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Speleoclimate Monitoring to Assess Cave Tourism Capacity in Gelatik Cave, Gunungsewu Geopark, Indonesia

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Abstract. Increased of the number of visitor at Gelatik Cave is a challenge in terms of cave management. In natural conditions, Caves are vulnerable with environmental changes especially microclimates condition. The change of microclimate inside the cave can destruct cave ornaments.Therefore, it is necessary to calculate the cave carrying capacity with microclimates as the main parameter. This research aims to (1) explore the daily variation of speleoclimate in Gelatik Cave Tourism and (2) analyze the cave tourism capacity in Gelatik Cave. Microclimate parameter that was measured in this research was temperature, relative humidity, and carbon dioxide inside the cave. Measurement of microlimate parameter was carried out automatically for 24 hours during peak season in December 2017 and low season in May 2018. Cave tourism capacity was measured using Lobo method (Lobo, 2015). The results showed that temperature, relative humidity, and carbon dioxide in the Gelatik Cave va ry due to tourism activities. The most sensitive parameter is the carbon dioxide concentration inside the cave. The maximum of tourists allowed to visit Gelatik Cave is 76 visitors/day during holidays and working days. Meanwhile, the maximum time of stay accepted for a particular area inside Gelatik Cave is 17 minutes 10 seconds during weekdays and 12 minutes 53 seconds during the holiday season.

Keywords: Speleoclimate, Cave Tourism Capacity, Gelatik Cave.

Abstrak. *Peningkatan jumlah kunjungan di Gua Gelatik menjadi tantangan tersendiri dalam hal manajemen pengelolaan gua. Sifat alami gua yang rentan terhadap perubahan lingkungan utamanya iklim mikro perlu dipertimbangkan guna melestarikan bentukan ornamen gua. Oleh karena itu, perlu adanya perhitungan daya dukung dengan iklim mikro sebagai parameter utamanya. Tujuan dari penelitian ini untuk mengeksplorasi dinamika harian iklim mikro di Gua Gelatik dan menganalisis daya dukung wisata di Gua Gelatik itu sendiri. Data iklim mikro yang diukur yaitu suhu, kelembaban, dan karbondioksida di dalam gua. Pengukuran iklim mikro dilakukan secara otomatis selama 24 jam pada saat peak season di Bulan Desember 2017 dan saat low season di Bulan Mei 2018. Analisis daya dukung wisata gua menggunakan metode Lobo (2015). Hasil penelitian menunjukkan bahwa suhu, kelembaban, dan karbondioksida di Gua Gelatik mengalami variasi temporal harian yang disebabkan karena aktivitas wisata. Parameter yang paling senstitif terhadap perubahan lingkungan akibat aktivitas wisata yaitu kandungan karbondioksida gua. Jumlah wisatawan yang diperbolehkan untuk berkunjung di Gua Gelatik sebanyak 76 orang perhari pada saat liburan dan hari kerja. Sementara, lama waktu pengunjung diperbolehkan berhenti pada suatu titik di Gua Gelatik yaitu 17 menit 10 detik saat hari kerja dan 12 menit 53 detik saat musim liburan.*

Kata kunci: *Iklim Mikro Gua, Daya Dukung Wisata Gua, Gua Gelatik.*

1. Introduction

The cave is one of the unique and typical natural wealth possessed by karst landscape. The cave naturally formed from the solutional process by rainfall in the carbonate rocks (Ford and William, 2007). This solutional process will produce a distinctive structure in the cave passages such a cave micro-ornaments (speleothem) and/or underground river systems (Haryono and Adji, 2004). The unique structure that are found inside the cave makes this cave widely used for tourism, research and education activities (Cigna and Forti, 2013; Lerra, 2003).

Caves ecotourism was developed after the 1980s century since the changing international tourism paradigm. The existence of the changing international tourism paradigm made the ecotourism concept more developed (Setiawan et al., 2017). Ecotourism is a form of tourism that is oriented towards environmental sustainability so that it provides economic benefits and maintains the cultural integrity of the local community (Fandelli and Mukhlison, 2000; Hayati, 2010). The natural and cultural landscape beauty are a primary attractiveness object of the ecotourism concept. One of object that has a beautiful natural landscape is the cave.

After developed in 1980's century, the number of cave visitors has increased until 1,000,000 visitors per year at show caves in Asia, Europe and North America (Cigna and Burri, 2000; Lobo et al., 2015). Similar to Asia, Europe, and North America, cave tourism in Indonesia was developed and also increased on the number of visitors. The number of visitors in Indonesia cave tourism such as Pindul Cave has increased 60% per year (Putra et al., 2017). The other cave tourism in Indonesia that has rapidly increased visitors is Gelatik Cave.

Gelatik Cave is a horizontal cave located in the Gunungsewu Geopark, Gunungkidul Regency. This cave has a narrow horizontal passage with various forms of cave ornaments. Gelatik Cave only has one cave entrance for in and out access. The air circulation inside the cave is only through the cave entrance. The primary attraction of Gelatik Cave is exploring the natural beauty of cave ornaments. Gelatik Cave becomes a part of Pindul Cave tourism area which provides as a supporting object of the main tourist attraction object, called Pindul Cave. The rapid increased of visitor numbers in the Pindul Cave area, affect the number of visitors in Gelatik Cave.

The impact of increasing visitors in Gelatik Cave has a positive and negative value. The positive value is the increasing of the total amount of revenue from the tourism sector in Gunungkidul Regency, while the negative value is an environmental change due to tourism activities. The number of visitors who enter simultaneously in the cave can change the microclimate condition so it can interfere with the quality of cave ornaments (de Freitas, 2010). Cave tourism activities can change the condition of temperature, relative humidity, and carbon dioxide concentration, thus trigger weathering in cave ornaments.

In natural condition, cave microclimate has relatively stable values, especially in closed cave types. Changing in cave microclimate occur because the intervention of human activities inside the cave (de Freitas, 2010). Tourism activities probably decrease relative humidity; increase cave temperature, and increase cave carbon dioxide concentration (Linhua et al., 2000; Fandeli and Adji, 2005; Lario and Soler, 2010; Sebela et al., 2012; Lobo et al., 2015, Lobo, 2015). The cave temperature can increase during relative humidity decreases due to cave lighting and accumulation of body heat. Increased cave carbon dioxide is caused by an accumulation of carbon dioxide emissions from visitors' breathing (Russell and MacLean, 2008; Lario and Soler, 2010).

Changing speleoclimate conditions in cave tourism needs to be monitored regularly as a basis for consideration of cave tourism management. Cave tourism management needs to be done in order to maintain the cave environmental sustainability and the comfort of visitors while traveling inside the cave. The form of cave tourism management can be done by limiting the number of visitors. Limiting the number of visitors can be based on safe limits of cave microclimate changing for human activities and cave environment (Calaforra et al., 2003; Cigna, 2004; de Freitas, 2010; Lobo et al., 2010). This concept is known as the cave tourism capacity. In Indonesia especially Gelatik Cave, cave carrying capacity was measured using Cifuentes method based on minimum area that can be used to tourism activity. Calculation of cave carrying capacity based on environmental change inside the cave has not been done. Therefore, routine monitoring of cave microclimate as a basis for calculating the cave carrying capacity needs to be done in Gelatik Cave.

Speleoclimate routine monitoring to determine the cave carrying capacity in Gelatik Cave can be done by measuring cave microclimate in peak and low season (Sebela and Turk, 2014a; Luetscher and Jeannin, 2004). Monitoring conditions in peak and low season intend to find out the ability of Gelatik Cave to recover speleoclimate conditions after tourism activities. The total recovery time will be used as the basis for determining the daily limit visitation inside the Gelatik Cave. In addition, this monitoring procedure can be used to identify trends in speleoclimate changing naturally and with an intervention of human activities. This research aims to (1) explore the daily variation of speleoclimate in Gelatik Cave Tourism and (2) analyze the cave tourism capacity in Gelatik Cave.

2. Research Method

2.1. Study Area

This research was conducted in Gelatik Cave that located in Gunungsewu Geopark, Gunungsewu Regency, D.I. Yogyakarta Province at 49M 461218 mT 9123765 mU. Gelatik Cave is dominated by a horizontal passage that allows for a cave tracing. The direction of the Gelatik Cave passage goes northeast with an elevation of ± 169 meters above sea level. The total length of Gelatik Cave passage is 54.23 meters. For more detail information about Gelatik Cave morphometry is presented in Figure 1.

Gelatik Cave include as the dry cave which there is no underground river inside the cave. The characteristic of Gelatik Cave has a narrow passage near the cave entrance and a large chamber at the end of cave hall. Gelatik Cave has one cave entrance which can be used as the only access in and out of this cave. This condition makes the flowing of air circulation in the Gelatik Cave more closed.

Gelatik Cave is an active cave because there are still water droplets from the stalactites. Some ornaments that can be found in the Gelatik Cave are stalactites, stalagmites, and pillars. The cave floor in Gelatik Cave is mud deposits with no additional construction inside the cave. Constructions such as floor hardening, lights installation, or a ladder of tracing lines are not found in the Gelatik Cave. The natural condition of Gelatik Cave is intentionally maintained to target tourists who want to explore natural caves.

2.2. Data Collection and Analysis

a. Data Collection

Data that were collected in this research is a primary and secondary data. Primary data for this research are the cave microclimate which consists of temperature, relative humidity, and carbon dioxide concentration. Other data that were collected is the number of visitors in Gelatik Cave. Cave microclimate parameters and the number of visitors were carried out directly in the field. The cave microclimate parameters were measured six times during peak season in December 2017 and low season in May 2018. Measurement of speleoclimate parameters was carried out inside the cave near the “Soko Guru” which tourists spend a lot of time in this place (see Figure 1). All of microclimate parameters were measured for 24 hours to determine the daily variation of speleoclimate.

Temperature and relative humidity were measured and recorded automatically using Hobo U12-013 every 15 minutes. Carbon dioxide concentration inside the cave was measured using the Hobo U12-013 and Telaire 7001 CO_2 Sensors every 15 minutes. The number of visitors was measured using the hand counter at the Gelatik Cave entrance every 15 minutes.

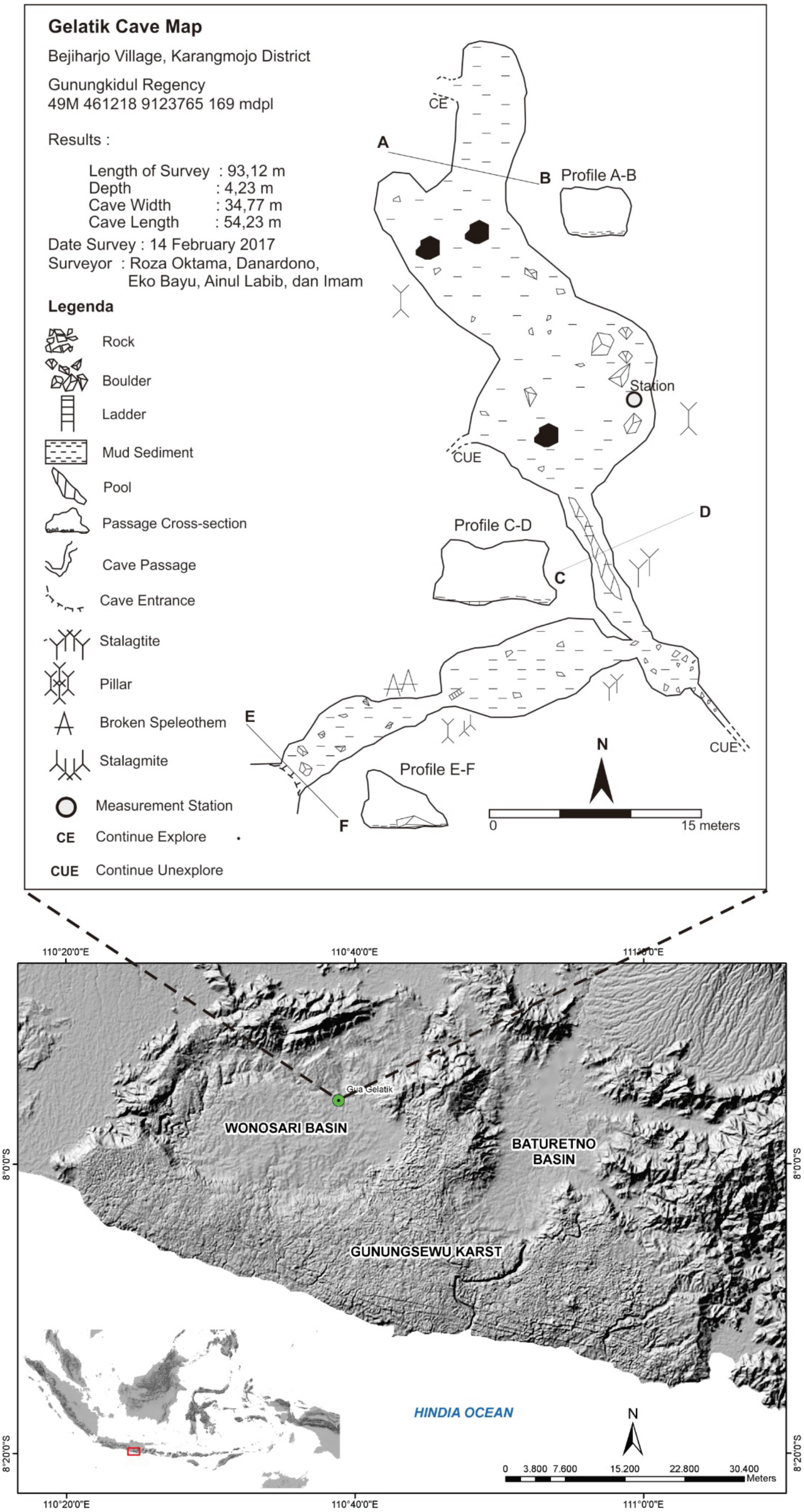

Figure 1. The map of Gelatik Cave.

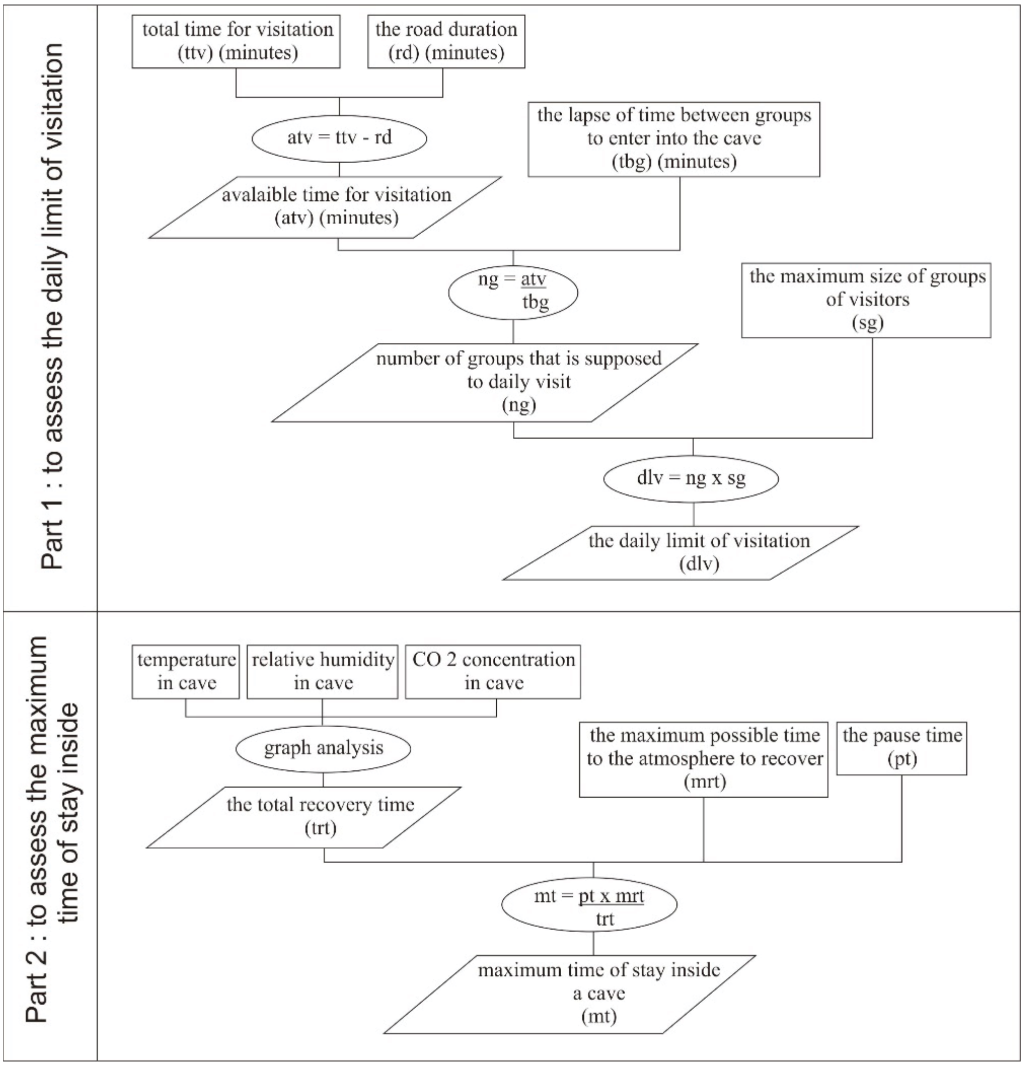

Figure 2. Flowchart process to identify cave tourism capacity

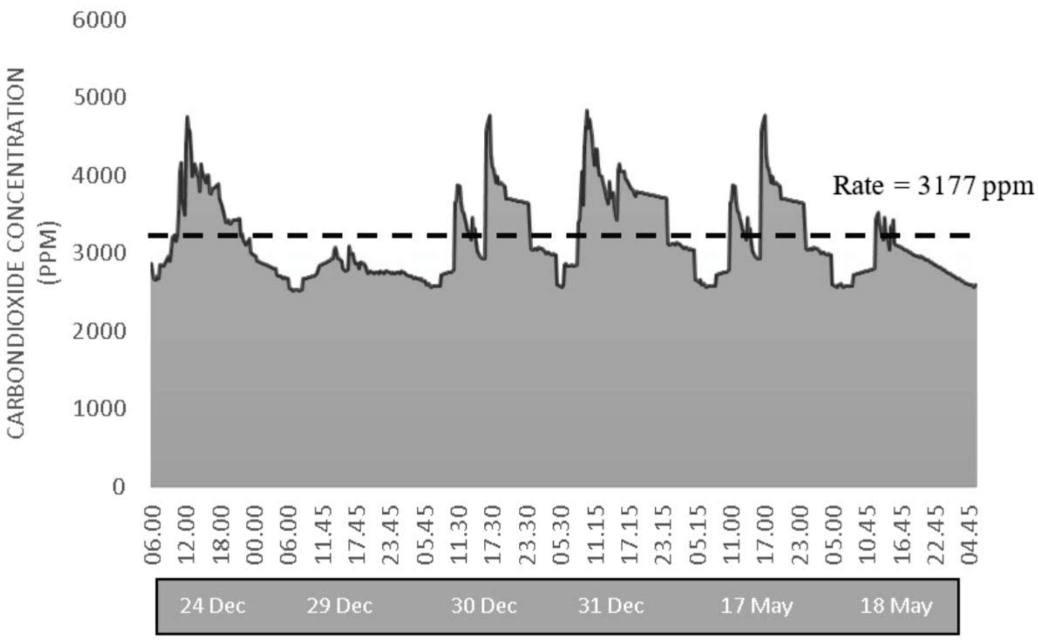

Figure 3. Daily variation of carbon dioxide concentration in Gelatik Cave.

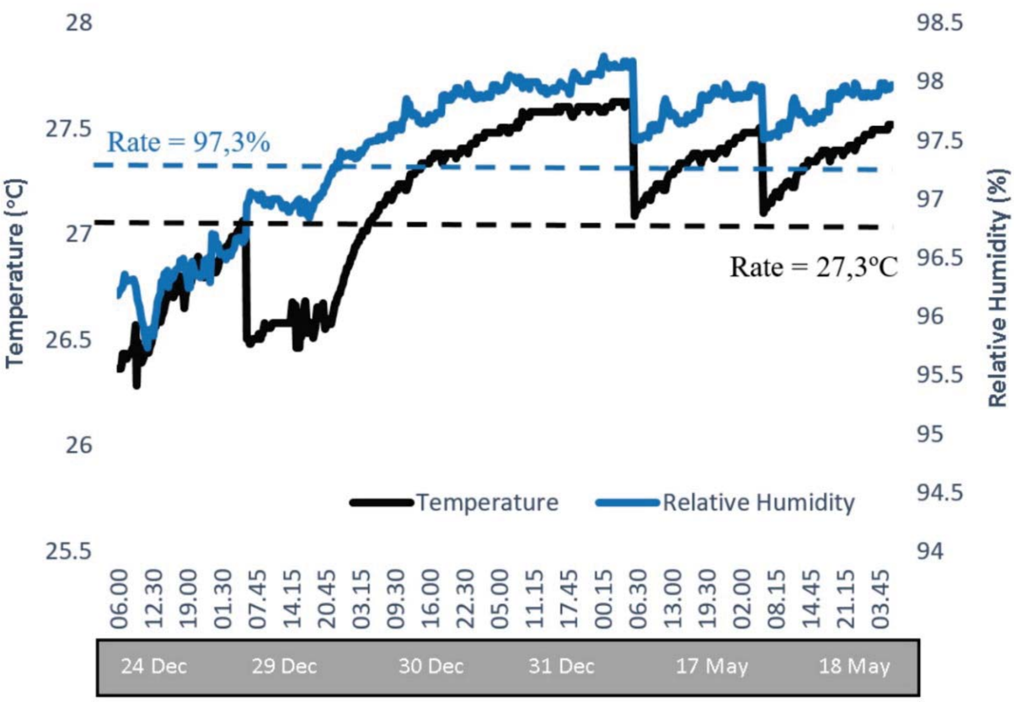

Figure 4. Daily variation of temperature and relative humidity in Gelatik Cave.

Table 1. Statisticv of speleoclimate in Gelatik Cave.

	Temperature (Celcius)	Relative Humidity (%)	CO_2 Concentration (ppm)
Lowest Value	26.2	95.7	2516
Highest Value	27.6	98.2	4830
Mean	27.1	97.4	3177

Table 2. Total recovery time in Gelatik Cave.

Date	Season	CO_2 before Tourism Activity (ppm)	Peak Time	Total Tourist	Closed Time	Stabilization Time	Total Recovery Time (minutes)
24-Dec-16	peak season	2790	12:00	34	14:00	03:45	825
29-Dec-16	low season	2696	16:30	7	17:00	02:45	525
30-Dec-16	peak season	2667	16:30	33	17:30	04:30	660
31-Dec-16	peak season	2847	10:00	37	16:00	05:00	720
17-May-17	low season	2667	11:00	14	17:30	04:45	675
18-May-17	low season	2694	12:30	14	16:00	02:15	615

Secondary data that needed in the research are the total time for visitation (difference between opening and closing hours) (atv), the route duration (rd), the lapse of time between groups to enter into the cave's tourist route (tbg), the initial hypothesis of the projected visitation scenario was complemented with the size of visitors' groups (sg). This data was obtained from the institutional data owned by the manager of Gelatik Cave tour.

b. Data Analysis

The dynamics of microclimate inside the cave was analyzed by graph pattern. Graph pattern analysis was carried out to find the daily changes in speleoclimate. In addition, this analysis was also used to determine the effect of tourism activities on speleoclimate.

Cave carrying capacity was analyzed by the method developed by Lobo (2015). This method was developed to determine the cave carrying capacity with speleoclimate data. Cave carrying capacity of Lobo (2015) was based on the ability of cave to restore speleoclimate on normal conditions. Outputs of cave carrying capacity were the daily limit visitation and the maximum time of stay inside accepted for a particular area inside the cave. The procedure for analyzing the cave carrying capacity is shown in Figure 2.

3. Results and Discussion

3.1. Results

a. Temporal Variation of Cave Microclimate

The cave microclimate parameters that measured in Gelatik Cave were temperature, relative humidity, and carbon dioxide concentration. These parameters were measured for six days with three days during peak season and three days during low season. Peak season was measured during weekends or long holidays, while low season was measured during weekdays.

Measurement results for all cave microclimate parameters show daily temporal variations. Speleoclimate parameter that has a high variation is carbon dioxide concentration. Cave carbon dioxide has increasing trend in the morning at 09.00AM until the afternoon at 06.00PM (when the cave tourism activities are opened). This carbon dioxide value will go back down at late night at 02.00PM. Cave carbon dioxide variation inside the Gelatik Cave can be seen in Figure 3. Based on Figure 3, the average value of carbon dioxide concentration in Gelatik Cave is 3177 ppm. The highest value of carbon dioxide in the Gelatik Cave occurs at 02.00PM with the concentration value of 4830 ppm. The lowest value occurs at 06.00AM with the concentration value of 2516 ppm.

The difference with cave carbon dioxide, temperature and relative humidity inside Gelatik Cave don't show a high variation range. Temperature and relative humidity changes only ranged between 0,8°C for air temperature and 1% for air humidity during observation. The value of temperature and relative humidity is relatively stable compared with carbon dioxide concentration. The variation of temperature and relative humidity in the Gelatik Cave can be seen in Figure 4.

Temperature in Gelatik Cave shows daily temporal variation that is increased in the morning at 09.00AM until the evening at 07.00AM. This value will be decreased again until reached the normal value before raising. The average value of temperature inside Gelatik Cave is 27,2°C. The highest temperature occurs at 01.00PM with the value of 27,6°C, while the lowest temperature occurs at 02.00AM with the value of 26,3°C.

Based on Figure 4, relative humidity in the Gelatik Cave shows daily temporal variation. In the morning until evening, relative humidity in Gelatik Cave increased because of temperature increases. The relative humidity will increase again in the night during the decreasing of temperature. The average value of relative humidity in Gelatik Cave is 97,3%. The highest relative humidity in the Gelatik Cave occurs at 2:00 AM of 98,2%, while the lowest relative humidity occurs at 3:00 PM of 95,7%. Statistic of Speleoclimate in Gelatik Cave is shown in Table 1.

b. Total Recovery Time

The total recovery time (trt) is the time needed by cave to restore microclimate on normal conditions. This parameter was used to determine the cave tourism capacity or cave carrying capacity. Not all speleoclimate parameters will be calculated, the calculation was conducted only for the parameters that have high variation and the most influential to the visitors' comfort for tourism activity. The total recovery time is calculated when the microclimate reach the maximum value until that value returns to normal condition. Speleoclimate parameter that was used to assess the total recovery time is carbon dioxide concentration because this parameter has a daily high variation.

The total recovery time in the Gelatik Cave vary for each season. The longest climate recovery time occurs in peak season or holiday. The total recovery time in peak or holiday season is 825 minutes or 13 hours 45 minutes. The total recovery time during peak season can be used to describe the time of speleoclimate recovery when there is a tourist activity inside Gelatik Cave. During low season, the total recovery time in Gelatik Cave has a low value. The total recovery time is about 525 minutes or 8 hours 45 minutes. The value of total recovery time at low season can be used to describe the natural ability of Gelatik Cave to restore speleoclimatic conditions. The difference in the total recovery time when peak and low season occurs because of differences in the maximum value of carbon dioxide in the two seasons. During peak season the maximum value of the carbon dioxide in the Gelatik Cave has a higher value than the maximum value of carbon dioxide during low season. The results of the total recovery time based on carbon dioxide concentration in Gelatik Cave can be seen in Table 2.

The average value of total recovery time in Gelatik Cave is 670 minutes or 11 hours 10 minutes. This value can be used as a consideration for the closing hours of tourism activity in Gelatik Cave thus the next day can be reused for tourism with the normal condition of carbon dioxide concentration. In addition, the total recovery time is one of the parameters to calculate the limitation of visitors in the Gelatik Cave.

c. Cave Tourism Capacity

Cave tourism capacity is calculated to determine the maximum value of visitors allowed to travel inside the cave so that the sustainability of the cave is maintained. Cave tourism capacity was measured using the method developed by Lobo (2015). The calculation of cave tourism capacity uses four analysis stages, namely 1) calculation of available time for visitation (atv); 2) calculation of the number of groups that are supposed to daily visit the cave (ng); 3) calculation of the daily limit of visitation (dlv); and 4) calculation of the maximum possible time to the cave atmosphere to recover(mt).

The calculation result of cave tourism capacity in Gelatik Cave is presented in Table 3. Based on the calculation of cave tourism capacity, the number of visitors allowed to tour in Gelatik Cave is 76 visitors per day. This value can be used as a benchmark for determining the daily limit visitation to maintain the preservation of Gelatik Cave. The daily limit of visitation in Gelatik Cave between low and peak season has the same value. The difference in cave tourism capacity during low and peak seasons is at the maximum time for each visitor stopped at a point in the Gelatik Cave. During peak season, the maximum time for visitors to stop at a point in the Gelatik Cave is 12 minutes 53 seconds. In low season, the maximum time of stay accepted for each visitor is 17 minutes 10 seconds. This condition happens because of the different time needed by the cave to restore microclimate conditions during low and peak seasons. The results of the maximum time of stay accepted for each visitor in Gelatik Cave is presented in Table 4.

3.2. Discussion

The microclimate condition in Gelatik Cave has the unique characteristics. Microclimate characteristics in Gelatik Cave have a relatively stable temperature with an average value of 27,1°C and relative humidity of 97,4%. The microclimate in Gelatik Cave has different values compared with the climate outside the cave (Bogli, 1980). Temperature and relative humidity inside the cave have a relatively high average value compared with climate conditions outside the cave.

Based on Heat and Discomfort Index (Euroweather, 2005), the natural conditions of microclimate in Gelatik Cave has the discomfort index in a range of 40-41 (See Figure 5). The disconformity index in Gelatik Cave has a higher value compared with the tourist comfort index criteria so most visitors can feel discomfort and deterioration of psychophysical conditions. Based on this disconformity index, we can know that Gelatik Cave is not convenient for tourism activities. This condition needs to be a concern because the cave microclimate condition has a fairly high variation value, especially in caves that are used for tourism activities (Cigna and Forti, 1986; Pflitsch and Piasecki, 2003; Luetscher and Jeannin, 2004).

Table 3. Cave tourism capacity in Gelatik Cave.

Cave	ttv (minutes)	rd (minutes)	atv (minutes)	tbg (minutes)	ng (group)	sg (person)	dlv (person)
Gelatik	600	30	570	60	9.5	8	76

Table 4. The maximum time of stay accepted for a particular area (mt) inside Gelatik Cave.

Season	Closed Time	Stabilization Time	Total Recovery Time (trt) (minutes)	Pause Time in Cave (pt) (minutes)	Maximum Possible Time to Atmosphere to Recover (mrt) (minutes)	Maximum Time of Stay Accepted (mt) (minutes)
low season	17.00	02.45	525	10	900	17,14
peak season	17.30	04.45	675	10	870	12,89

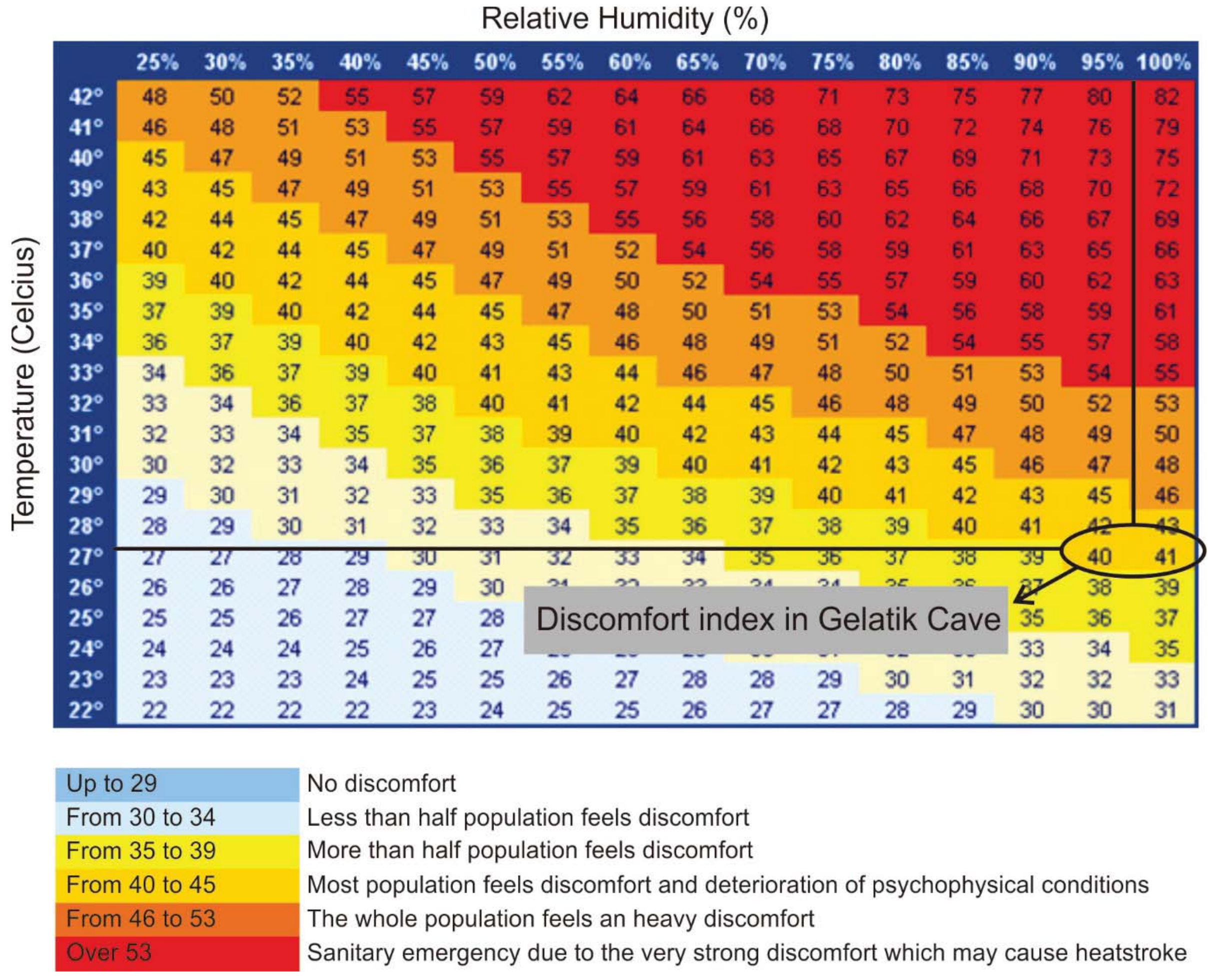

Figure 5. Classification of Heat and Discomfort Index in Gelatik Cave

Gelatik Cave microclimate shows a daily high variation value, especially the cave carbon dioxide concentration. Increasing microclimate in Gelatik Cave occurs in the morning until the evening then falls back at night. The value of cave microclimate increases in the morning until evening due to tourism activities in Gelatik Cave. This condition is in accordance with the research which conducted in Baiyun Cave, China (Linhua et al., 2000); Pozalagoa Cave, Spain (Lario and Soler, 2010); Postojna Cave, Slovenia (Sebela et al., 2014a); and Santana Cave, Brazil (Lobo et al., 2015; Lobo, 2015). The microclimate in Gelatik Cave has increased during the number of tourists raised and will come back down after tourism activities in

Gelatik Cave are closed. The maximum value of each microclimate parameters occurs when a large number of tourists are in the Gelatik Cave. The trend of microclimate change in Gelatik Cave compared with the number of tourists can be seen in Figure 6.

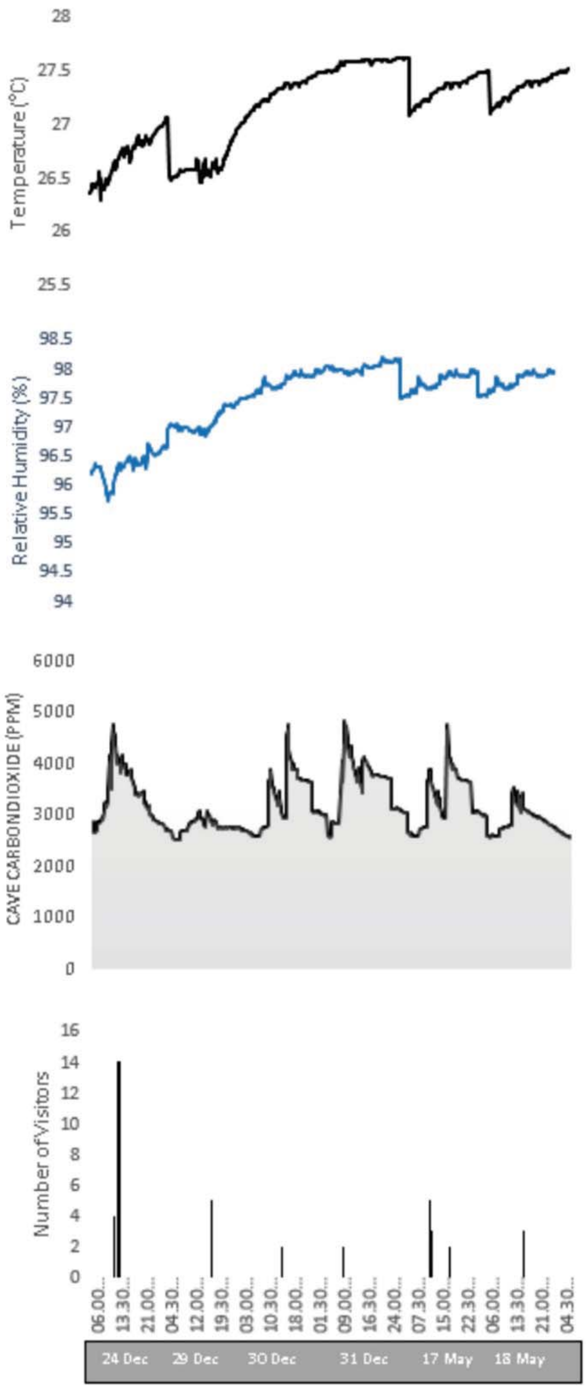

Figure 6. Speleoclimate Variation in Gelatik Cave

Based on Figure 6, it can be seen that not all microclimate parameters are sensitive to environmental changes due to tourism activities. Gelatik Cave microclimate parameter which is the most sensitive to the cave tourism activities is carbon dioxide concentration. Carbon dioxide concentration has an increased value up to 508 ppm when Gelatik Cave is used for tourism activities. Raised cave carbon dioxide concentration is caused by the accumulation of carbon dioxide emissions from visitors breathing (Lario and Soler, 2010; de Freitas, 2010). Cave carbon dioxide in Gelatik Cave has a high raising value compared with Pindul and Baru Cave, Indonesia (Putra et al., 2017); Santana Cave, Brazil (Lobo, 2015); Balcarka Cave, Slovenia (Lang et al., 2015) (See Table 5). This condition happens due to the differences characteristics of the Gelatik Cave with other caves. Gelatik Cave which has a narrow passage and one air circulation through the cave entrance makes the process of exchanging air inside and outside the cave last longer. The lack of air circulation in the Gelatik Cave causing human respiratory gas emissions accumulate inside the cave.

Gelatik Cave temperature doesn't have a high range of variation. The existence of tourism activities in the cave can increase the cave temperature, but the raised of cave temperature is only 0,03^{o}C. Temperature in the Gelatik Cave is relatively stable due to the absence of factors that can changes temperature inside the cave. This condition is different with other research in Pindul and Baru Cave, Indonesia (Putra et al., 2017); and Santana Cave, Brazil (Lobo, 2015) which there is a significant change in air temperature when tourism activities are opened. This difference condition is caused by the absence of additional infrastructure such as lighting lamps in Gelatik Cave. The presence of lighting lamps and human heat body inside the cave can increase cave temperature (de Freitas, 2010). The lighting is intentionally not installed due to the tourism concept offered by Gelatik Cave. This cave is offered cave adventure with the main attraction of cave natural beauty.

Table 5. Comparison of speleoclimate value in Gelatik with other caves.

	Gelatik Cave	Pindul Cave	Baru Cave	Santana Cave
The rate of temperature (°C)	27,1	27,1	26,5	19,3
Confirmed human impact on temperature	+0,035	+0,125	+0,028	+1,101
The rate of relative humidity (%)	97,4	93,5	97,8	99,9
Confirmed human impact on relative humidity	+0,14	-0,54	-0,17	-
The rate of cave CO_2 (ppm)	3177,3	625,3	921,3	1091,7
Confirmed human impact on CO_2 cave	+508,2	+146,9	+111,1	+160,0

Relative humidity in Gelatik Cave doesn't show high variations due to tourism activities. Tourism activities can increase relative humidity only 0,14%. This condition is different from other research in Pindul and Baru Cave, Indonesia (Putra et al., 2017); and Santana Cave, Brazil (Lobo, 2015). The absence of significant changes in Gelatik Cave humidity due to the absence of human activity that can change the cave environmental conditions. Based on previous studies, change in cave relative humidity can occur due to the used of fire as lighting inside the cave (Lobo, 2015).

Changed the cave microclimate that occurs due to tourism activities need to get serious attention, especially in carbon dioxide concentration. Increasing carbon dioxide concentration in the Gelatik Cave can threaten cave ornaments/ speleothem. The accumulation of visitor's breathing can combine with air in cave atmosphere so it can corrode speleothem and stones in the Gelatik Cave (Cigna, 2004; Russell and MacLean, 2008; de Freitas, 2010). This condition makes it necessary to calculate the cave carrying capacity to maintain resource sustainability in the Gelatik Cave. The carrying capacity for cave tourism is calculated to limit the number and time of daily visiting visitors in Gelatik Cave (Cigna and Forti, 2013; Hoyos et al., 1998).

The calculation results of the cave tourism capacity in Gelatik Cave indicate that the number of tourists allowed is 76 people per day. Maximum time of visitors in the cave is limited of 17 minutes 10 seconds during weekdays and 12 minutes 53 seconds during holidays. The cave tourism capacity in Gelatik Cave is different with the cave tourism capacity in Pindul and Baru Cave, Indonesia (Putra et al., 2017); Santana Cave, Brazil (Lobo, 2015); and Balcarka Cave, Slovenia (Lang et al., 2015). The difference in carrying capacity is due to differences in the ability of each cave to restore cave microclimate conditions (Calaforra et al., 2003; Fernandez-Cortes et al., 2006; Hoyos et al., 1998; Sanchez-Moral et al., 1999) The total recovery time of microclimate (trt) in Gelatik Cave has a higher value than Pindul and Baru Cave, Indonesia (Putra et al., 2017); Santana Cave, Brazil (Lobo, 2015); Balcarka Cave, Slovenia (Lang et al., 2015). Therefore, the number of visitors who can enter Gelatik Cave is also relatively small to maintain the cave environment sustainability and comfort of visitors.

The cave carrying capacity in the Gelatik Cave can be used to determine the fragility of this cave. Heaton (1986) explains that there are three cave categories based on their vulnerability, namely the high energy cave, intermediate cave, and low energy cave. The cave that has greater energy will have a low level of cave fragility and vice versa. Based on the calculation of cave carrying capacity, Gelatik Cave is categorized as low energy cave. This measurement result shows that Gelatik Cave is very vulnerable and easily damaged due to changes in the cave environment (Heaton, 1986; Ford and William, 2007). The low ability of Gelatik Cave to restore speleoclimate conditions causes the cave carrying capacity for tourism activities inside the cave is also relatively small and vulnerable to damage. Therefore, the tourism management in Gelatik Cave needs to consider the policy of limiting number and duration of visitors in the Gelatik Cave.

4. Conclusion

Speleoclimates that consists of temperature, relative humidity, and carbon dioxide in Gelatik Cave are increased during the day and will decrease during the night. Increased value of speleoclimate during the day is caused by tourist activity inside the Gelatik Cave. Speleoclimate parameter that is very sensitive with human activities is cave carbon dioxide. The value of carbon dioxide increased significantly by 508 ppm when Gelatik Cave was opened for tourism activity. Accumulation of carbon dioxide from tourist respiratory gas is a major factor of increasing cave carbon dioxide. The effect of cave passage morphology on the microclimate variation can't be known certainty because this measurement is only carried out at one location. For further research, speleoclimate measurement in several location inside Gelatik Cave needs to be done to determine the impact of cave passage morphology on speleoclimate.

Increased carbon dioxide inside the Gelatik Cave needs to be controlled to keep tourists comfortable. One of the management practices that can be used to control carbon dioxide concentration is limiting the number of tourists and the maximum time of stay accepted in particular area inside the Gelatik Cave. The daily maximum tourists allowed to visit the Gelatik Cave is 76 visitors per day either on holidays or weekdays. The maximum time of stay accepted in a particular area inside the Gelatik Cave during the holidays is 12 minutes 53 seconds, while on weekdays is 17 minutes 10 seconds. Calculation of cave carrying capacity is only carried out at one location without consideration of spatial variations inside Gelatik Cave. For further research, measurement of cave carrying capacity needs to be done on each variation of cave passage morphology to find out the spatial variation of cave carrying capacity inside the Gelatik Cave.

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