northern Vietnam was extensively explored over the last 15 years and several cave exploration reports, karst geology and hydrology papers are available: Brouquisse (1998/1999), Holroyd and his team (2003, 2005, 2010), Limbert and his team (1999, 2007), Nyuyen Thi Thuy (2007) and Italian-French-Vietnamese Caving Project (2007).

## 2. Geology

The Cao Bang province is underlain by a variety of rocks ranging in age from Cambrian to Quaternary. The majority of the karst features identified in the field and water samples collected in March 2012 are hosted in the Bắc Sơn formation of Carboniferous–Permian age (C-P bs) which consists of siliceous shales, shaly limestones, and limestones. The limestone unit is up to 800 m thick. The Bac Son limestone is finely crystalline, light gray to dark gray. Bedding is generally 30 to 50 cm thick, oriented NW–SE, dipping 19º to 25º. Groundwater movement occurs along solutionally enlarged fractures, cavities, joints, and bedding planes. The area underlain by limestones is extensive. The topography consists of large poljes, surrounded by prominent limestones pinnacles and tower karst.

## 3. Karst hydrogeological observations in the Tra Linh – Thang Hen lake area

The Tra Linh – Thang Hen Lake area is formed by a sequence of poljes and karst windows developed along the Tran Linh River (Q ~400 l/s in March 2012). The limestone massifs are traverse by caves that carry rivers from one polje to the next. In some areas two levels of cave passages are developed, one as a stream passage at the present flood plain level, and a fossil one at 50 m relative altitude, marking a former flood plain level.

The Tra Linh River is collecting its waters a few kilometers north of the border with China. Fourteen km downstream, the river is disappearing underground at the base of a limestone massif, reappearing 500 m downstream in an underwater cave, which ends with a large spring. Hundred meters downstream from the cave entrance an 8 m high waterfall is formed. Downstream, the Tra Linh River is meandering through a large polje, covered with alluvial deposits, sinking for the second time in a cave/swallet, which is penetrable for about 100 m (Fig. 2). The end sump is clogged with alluvial deposits, trash and tree branches. The sump was not explored due concerns that flash flood waters moved unexploded ordinances from the Vietnam War era into the cave. One km north from the cave, a stream with a flow of about 10 l/s is disappearing underground through an impenetrable swallet.

The Tra Linh River continues the underground pathway, reappearing for about 100 m, in two separate karst windows (Karst Window 105 and Tra Linh Sinking Stream Ponor 107 on Fig. 1b), and later is recharging the Thang Hen Lake through a stream cave. The lake is a large swallet, located at the bottom of a polje, where the Tra Linh River is sinking underground for the fifth time, recharging the main spring located at 374 m elevation, 5 km away. In March 2012, the lake was about 300 m long and 150 wide. Around the lake several dry swallets were identified. The main spring, with a discharge of 200 l/s represents the partial outlet of the system. Along the river, additional groundwater sources recharge the stream. About 1 km downstream from the spring, the yield of the river reaches 1,000 l/s.

The type of the tower karst landscape develop along the Tra Linh River is "Residual Hills on a Planed Limestone Surface" (Ford and Williams 2007). During the raining season, the water level can rise up to 50 m in the area, the poljes mention above being flooded and interconnected, forming a large lake. A cross section along Tra Linh River, traversing tower karst landscape is shown in Figure 3.

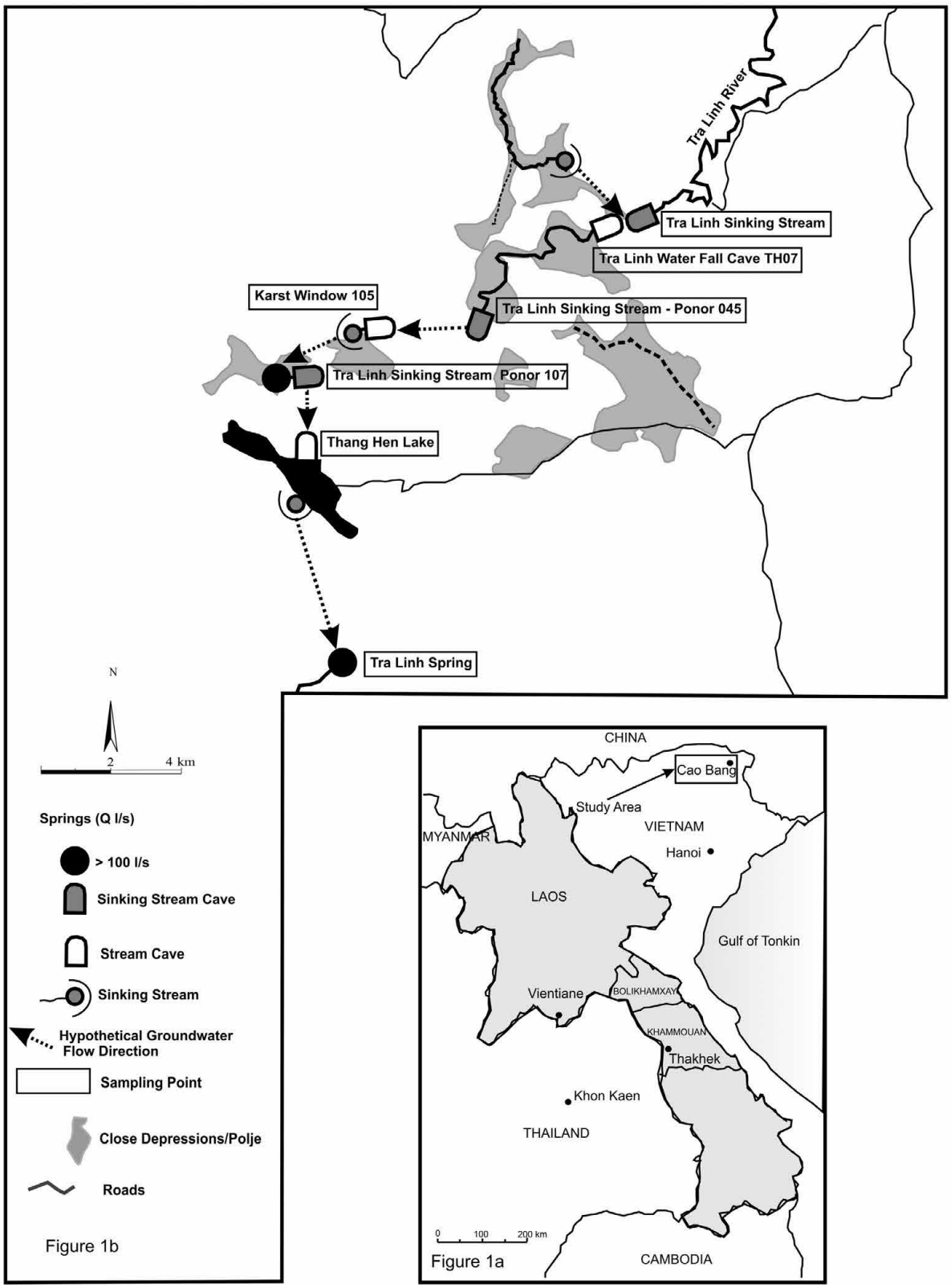


*Figure 1. Location of the study area within the Cao Bang Province in the northern part of Vietnam.*

*Figure 2. Polje along the Tra Linh River with a fossil cave marking the former flood plain level (Photo Gheorghe Ponta with Geokarst Adventure).*

## 4. Sampling and methods

Fourteen water samples were collected and analyzed from the following areas: Thang Hen Mountain Lake (7), Trung Han (2), Bao Lac (2), Bang Ga (2; one spring and one cave pool water), and one rain water sample. Only the seven sampling point in the Tra Linh – Thang Hen Lake area are shown on Figure 1b.

The water samples were analyzed for anions, metals, and stable isotopes. Field parameters, including temperature, pH, specific conductance, and salinity, were measured with an YSI 63 instrument. A digital titrator (Hach Model 16900) was used to determine alkalinity and total hardness as $CaCO_3$ and carbon dioxide in the field (Table 1).

Anion analyses were performed at the University of Alabama, whereas the metals and stable isotopes at the Department of Geology, University of South Florida. Anions were analyzed using a Dionex DX 600 Ion Chromatograph, trace metals analysis was achieved using a Perkin-Elmer Elan DRC II Quadrupole inductively coupled plasma mass spectrometer (ICP-MS) analytical instrument. Standards used were formulated stock standards with metals in concentrations from 1,000 mg/l to 10,000 mg/l. US EPA Test Methods 200.7 and 6010B were performed to complete the metals testing and analysis. The stable isotope analyses were conducted on a Thermo Fisher Scientific (Finnigan) Delta V Isotope Ratio Mass Spectrometer.

*Table 1. Field parameter data. 1: Trung Han cave system; 2: Bao Lac; 3: Thang Hen cave system; mean sea level (MSL).*

| Sample Name | Date | Time | Elevation | Discharge (Q) | ph | Temperature (T) | Specific Conductance | Salinity | Alkalinity as $CACO_3$ | Carbon Dioxide | Total Hardness as $CACO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | | m (MSL) | l/s | | °C | µS/cm | ppt | mg/l | mg/l | mg/l |
| [1/] Trung Han Spring 1 HQ 31 | 3/13/2012 | 13:50 | 475 | 100 | 7.54 | 21.70 | 352.30 | 0.20 | 156.00 | 115.60 | 326.00 |
| [1/] Trung Han Spring 2 HQ 32 | 3/13/2012 | 15:14 | 443 | 250 | 8.25 | 19.80 | 339.60 | 0.20 | 186.00 | 92.60 | 274.00 |
| [2/] Bao Lac HQ14 Spring | 3/15/2012 | 14:22 | 219 | 20 | 7.31 | 20.10 | 232.60 | 0.10 | 192.50 | 74.40 | 85.00 |
| [2/] Bao Lac Sump in Hang Kanh Xuan BL14 Cave | 3/15/2012 | 16:09 | 249 | 20 | 7.47 | 20.40 | 241.20 | 0.10 | 92.50 | 40.60 | 120.00 |
| [3/] Tra Linh Sinking Stream | 3/19/2012 | 15:45 | 643 | 400 | 7.76 | 23.50 | 279.40 | 0.10 | 119.00 | 32.40 | 147.00 |
| [3/] Tra Linh Water Fall Cave TH 07 | 3/18/2012 | 14:02 | 635 | 250 | 7.11 | 18.60 | 300.50 | 0.10 | 118.00 | 48.80 | 163.00 |
| [3/] Tra Linh Sinking Stream Ponor 045 | 3/18/2012 | 11:44 | 625 | 250 | 6.51 | 19.10 | 297.60 | 0.10 | 124.00 | 40.20 | |
| [3/] Karst Window 105 | 3/21/2012 | 14:47 | 603 | 300 | 7.73 | 21.60 | 296.60 | 0.10 | 131.00 | 45.60 | |
| [3/] Tra Linh Sinking Stream Ponor 107 | 3/21/2012 | 16:00 | 593 | 100 | 7.78 | 21.50 | 296.50 | 0.10 | 125.00 | 49.00 | 188.00 |
| [3/] Thang Hen Lake | 3/21/2012 | 11:11 | 590 | 400 | 8.29 | 20.60 | 371.00 | 0.20 | 168.00 | 42.60 | 151.00 |
| [3/] Tra Linh Spring | 3/19/2012 | 13:10 | 374 | 50 | 7.70 | 21.70 | 325.40 | 0.20 | 119.00 | 91.80 | 193.00 |
| Bang Ga Gour Cave TR 09 | 3/20/2012 | 14:46 | 698 | 0.0001 | 7.88 | 16.40 | 166.90 | 0.10 | 68.00 | 45.40 | 123.00 |
| Bang Ga 098 Spring TR 04 | 3/20/2012 | 17:24 | 602 | 5 | 7.20 | 20.40 | 318.70 | 0.20 | 136.00 | 74.00 | 273.00 |

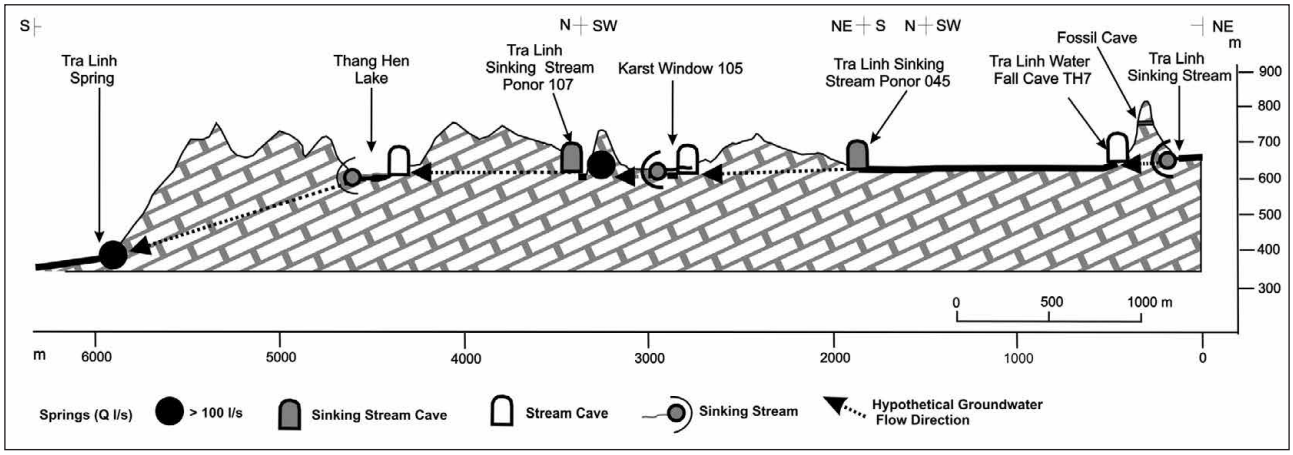


*Figure 3. Cross section along Tra Linh River, traversing tower karst landscape.*

## 5. Water quality data

Laboratory results for anions and cations are provided in Table 2. Sampling locations are shown on Figure 1b. The elevations of sampling points range between 219 m and 698 m. The estimated flow rates of the sampled springs range between 20 l/s and 400 l/s. The pH value ranges between 6.51 and 8.29, typical for karst waters. Temperatures ranged between 18.6 and 23.5 ºC, which correspond to mean annual air temperature in the area.

The values we measured for the specific conductance are typical for caves waters (between 232.6 and 371 µS/cm). Total alkalinity as $CaCO_3$ ranges between 92.5 and 186 mg/l (gour 68), and the total hardness as $CaCO_3$ varies between 85 and 326 mg/l.

Calcium concentration ranges between 48.60 and 97.94 mg/l, with the highest values at the Thang Hen Lake, whereas the magnesium concentration was found to fluctuate between 0.30 and 5.76 mg/l.

Carbon dioxide concentration ranges between 32.40 to 115.60 mg/l.

The highest pH value (8.29), specific conductance (371 µS/cm) and concentration of calcium (97.93 mg/l) were recorded at Thang Hen Lake.

The lowest temperature of 16.4 ºC, specific conductivity of 166.9 µS/cm, and Total Alkalinity as Ca $CO_3$ of 68 mg/l were recorded in the water sample collected in the gour of Bang Ga T09 Cave. The waters are bicarbonate calcium type.

## 6. Stable isotopes

Isotope fractionation accompanying evaporation from the ocean and condensation during atmospheric transport of water vapour causes spatial and temporal variations in the deuterium and $^{18}O$ composition of precipitation (Dansgaard 1964). Regional-scale processes such as water vapor transport patterns across landmasses and the average rainout history of the air masses precipitating at a given place controls the isotopic composition of local precipitation (Table 3).

*Table 2. Summary of the water quality data. 1: Trung Han cave system; 2: Bao Lac; 3: Thang Hen cave system. As, Cd, Cr, Zn, F, and Br were not detected.*

| | | | CATIONS (METALS) | | | | | | ANIONS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Date | Time | Total Calcium | Total Magnesium | Total Manganese | Total Potassium | Total Sodium | Total Strontium | Chloride | Nitrate | Phosphate | Sulfate |
| Units | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| [1] Trung Han Spring 1 HQ 31 | 3/13/2012 | 13:50 | 95.42 | 2.45 | 0.02 | 0.55 | 1.80 | 0.05 | 1.27 | 3.54 | 0.18 | 4.40 |
| [1] Trung Han Spring 2 HQ 32 | 3/13/2012 | 15:14 | 94.37 | 3.13 | 0.02 | 0.62 | 2.09 | 0.05 | 1.23 | 3.05 | 0.09 | 4.71 |
| [2] Bao Lac HQ14 Spring | 3/15/2012 | 14:22 | 57.02 | 4.25 | 0.00 | 0.59 | 2.98 | 0.08 | 0.73 | 3.64 | 0.02 | 4.92 |
| [2] Bao Lac Sump in Hang Kanh Xuan BL14 Cave | 3/15/2012 | 15:37 | 57.67 | 4.38 | 0.01 | 0.67 | 3.73 | 0.09 | 0.62 | 3.94 | 0.00 | 4.94 |
| [3] Tra Linh Sinking Stream | 3/19/2012 | 15:45 | 57.67 | 4.38 | 0.01 | 0.67 | 3.73 | 0.09 | 1.61 | 2.01 | 0.00 | 5.79 |
| [3] Tra Linh Water Fall Cave TH 07 | 3/18/2012 | 14:02 | 82.23 | 5.77 | 0.05 | 0.91 | 3.51 | 0.07 | 1.60 | 2.06 | 0.01 | 5.76 |
| [3] Tra Linh Sinking Stream Ponor 045 | 3/18/2012 | 11:44 | 75.31 | 5.35 | 0.05 | 0.97 | 3.28 | 0.07 | 1.61 | 2.79 | 0.01 | 5.76 |
| [3] Karst Window 105 | 3/21/2012 | 14:47 | 75.31 | 5.35 | 0.05 | 0.97 | 3.28 | 0.07 | 1.67 | 2.28 | 0.05 | 5.77 |
| [3] Tra Linh Sinking Stream Ponor 107 | 3/21/2012 | 16:00 | 48.60 | 0.30 | 0.00 | 0.18 | 1.70 | 0.02 | 1.64 | 2.56 | 0.01 | 5.82 |
| [3] Thang Hen Lake | 3/21/2012 | 11:11 | 97.94 | 1.15 | 0.01 | 0.42 | 1.89 | 0.06 | 1.70 | 2.77 | 0.03 | 5.88 |
| [3] Tra Linh Spring | 3/19/2012 | 13:10 | 86.87 | 5.76 | 0.37 | 1.07 | 3.78 | 0.08 | 1.48 | 3.21 | 0.00 | 5.61 |
| Bang Ga Gour Cave TR 09 | 3/20/2012 | 14:46 | 84.78 | 5.68 | 0.20 | 1.15 | 3.98 | 0.08 | 0.65 | 1.33 | 0.00 | 8.30 |
| Bang Ga 098 Spring TR 04 | 3/20/2012 | 17:08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.78 | 3.76 | 0.11 | 5.60 |

The $\delta^{18}O$ values of the water samples collected over 8 days ranged from -9 to -7.62‰. The δD values in the cave waters, springs, and rivers ranged from -55 to -42‰. The only rainfall sample collected on March 13, 2012 stands out with its very positive values for both $\delta^{18}O$ and δD (see Table 3).

The relationship between $^{18}O$ and $^{2}H$ in world's fresh surface / cave waters is predicted by the GMWL defined by Craig (1961) as:

$$\delta D = 8\delta^{18}O + 10 \text{ (‰)}.$$

The local meteoric water line (LMWL) for the investigated region is δD = 7.8359x + 14.694 and shows a higher intercept and slope value than the GMWL, suggesting major changes in the origin of precipitation during the seasonal rain cycles. Although we called LMWL, we are fully aware that the isotopic compositions undergoes variations on event-based and therefore, our LMWL solely reflects the conditions during those 8 days of sampling, therefore, the results need to be considered as preliminary and used with caution if comparisons with other regions or data sets are sought.

*Table 3. Summary of the stable isotope data. 1: Trung Han cave system; 2: Bao Lac; 3: Thang Hen cave system.*

| Sample | $\delta^{18}O$ (‰) | δD (‰) | *d*-excess (‰) |
|---|---|---|---|
| [1]Trung Han Spring 1HQ 31 | -7.86 | -49.12 | 13.74 |
| [1]Trung Han Spring 2HQ 32 | -7.78 | -46.19 | 16.06 |
| [2]Bao Lac Spring | -8.93 | -55.23 | 16.22 |
| [2]Bao Lac Sump in Hang Kanh Xuan Cave | -9.00 | -52.54 | 19.49 |
| [3]Tra Linh sinking stream | -7.76 | -45.34 | 16.73 |
| [3]Tra Linh Water Fall Cave TH 07 | -7.63 | -42.35 | 18.66 |
| [3]Tra Linh Sinking Stream Ponor 045 | -7.98 | -44.29 | 19.52 |
| [3]Karst Window 105 | -7.66 | -53.96 | 7.31 |
| [3]Tra Linh Sinking Stream Ponor 107 | -7.62 | -54.15 | 6.85 |
| [3]Thang Hen Lake | -7.71 | -48.51 | 13.16 |
| [3]Tra Linh Spring | -8.08 | -45.27 | 19.37 |
| Bang Ga gour | -8.39 | -42.49 | 24.60 |
| Bang Ga Spring T4 | -8.24 | -50.79 | 15.10 |
| Rain Water | 1.37 | 26.80 | 15.85 |

More samples of precipitation and fresh groundwater are needed to construct a real LMWL for this region, and to calculate the deuterium excess value, defined as:

$$d = \delta D - 8\delta^{18}O \text{ (‰)}.$$

This parameter is a valuable indicator of the source area of the water vapor. Values around +10‰ are typical for most continental meteoric waters, whereas values well above +10‰ suggest more evaporated moisture being added to the atmosphere (Rozanski et al. 1992).

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Topographic map of Na Khoang, 1:50,000.

Topographic map of Cao Bang, 1:50,000.