Carbon dioxide variability in Gong Cave, Pacitan Regency, Indonesia

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Abstract. Gong Cave is one of the karst caves in Pacitan Regency which is managed for show cave. This study aims to analyze the effect of tourist visit on the spatial variability of CO\textsubscript{2} levels. CO\textsubscript{2} measurement was conducted during low and peak season. Measurement was conducted in 23 sites starting from the entrance to the chamber along the tourist track. Spatial characteristics of CO\textsubscript{2} in the cave was analyzed by the interpolation method. The result shows that the CO\textsubscript{2} levels in the Gong cave higher in the cave inner chamber compared to the cave entrance, also the CO\textsubscript{2} levels increasing after passing a narrow passage.

1. Introduction
Java Island had several karst regions, one of them is Gunungsewu Karst Region located in the southern part of Java Island. Some karst caves are opened as an ecotourism destination. One of the famous show cave in the area is Gong Cave, located in Punung District, Pacitan Regency. Gong Cave has an attraction in the form of beautiful and exotic speleothem as shown in Figure 1. This speleothem growth process strongly influenced by the cave microclimatic condition [1]–[3].

The microclimate in the show cave draws cave specialist since the last nineteenth century [4]–[9]. Understanding cave CO\textsubscript{2} and cave microclimate are essential to figure out the cave carrying capacity [7]–[10]. Cave CO\textsubscript{2} is also one of the carbon fate in the karst carbon cycle, which is currently becoming a hot issue in the karst study [11], [12].

Gong Cave as a show cave is growing significantly, which is indicated by increasing numbers of visitors (Figure 2). Cave tourism had a very limited area and a minimal ventilation. Ventilation for air exchange in the cave only comes from the cave entrance and small gaps in the cave wall. The number of visitations usually will increase during the weekends or holidays (peak season). The activity of tourist visit inside the cave can change the condition of the cave's microclimate, such as increasing levels of CO\textsubscript{2} in the cave [6], [7]. The change of cave's microclimate conditions in the cave can affect the process of speleothem's growth, in certain conditions, the speleothem can become easily weathered [13], [14].

Research on the influence of visitors on air temperature and relative humidity has been preliminary carried out by Fandeli & Adji [15]. Accordingly, this study aims at determining Gong Cave microclimate in more detail, especially CO\textsubscript{2} levels. Understanding the variability and dynamics of cave CO\textsubscript{2} levels is essential because the growth rate of speleothem in caves is closely related to its CO\textsubscript{2} levels [16]–[18].
2. Study Area
The research conducted in Gong Cave, one of the karst caves in the Gunungsewu Karst Region. Gunungsewu Karst Region stretches for 85 km from Gunungkidul Regency (Daerah Istimewa Yogyakarta) to Pacitan Regency (East Java). Gunungsewu Karst Region is dominated by the conical hill, with around 40,000 karst hills. The coordinate of Gong Cave is 497,921.38 mE and 9,097,569.38 mS Zone 49L. Administratively, the location of Gong Cave is located in Bomo Village, Punung District, Pacitan Regency, East Java Province. The cave lies in the Wonosari Formation, which is formed by bedded limestone and reef limestone [19], [20]. The thickness of Wonosari Formation estimated to be more than 800 m [21]. The highest monthly rainfall ever recorded in 2017 was 674 mm/month in the rainy season [22].

The length of the cave is about 50 meters, with the total tourist track length of around 111 meters. The form of Gong Cave's entrance looks like an aisle with 2 meters width. Ten meters from the entrance there is a narrow passage, door-like pillars that dividing the entrance and the inner chamber of Gong Cave (Figure 3). The inner chamber of Gong Cave is quite large compared to its entrance passage, the inner chamber width is 20 meters in average, and the 15 meters high.

3. Materials and Methods
The CO₂ levels inside the cave are measured during the dry season. Measurements were made at 23 measurement sites (Figure 3) using portable Telaire 7001 CO₂ (factory calibrated) with a resolution of 1 ppm, and accuracy ±50 ppm or 5% reading. Measurements were taken at the low season with the number of visitors amounting 97 persons (8 August 2018) and 68 persons (9 August 2018), as well as during the peak season season/weekends with 393 visitors (18 August 2018) and 1,602 visitors (19 August 2018). The portable measuring instrument was placed about 1 meter above the cave floor. The measurement was conducted at two different time, i.e. 12 PM and 04 PM consecutively. Data processing is carried out with interpolation method to analyze the CO₂ spatial variability [13], [23], [24].
Figure 3. Map of Gong Cave (adapted from Fandeli & Adji [15]. Numbers indicate the measurement sites.

4. Results

4.1. Carbon Dioxide Spatial Variability in the Low Season
The spatial variability of CO$_2$ levels during low season are represented by measurements on 8-9 August 2018, shown in Figure 4. Measurements on 8 August showed the high CO$_2$ levels in the three cave sections: (1) around the measurement point 10 right after passing through the narrow passage between two pillars, (2) between the measurement points 14 to 16, (3) around the measurement point of 23. The three areas are in the cave's chamber, with the value above 8,800 ppm. The high CO$_2$ levels in the corner of the cave is likely due to the low air circulation, as at measurement point 10 is hindered
by some boulders. The area around the measurement points 14 to 16 is a narrow passage bounded by boulders and other speleothems. Measurement site 23 close to measurement 6 which is the meeting point between entering track and exit track tour in the inner chamber. The high CO$_2$ levels in this area is resulted from visitor’s accumulation. Measurements on 9 August showed higher CO$_2$ levels between measurement points 13-15 with the CO$_2$ levels above 9,000 ppm; this area is a narrow passage bounded by some boulders. The high concentration of CO$_2$ levels occurs in site measurement 17 to 23, which is

**Figure 4.** Carbon dioxide spatial variability in the low season
the final track of the cave tour. A similar trend also found in the during measurements on 8 August, with the higher CO\textsubscript{2} by 200 ppm on 9 August.

In general, CO\textsubscript{2} levels during the low season in the entrance are relatively low compared to the inner chamber of the cave. The CO\textsubscript{2} levels in the low season from entrance to the chamber can be formulated as a logarithmic function (Formula 1) with a $R^2$ value of 0.7924.

$$y = 446.72\ln(x) + 7314.8$$

The CO\textsubscript{2} levels increase from entrance to the 15 meters, and getting constant to the deepest tourist track (measurement point 16). The volume of the chamber is greater than the narrow passage entrance. The difference of air exchange capabilities may be the reason for the higher CO\textsubscript{2} levels in the cave chamber.

4.2. Carbon Dioxide Spatial Variability in the Peak Season
The spatial variability of CO\textsubscript{2} levels during peak season are represented by measurements on 18-19 August 2018, shown in Figure 5. Measurements on 18 August showed a trend of higher CO\textsubscript{2} levels starting at the measurement site 6, with the highest levels of 10,850 ppm. The number of visitors during the measurement in the cave was 393 visitors. The highest CO\textsubscript{2} levels is around the measurement sites of 13 to 15, with the highest level of 9,340 ppm. A similar case was also found in the low season, the area around measurement points of 13 to 15 with a narrow passage geometry. Measurements on 19 August showed that CO\textsubscript{2} levels in the chamber (started from the point 3) encountered 10,850 ppm, compared to that in the previous day which was 9,340 ppm. The number of visitors during the measurement was 1,602 people/day. The increasing value of CO\textsubscript{2} levels on 19 August was resulted from the higher number of visitors, compared to the previous day.

In general, CO\textsubscript{2} levels around the narrow passage entrance (points 1 to 3) are lower than CO\textsubscript{2} levels in the chamber of the cave. The CO\textsubscript{2} levels in peak season is stable after 20 meters from cave entrance. As shown at Figure 5, the CO\textsubscript{2} levels has a relationship with the distance from cave entrance with $R^2$ of 0.9281 and can be formulated (Formula 2) as:

$$y = 968.59\ln(x) + 6569.1$$

5. Discussion
The result shows that CO\textsubscript{2} level in the cave is affected by the number of visitors. The microclimatic condition, especially CO\textsubscript{2} levels in Gong Cave is considered at high levels. This high value of CO\textsubscript{2} levels rarely found in previous studies around Gunungsewu karst area. The maximum CO\textsubscript{2} levels in another famous show caves in this region (Baru Cave and Pindul Cave) is less than 2,400 ppm [8], also in the Gelatik Cave which has maximum CO\textsubscript{2} levels of 4,800 ppm [9]. The cave characteristic of Baru Cave and Gelatik Cave is similar to Gong Cave; the caves do not have any sinking stream.

In the other research from different countries are not higher than 6,000 ppm, as reported by [1], [5], [7], [23], [25]–[27]. However, several studies [28], [29] show very high CO\textsubscript{2} levels. The maximum value 40,000 to 60,000 ppm (4% to 6%). This difference of CO\textsubscript{2} levels between this area compared to the other studies that were carried may be due to the difference of cave morphology. In addition, measurements were taken in different season also possibly affect the cave CO\textsubscript{2} levels [1]–[3].

The CO\textsubscript{2} input in Gong Cave only take into account anthropogenic activities, and does not considered the input from other sources, such as soil and another living things/animal. The CO\textsubscript{2} input produced from soil also contributes to the dynamics of CO\textsubscript{2} levels in the cave atmosphere, but not as much as the anthropogenic sources [5], [30]. The larger and better ventilation rate usually related to low CO\textsubscript{2} levels in the cave atmosphere, because the CO\textsubscript{2}-rich air is easier to move out from the cave [18].

The tendency of CO\textsubscript{2} levels in the cave is higher in the inner chamber compared to the entrance passage, with a narrow passage as the divider. The other similar studies also confirmed that CO\textsubscript{2} levels increase after passing through a narrow passage or narrow hallway [23], [25], in this case of Gong Cave is the boundary between cave entrance and inner chamber. The capability of air exchange between entrance hallway and inner chamber can be different, the air exchange in the entrance hall is low because there are not many barriers for the outside air to exchange with the entrance hallway's air. The tendency
of high CO$_2$ levels in the chamber seems due to a lower ventilation rate compared to the entrance passage, but this study did not calculate the ventilation rate, therefore the relationship between CO$_2$ levels and ventilation rate in Gong Cave could not be confirmed yet.

![Carbon dioxide spatial variability in the peak season](image)

**Figure 5.** Carbon dioxide spatial variability in the peak season

The effects of CO$_2$ levels in the cave atmosphere in Gong Cave are not categorized as dangerous to visitors, but maybe can discomort the visitors. The limit of 8 hours CO$_2$ exposure that can be tolerated is 5,000 ppm [31], however visitors will only be in the cave for around 30 minutes to 1 hours. Once
there were visitors (child) who lost consciousness in Gong Cave during peak season, but the medical team stated that the incident was not only caused by the cave atmosphere, but also because of the poor health of the visitor (child). Effects of various CO₂ levels in atmosphere [32] described in Table 1.

Table 1. Effects of various CO₂ levels in atmosphere

| CO₂ Levels (ppm) | Effects                                      |
|------------------|----------------------------------------------|
| 5,000            | 8 hours indoor exposure limit [31]           |
| 20,000           | Increased respiratory rate                   |
| 50,000           | Dizziness, confusion, dyspnea                |
| 80,000           | Severe headache, dizziness, confusion, dyspnea |
| 100,000          | Loss consciousness                           |

6. Conclusions
Cave visitor affect significantly CO₂ level of the cave. The CO₂ level varies spatially from the entrance to the chamber. The measurement results during the low season and peak season showed that CO₂ levels were relatively higher in the cave chamber compared to the cave entrance narrow passage. The morphology of the cave entrance passage is narrower compared to the cave chamber, causing the increase of CO₂ levels after passing the narrow cave boundary and also in the other narrow passage inside the inner chamber. The difference between air exchange capability between cave chamber and cave entrance passage are the reason account for higher CO₂ levels in the cave chamber, but this study not measure and calculate the cave ventilation rate so the effect of ventilation rate in the Gong Cave could not be confirmed.

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