CHAPTER 3: RESULT AND DISCUSSION

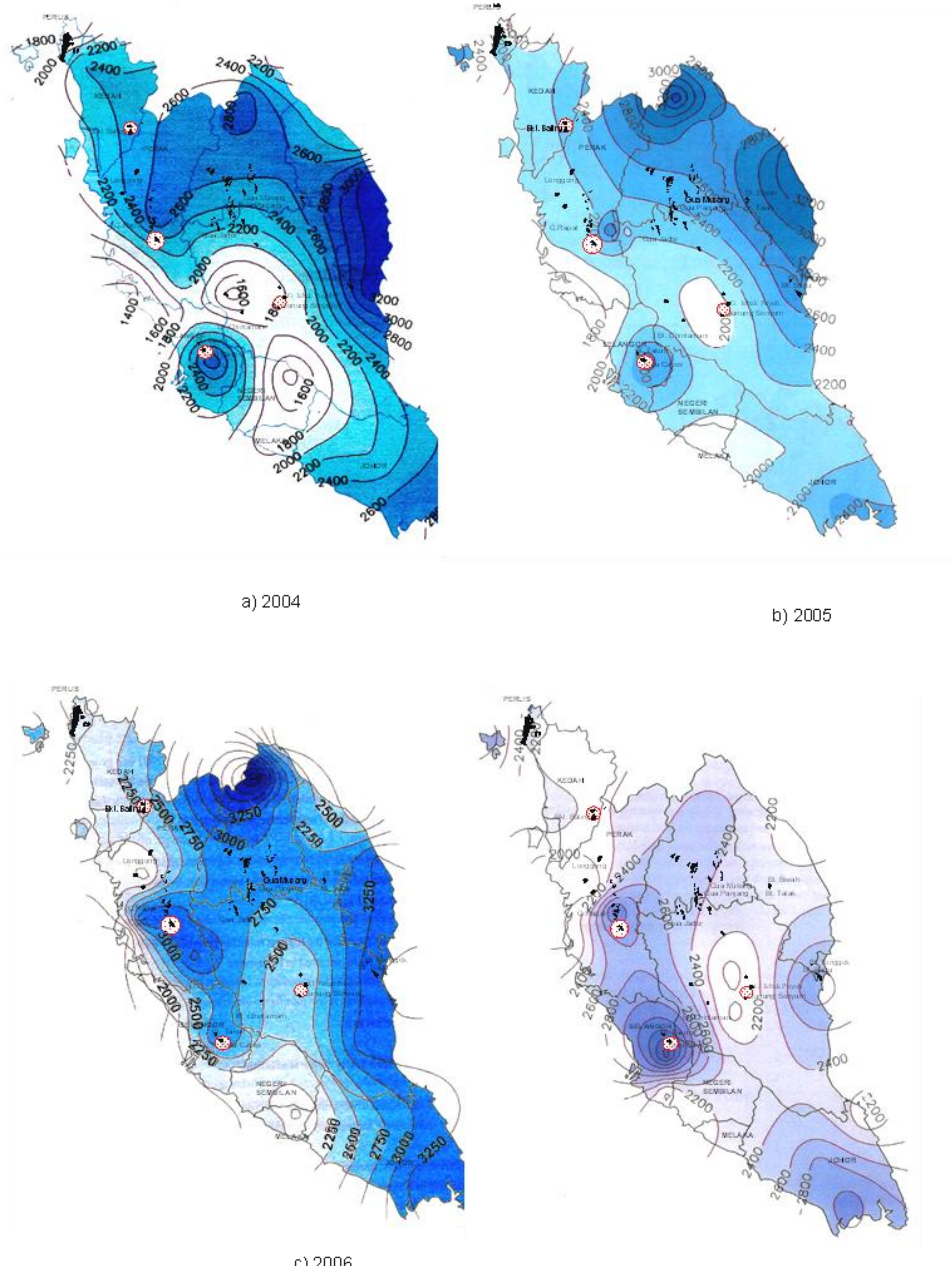
3.1 Rainfall Distribution in Study Area

Figure 3.1 shows annual rainfall distribution pattern in Peninsular Malaysia. Generally, most areas in the west coast states, inland areas of Pahang, Terengganu and Kelantan are receiving high annual rainfall. The rainfall distribution in Peninsular Malaysia is influenced by the cyclic of southeast monsoon, northeast monsoon, and intermonsoon season.

Table 3.1 shows annual rainfall in the study areas. Overall, Batu Caves received high annual rainfall compared to the other study area and the average value is 2937.5 mm. Meanwhile, Gunung Jebak Puyuh and Gunung Senyum received relatively low annual rainfall and range from 1800 mm – 2500mm.

Table 3.1: Annual rainfall in study area 2004 - 2007 (courtesy from MET)

Location / Year	2004 (mm)	2005 (mm)	2006 (mm)	2007 (mm)	Average (mm)
Batu Caves	2600	2800	2750	3600	2937.5
Gua Tempurung	2200	2200	3000	3000	2600.0
Gunung Senyum	1800	2000	2500	2200	2125.0
Gunung Jebak Puyuh	1800	2000	2500	2200	2125.0
Kaki Bukit	2000	2200	2250	2400	2212.5
Bukit Baling	2400	2200	2250	2000	2212.5



a) 2004

b) 2005

c) 2006

d) 2007

Figure 4.1: Annual rainfall pattern in Peninsular Malaysia (courtesy from MET)

3.2 Physical Parameter

Table 3.2, 3.3, 3.4, 3.5 and 3.6 summarize the result of physical parameter of karst water. The physical parameters measured are drip rates, pH, temperature, conductivity, dissolved oxygen and TDS. These parameters provide better understanding of the physical characteristic of drip water. However, it should be noted that due to insufficient volume of water samples, not all physical parameter are measured, especially in Gua Jebak Puyuh, Gua Angin, Gua Straw, Gua Berlian and Gua Wang Burma.

3.2.1 Drip rates

The preliminary study of drip rates characteristic is carried out only at Batu Caves. Most of accessible caves in Peninsular Malaysia are tourism attraction and open to public, therefore auto sampler installation is not suitable due to security issues and vandalism. The drip rates were measured manually at a fortnightly basis in Villa Cave and Dark Cave starting on October 2007 until October 2007 and March 2008 - l May 2008, respectively. The coarse resolution of the data sets precludes precise characterization of and individual drip's temporal behavior. Therefore, the discussion is focusing on spatial variability and the time series data sets are used to characterize the flow regime of individual drip sites.

The drip water demonstrates that all drip sites maintain the flow throughout the year, with the mean drip rates between 0.02 ml/s – 1.02 ml/s. The mean discharge of drip sites in relation to the variation in discharge plotted on the definition grid of Smart and

Table 3.2: Summary of physical parameters of sampling sites in Villa Cave

Station ID	n	Statistic	Physical Parameter					
			Drip rates	Temperature	pH	TDS	Conductivity	Dissolved Oxygen
			ml/s	^{0}C		mg/l	uS/cm	mg/l
CA1	5	Mean Range (STDEV)	0.36 0.09-0.69 (0.29)	25.63 24.6-27.4 (0.63)	7.12 6.37-7.99 (0.534)	291.24 94-431 (120.33)	418.98 196.90-843 (227.118)	4 3.05-4.54 (0.90)
CA2	7	Mean Range (STDEV)	0.18 0.03-0.50 (0.18)	25.67 25.5-26.2 (0.24)	7.29 6.30-8.02 (0.65)	192.99 79.70-574.00 (173.07)	390.06 113.20-1166 (355.69)	5.1 4.5-6 (0.51)
CA3	11	Mean Range (STDEV)	0.15 0.04-0.37 (0.11)	26.5 25.4-27.5 (0.67)	7.36 6.00-8.32 (0.74)	154.15 83.1-380. (107.65)	321.3 166.7-779.00 (225.72)	4.5 3.2-5.8 (0.86)
CA4	21	Mean Range (STDEV)	0.29 0.08-0.63 (0.15)	25.63 24.6-27.4 (0.63)	7.8 6.4-8.35 (0.45)	194.9 69.1-516 (112.25)	416.12 150.6-1050 (223.20)	4.35 3.08-6.2 (0.88)
CA5	23	Mean Range (STDEV)	0.44 0.18-1.02 (0.18)	25.60 24.7-27.1 (0.58)	7.84 6.40-8.23 (0.41)	239.65 62.9-946 (224.04)	434.22 132-1601 (324.24)	4.48 3.00-5.6 (0.79)

Notes: Standard Deviation (STDEV

Table 3.3: Summary of physical parameters of sampling sites in Dark Cave.

Station ID	n	Statistic	Physical Parameter					
			Drip rates	Temperature	pH	TDS	Conductivity	Dissolved Oxygen
			ml/s	^{0}C		mg/l	uS/cm	mg/l
A1	6	Mean Range (STDEV)	0.51 0.18-0.97 (0.36)	25.67 25.5-26.2 (0.24)	8.07 7.64-8.25 (0.23)	154.88 80.60-371.00 (108.99)	321 766-168.6 (224.09)	4.07 3.9-4.3 (0.16)
A2	6	Mean Range (STDEV)	0.17 0.05-0.28 (0.10)	26.5 25.4-27.5 (0.67)	7.82 7.46-8.1 (0.23)	221.52 124.6-552.00 (165.07)	456.33 260-1122 (332.65)	4.1 3.6-4.8 (0.43)
A3	6	Mean Range (STDEV)	0.05 0.02-0.07 (0.02)	25.63 24.6-27.4 (0.63)	8 7.75-8.23 (0.18)	239.7 118.9-679 (216.08)	491.83 248-1372 (433.04)	4.05 3.1-4.7 (0.56)
A4	6	Mean Range (STDEV)	0.07 0.04-0.12 (0.03)	25.60 24.7-27.1 (0.58)	8.09 7.8-8.4 (0.23)	129.77 69.7-300 (87.20)	267.8 146-618 (178.68)	3.9 3.5-4.7 (0.44)
A6	6	Mean Range (STDEV)	0.11 0.08-0.17 (0.04)	25.60 24.7-27.1 (0.58)	7.95 7.57-8.15 (0.21)	140.6 89.9-268 (65.90)	292.5 188-554 (135.29)	4.05 3.6-4.5 (0.32)

Notes: Standard Deviation (STDEV

Table 3.4: Summary of physical parameters of sampling sites in Gua Tempurung

Water types	Station ID	n	Statistic	Physical Parameter				
				Temperature	pH	TDS	Conductivity	Dissolved Oxygen
				^{0}C		mg/l	uS/cm	mg/l
i) Drip water	GT1	6	Mean Range STDEV	26.63 25.4-28.4 1.21	7.95 7.62-8.09 0.17	95.25 82.5-115.7 12.45	203.65 173.8-241 22.03	4.81 3.8-5.7 0.65
	GT2	6	Mean Range STDEV	27.11 25.9-27.9 0.76	7.99 7.79-8.21 0.16	81.3 63-103.8 17.96	175 132-217 33.64	4.81 3.8-5.7 0.65
	GT3	8	Mean Range STDEV	27.5 26-29 1.014	8.09 7.53-8.31 0.25	86.41 37.6-126.4 38	181.75 80-264 77.43	5.31 4.5-6.5 0.71
	GT11	6	Mean Range STDEV	27.75 26.9-28.8 0.66	7.83 7.19-8.08 0.33	84.35 64.2-103.9 20.81	177.07 134.9-217 41.98	4.7 3.8-6 0.92
	*GT21	2	Mean Range STDEV	-	8.11-8.31	53-125.1	111.4-262.15	4.7-5.3
ii) Spring	GT4	6	Mean Range STDEV	26.48 25.6-27.4 0.74	7.74 7.35-7.69 0.23	102.38 40.9-156.4 47.06	212.88 86.4-325 97.62	5.11 4.0-6.0 0.69
	GT6	6	Mean Range STDEV	27.38 25.9-29 1.07	7.85 7.5-8.14 0.26	136.95 96.2-165 31.13	283.55 190.3-343 67.45	4.77 4-5.6 0.74
iii)Pond	GT5	8	Mean Range STDEV	27.24 25.8-28.5 0.87	8.07 7.56-8.3 0.25	97.61 63.3-121 21.77	194.25 132.9-223 37.69	4.5 2.6-5.5 0.92

Notes: Standard Deviation (STDEV)
*only two samples

Table 3.5: Summary of physical parameters of sampling sites in Sungai Tempurung

Water types	Station ID	n	Statistic	Physical Parameter				
				Temp	pH	TDS	Conductivity	Dissolved Oxygen
				^{0}C		mg/l	uS/cm	mg/l
River	SGT1	3	Mean	26.77	7.78	121.7	253.47	4.03
			Range	26.1-27.5	7.72-7.89	89.6-140	187.4-291	2.6-5.6
			STDEV	0.702	0.09	27.89	57.39	1.50
	SGT2	5	Mean	27.06	7.44	61.74	127.34	5.33
			Range	26.1-27.9	6.53-7.83	56.8-66.9	110.4-140.7	4.8-5.5
			STDEV	0.77	0.52	4.64	12.99	0.35
	SGT7	5	Mean	27.18	7.26	161.78	161.78	4.38
			Range	26.5-28.3	7-7.71	136.7-217	136.7-217	3.3-5.6
			STDEV	0.70	0.30	32.38	32.38	01.00
	SGT3	6	Mean	26.8	7.89	70.47	147.22	4.85
			Range	25.2-29	7.32-8.13	54.1-80.2	109.3-168	3.3-5.6
			STDEV	1.49	0.291	10.17	22.48	1.05
	SGT8	3	Mean	27.83	7.58	163.4	163.4	6.00
			Range	25.6-29.8	7.1-8.19	144.5-179.3	144.5-179.3	4.2-8
			STDEV	2.11	0.55	17.59	17.52	1.91
	SGT4	6	Mean	27.43	8.05	72.57	157.28	4.8
			Range	25.3-29.8	7.64-8.42	51.9-89.7	109.5-188.9	3.8-5.7
			STDEV	1.55	0.26	13.06	30.57	0.90
	SGT9	5	Mean	26.82	7.89	146.6	146.6	4.8
			Range	26-27.9	8.11-7.58	97.7-181	97.7-181	3.7-6.2
			STDEV	0.74	0.23	32.69	32.69	1.04
	SGT5	4	Mean	27.5	8.09	71.15	151.43	4.87
			Range	26.8-27.7	7.98-8.26	67.4-81	142.8-169.7	4.0-5.5
			STDEV	0.44	0.12	6.58	12.51	0.78
	SGT6	4	Mean	27.5	7.98	69.43	147	4.83
			Range	26.9-27.8	7.56-8.23	60.6-81.1	131.7-169.7	4.0-5.5
			STDEV	0.41	0.3	8.56	16.1	0.62

Notes: Standard Deviation (STDEV

Table 3.6: Summary of physical parameters of drip sites : Gunung Jebak Puyuh (Gua Straw), Gunung Senyum (Gua Angin), Kaki Bukit (Gua Kelam and Gua Burma),Bukit Baling (Gua Berlian)

Date	Station	Sample ID	Physical Properties			
			Temperature	pH	TDS	Conductivity
			°C		mg/l	uS/cm
15/15/08	Gua Straw	GSTRW	29.3	7.89	204	97.8
15/15/08		GSTRW	28.1	8.12	97.5	46.4
13/5/2008	Gua Angin	GA3	26.3	7.26	374	180.3
13/5/2008		GA4	27.6	8.34	191.4	91.4
14/5/2008		GA2	28.3	7.88	341	164.8
8/11/2007	Gua Wang Burma	**BU	na	8.2	na	na
28/7/2008		SGWB1	25.6	7.32	87	142
28/7/2008		SGWB2	25.7	7.12	119	234
29/7/2008		SGWB3	26.3	7.61	94	167
28/7/2008	Gua Kelam	KE1	26.3	7.5	154	385
28/7/2008		KE2	25.9	7.21	156	587
9/11/2007		KE1	25.5	8	297	612
9/11/2007		KE2	25.7	7.2	238	488
8/11/2007	Gua Berlian	BE1	25.1	7.6	294	141.1
8/11/2007		BE2	25.4	6.69	244	116.8
8/11/2007		BE3	25.3	6.92	477	231
8/11/2007		BE4	25.3	6.76	394	190
29/7/2008		BE1	27.1	7.65	279	134.1
29/7/2008		BE2	28.1	8.19	203	97
29/7/2008		BE3	27.7	8.12	288	138.5
29/7/2008		BE4	28.8	7.95	458	221

Notes: Standard Deviation (STDEV)
*only two samples

Friederich (1986) as modified by Baldini et al., (2006). Figure 3.2 show a positive log-linear correlation exists between the coefficient variation (C.V) and maximum discharge, indicating the faster drips tends to exhibit in variable discharge. Drip sites are grouped intotwo groups in terms of hydrological response to discharge which are seepages flow (CA5, A6, A4 and A3) and seasonal flow (CA1, CA2, CA3, CA4, A1 and A2). Seepages flow characterizes as a medium variable drips and the C.V varies from 33.24 – 46.08. Besides, seasonal flow characterizes as a high variability drips and response intermittently with water excess. The C.V is range from 51.66 – 102.87.

3.2.2 pH

Figure 3.3 show the pH value of meteoric water in Peninsular Malaysia from 2006-2008. Generally meteoric water in the western and southern states is slightly acidic and pH values range from 4.4 - 4.8. Overall, the water samples show that pH values above 6 and designate a bicarbonate environment. The pH value in Dark Cave shows a greater value than Villa Cave. The value varies from 7.46- 8.4 and 6.00-8.35, respectively. The mean value of drip, pond and spring from Gua Tempurung show high pH which is value range from 7.74 - 8.99 and Sungai Tempurung show the mean value varies from 7.26 - 8.09.

Besides, samples water from Gua Kelam and Gua Berlian illustrate the pH value that varies from 7.2 – 8 and 6.69 – 8.19, respectively. Gua Straw, Gua Angin and Gua Wang Burma show the pH value range from 7.89 – 8.12, 7.26 – 8.34 and 7.12 – 8.22, respectively.

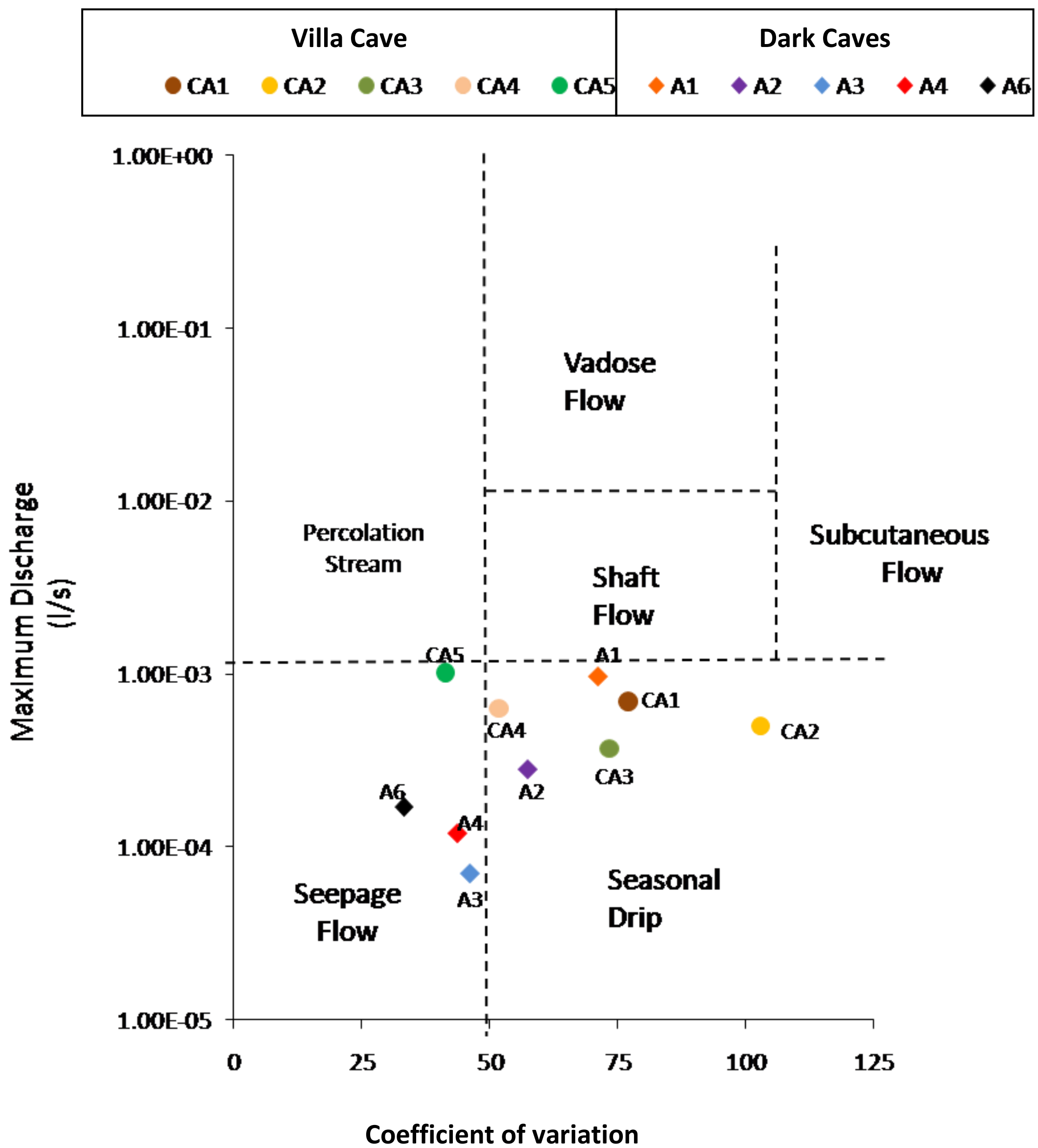


Figure 3.2: Maximum measured discharge for the drip rates plotted against the coefficient of variation (standard deviation/mean x 100). Adapted from Baldini et al, (2006) after Smart and Friederich, (1986)

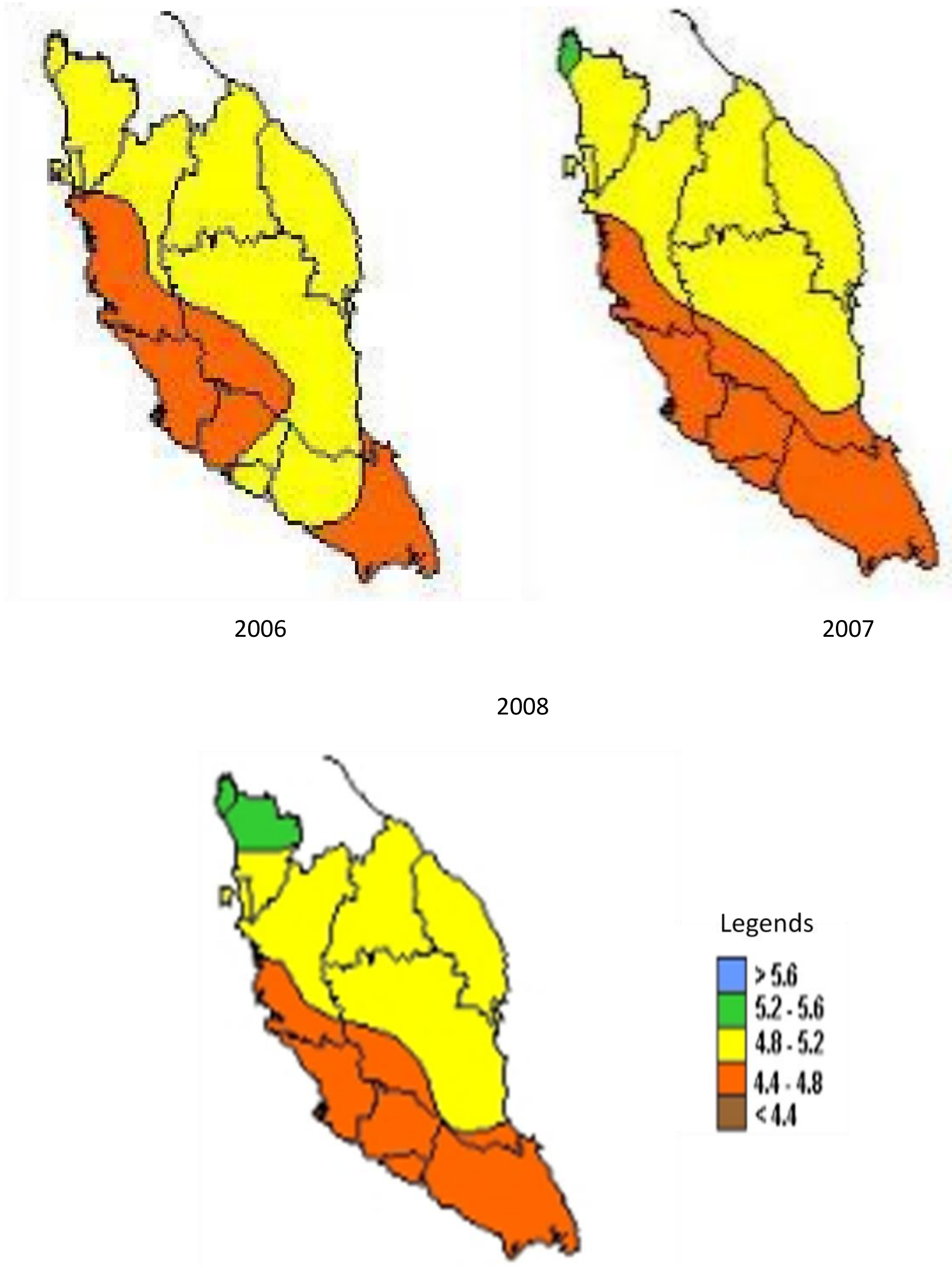


Figure 3.3: Rainfall pH in Peninsular Malaysia 2006 - 2008 (courtesy from MET)

3.2.3 TDS and Conductivity

TDS and conductivity are proportional to each other (Hounslow, 1995). Most of water samples demonstrate that the TDS values are below that 500 mg/l and indicate the silicate weathering (Hounslow, 1995). However, water samples from Villa Cave show several episode of greater TDS value which exceed 500 mg/l on 11/02/08 and 29/02/08. Gua Straw, Gua Angin and Gua Wang Burma show the TDS value range from 97.50 mg/l – 204.00 mg/l, 191.40 mg/l – 374.00 mg/l and 87.00 mg/l – 119.00 mg/l, respectively. Besides, water samples from Gua Kelam and Gua Berlian illustrates the TDS value varies from 154.00 mg/l – 238.00 mg/l and 203.00 mg/l – 477.00 mg/l, respectively. On the other hand, the results show that spring samples (GT4 and GT6) indicate the highest value compared to other sampling sites in Gua Tempurung. The mean value ranges from 102.38 mg/l – 136.95 mg/l.

3.2.4 Dissolved Oxygen (DO)

The results demonstrate that the mean value of DO varies from 4.00mg/l – 5.01 mg/l (Batu Caves) and 4.03 mg/l – 5.33 mg/l (Gua Tempurung).

3.2.5 Temperature

Overall, the result show broad value of the temperature which is ranging from 24.6 °C – 29.3 °C and the STDEV is below 3.

4.3 Chemical Properties

Table 3.7, 3.8, 3.9, 3.10, 3.11 and 3.12 summarize the result of chemical properties of karst water. These parameters allow gaining better understanding of the chemical characteristic of drip water.

3.3.1 Chemistry contents

The chemistry contents of meteoric water comprise of Ca, Mg, Na, K, NO_3 and SO_4 (see Table 3.7). Meteoric water in Ipoh is high in Ca and could be derived from limestone quarry activities surrounded. On the other hand, meteoric water from Kajang and Kuala Lumpur are high in NO_3 and SO_4. The mean value varies from 1.72 mg/l – 2.17 mg/l and 1.12 mg/l – 1.22 mg/l respectively.

The results show that there are high variability on Ca concentration and range from 27.16 mg/l-78.75 mg/l (Villa Cave), 24.28 mg/l-73.50 mg/l (Dark Cave), 34.16 mg/l - 86.61 mg/l (Gua Tempurung), 19.56 mg/l – 72.26 mg/l (Sungai Tempurung), 181.00 mg/l - 31.31 mg/l (Gunung Jebak Puyuh), 122.00 mg/l - 54.92 mg/l (Gunung Senyum), 56.43mg/l - 103.7mg/l (Gua Berlian) and 86.7mg/l - 104.9mg/l (Gua Kelam). Water samples in Gua Angin (Gunung Senyum) and Batu Caves show that the chemistry content are high in Mg and range from 8.392 mg/l – 16.37 mg/l and 4.01 mg/l – 12.03 mg/l, respectively. Meanwhile, the water samples show that the Mg less that 7.00 mg/l.

Table 3.7: The average value of chemical parameters of meteoric water

Station ID	n	Chemical Parameter										
		K	Ca	Mg	Na	Al	Zn	Fe	F	Cl	NO3	SO4
		mg/l										
RIPOH	3	1.23	1.73	bdl	0.76	0.02	bdl	bdl	bdl	0.11	0.28	0.53
RKL	4	0.74	1.38	bdl	0.94	0.02	0.01	bdl	0.05	0.19	2.17	1.12
Kajang*	3	0.84	1.17	bdl	1.08	0.02	0.01	0.11	0.04	0.33	1.72	1.22
Selangor**			1.48	0.14								
Kinta Valley**			0.4	0.05								
Boundary Range**			1.02	0.09								
Pasoh Forest Reserve, Negeri Sembilan***			0.18	0.03								

Note:
bdl-below detection limit
* Yee, 2008
** Crowther, 1989
*** Manokaran, 1980 after Crowther, 1989

Table 3.8: Summary of chemical properties for drip sites in Villa Cave

Chemical Properties (mg/l)	Station ID	CA1	CA2	CA3	CA4	CA5
	Water Types	Drip water				
	Statistic n	5	7	11	21	29
pH	Mean Range (STDEV)	7.12 6.37-7.99 (0.534)	7.29 6.30-8.02 (0.65)	7.36 6.00-8.32 (0.74)	7.8 6.4-8.35 (0.45)	7.84 6.40-8.23 (0.41)
Ca	Mean Range (STDEV)	67.89 31.25-78.75 (20.54)	48.93 28.31-79.69 (15.38)	33.545 27.16-67.73 (12.81)	51.43 32.00-71.60 (7.909)	50.280 41.88-56.36 (3.979)
Mg	Mean Range (STDEV)	9.24 5.10-11.18 (2.50)	6.31 4.91-10.61 (1.94)	8.252 5.713-17.98 (4.70)	16.888 9.06-23.02 (3.25)	9.445 7.01-19.14 (3.02)
Na	Mean Range (STDEV)	2.82 1.84-3.32 (0.59)	3.5 1.39-13.60 (4.47)	10.00 2.55-13.47 (3.80)	2.58 1.64-5.12 (0.84)	4.20 2.35-5.31 (0.61)
K	Mean Range (STDEV)	1.98 1.10-3.11 (0.97)	2.00 0.97-3.5 (0.79)	3.26 1.34-4.82 (1.06)	1.627 0.97-3.53 (0.645)	3.34 1.49-4.27 (0.68)
Fe	Mean Range (STDEV)	0.03	0.004 0.003-0.005 (0.001)	bdl	bdl	bdl
Mn	Mean Range (STDEV)	0.02	bdl	0.001-0.003	0.049	0.001-006
Al	Mean Range (STDEV)	0.001-0.015	0.01-0.009	0.001-0.474	0.015	0.001-0.015
Pb	Mean Range (STDEV)	0.003	bdl	0.01	0.001-0.013	0.008-0.021
Zn	Mean Range (STDEV)	0.015-0.029	0.012-0.022	0.007-0.154	0.008-0.024	0.003-0.101
Cl	Mean Range (STDEV)	5.58 2.32-12.01 (3.77)	4.8 3.61-6.19 (0.79)	12.91 1.03-19.92 (6.81)	4.61 3.04-5.77 (0.73)	5.44 3.72-7.27 (0.90)
F	Mean Range (STDEV)	bdl	0.02-0.03	bdl	bdl	bdl
SO4	Mean Range (STDEV)	21.28 27.86-3.93 (10.11)	10.57 4.35-25.88 (9.14)	7.07 2.39-9.12 (2.17)	21.96 9.51-30.11 (4.14)	25.27 10.51-32.03 (4.35)
NO3	Mean Range (STDEV)	35.66 21.76-61.16 (15.28)	35.01 21.75-58.93 (13.42)	42.52 28.28-75.3 (19.48)	64.45 46.68-83.36 (8.72)	70.84 30.34-85.85 (11.71)
CO3	Mean Range (STDEV)	2.94 2.1-3.4 (0.53)	3.22 1.24-5.70 (2.04)	1.50 0.62-3.08 (0.82)	3.78 1.5-7.9 (1.77)	3.32 2.00-5.00 (1.03)
HCO3	Mean Range (STDEV)	219.96 111.00-320.4 (93.70)	187.22 119.14-381.39 (89.39)	139.78 74.00-234.83 (50.68)	164.94 95.17-272.12 (51.12)	132.1 55.29-214.79 (40.76)

Notes: bdl-below detection limit

Table 3.9: Summary of chemical properties for drip sites in Dark Cave

Chemical Properties (mg/l)	Station ID	A1	A2	A3	A4	A6
	Water Types	Drip water				
	n Statistic	6	6	6	6	6
pH	Mean Range (STDEV)	8.07 7.64-8.25 (0.23)	7.82 7.46-8.1 (0.23)	8 7.75-8.23 (0.18)	8.09 7.8-8.40 (0.23)	7.95 7.57-8.15 (0.21)
Ca	Mean Range (STDEV)	44.13 38.89-46.89 (3.01)	71.39 69.65-73.50 (1.48)	58.07 50.49-68.03 (7.84)	40.60 34.5-45.96 (5.02)	43.58 24.28-50.48 (9.85)
Mg	Mean Range (STDEV)	9.56 9.19-10.25 (0.38)	7.58 7.01-7.87 (0.32)	10.33 8.84-12.03 (1.53)	4.72 4.01-5.30 (0.49)	8.48 7.74-8.97 (0.48)
Na	Mean Range (STDEV)	1.38 1.27-1.48 (0.08)	1.36 1.46-1.28 (0.06)	2.21 1.77-2.66 (0.40)	1.37 1.21-1.49 (0.09)	1.34 1.17-1.77 (0.22)
K	Mean Range (STDEV)	0.70 0.67-0.74 (0.03)	0.7 0.67-0.74 (0.03)	0.89 0.83-0.98 (0.07)	0.74 0.65-0.78 (0.05)	0.89 0.82-1.02 (0.08)
Fe	Mean Range (STDEV)	bdl	0.05 0.03-0.13 (0.04)	0.14 0.01-0.39 (0.17)	0.04 0.01-0.14 (0.06)	0.06 0.01-0.15 (0.08)
Mn	Mean Range (STDEV)	bdl	bdl	bdl	bdl	bdl
Al	Mean Range (STDEV)	0.28	bdl	0.01	0.20-0.30	bdl
Pb	Mean Range (STDEV)	bdl	bdl	bdl	bdl	bdl
Zn	Mean Range (STDEV)	bdl	bdl	bdl	bdl	bdl
Cl	Mean Range (STDEV)	1.09 0.90-1.35 (0.16)	0.76 0.07-1.07 (0.3)	2.46 (5) 1.22-3.09 (0.77)	0.96 0.56-1.18 (0.22)	0.99 0.90-1.06 (0.07)
F	Mean Range (STDEV)	0.03 (3) 0.02-0.04 (0.01)	0.05 (3) 0.03-0.06 (0.02)	0.4 (2) 0.02-0.06 (0.03)	0.05 0.02-0.15 (0.05)	0.06 0.04-0.07 (0.02)
SO4	Mean Range (STDEV)	5.84 5.56-6.07 (0.2)	8.42 6.06-13.60 (2.62)	17.34 (5) 8.39-22.01 (5.92)	7.20 3.99-11.89 (2.6)	5.53 5.35-5.69 (0.12)
NO3	Mean Range (STDEV)	12.42 10.56-15.14 (1.78)	6.85 2.61-7.99 (2.09)	70.21 21.95-99.24 (33.94)	6.63 3.95-7.81 (1.4)	10.56 9.92-11.56 (0.59)
CO3	Mean Range (STDEV)	4 4.7-3.4 (6.36)	4.12 3.2-5 (0.74)	5.00 3.40-6.70 (1.22)	4.64 3.20-9.20 (2.56)	4.4 2.9-8 .00 (2.07)
HCO3	Mean Range (STDEV)	159.49 152.33-167.23 (6.36)	232.94 224.51-243.25 (6.96)	134.75 102.59-181.70 (28.44)	126.8 104.75-153.64 (17.31)	153.47 97.61-185.08 (31.12)

Notes: bdl-below detection limit

Table 3.10: The summary of chemical properties of drip rates : Gua Tempurung (GT1-GT21)

Chemical Properties (mg/l)	Station ID	GT1	GT2	GT3	GT11	GT21	GT4	GT6	GT5
	Water Types	Drip water					Spring		Pond
	n Statistic	6	6	6	6	2	6	6	8
pH	Mean Range STDEV	7.95 7.62-8.09 0.17	7.99 7.79-8.21 0.16	8.09 7.53-8.31 0.25	7.83 7.19-8.08 0.33	8.11-8.31	7.74 7.35-7.69 0.23	7.85 7.5-8.14 0.26	8.07 7.56-8.3 0.25
Ca	Mean Range STDEV	53.12 34.16-86.61 19.464	58.28 46.39-76.06 0.86	57.07 51.41-69.71 6.24	42.79 35.96-47.40 3.73	51.42-58.50	57.29 46.70-61.61 5.88	60.11 51.41-72.06 7.989	48.01 41.66-54.91 4.89
Mg	Mean Range STDEV	0.65 0.34-0.78 0.16	0.60 0.26-0.86 0.21	1.98 1.14-5.94 1.61	1.96 0.64-6.75 2.35	0.61-0.75	3.37 2.75-3.76 0.40	5.26 1.50-6.59 1.90	0.67 0.40-0.97 0.24
Na	Mean Range STDEV	1.93 0.97-2.97 0.70	1.55 0.79-3.10 0.86	1.35 0.80-1.96 0.50	1.29 0.15-2.63 1.04	1.57-2.59	1.23 0.60-2.19 0.55	1.67 0.051-4.29 1.50	0.97 0.06-2.07 0.56
K	Mean Range STDEV	0.79 0.06-1.60 0.51	0.38 0.07-0.77	0.60 0.10-1.30 0.38	1.001 0.70-1.42 0.31	0.07-1.20	0.65 0.26-0.84 0.23	0.60 0.11-1.12 0.38	0.48 0.07-0.74 0.26
Fe	Mean Range STDEV	0.04 0.02-0.06 0.02	0.004-0.082	0.005-0.39	0.04 0.64-6.75 2.35	0.032-0.14	0.006-0.018	0.004-0.015	0.24 0.01-0.67 0.24
Mn	Mean Range STDEV	0.001-0.634	0.401 0.003-1.143 0.504	0.001	0.001-0.002	0.005-0.003	0.002-0.008	0.004-0.01	0.008-0.042
Al	Mean Range STDEV	bdl	0.103-0.892	0.003-0.041	bdl	bdl	bdl	0.005-0.028	0.357 0.116-0.617 0.171
Cd	Mean Range STDEV	0.006-0.007	0.005-0.007	0.006-0.007	0.006	0.269	0.006	0.005-0.006	0.006
Cu	Mean Range STDEV	0.004-0.026	0.01-0.043	0.001-0.007	0.007-0.063	0.005	0.006-0.007	0.001-0.014	0.008-0.024
Zn	Mean Range STDEV	0.007-0.142	0.063 0.002-0.156 0.08	0.012-0.047	0.002-0.032	0.009	0.023 0.004-0.055 0.027	0.003-0.043	0.003-0.93
Cl	Mean Range STDEV	2.01 0.22-6.85 2.40	2.49 1.17-7.25 2.37	1.35 0.63-5.25 1.58	3.54 1.39-8.21 2.85		0.66 0.08-1.03 0.35	1.34 0.68-3.34	2.55 0.74-6.48 2.24
F	Mean Range STDEV	0.73-6.85	0.07-1.18	0.02-0.07	0.4770.04- 1.400.63		0.090.03- 0.260.11	0.12	0.02-0.76
SO4	Mean Range STDEV	3.81 0.64-4.74 1.56	4.50 4.21-4.84 0.33	2.96 2.57-3.22 0.20	1.57-1.67	0.91-3.47	2.88 1.87-3.67 0.73	3.22 2.67-3.80 0.41	2.74 0.48-6.33 1.98
NO3	Mean Range STDEV	7.54 2.58-10.82 2.83	6.25 4.39-9.49 1.91	6.37 3.02-8.27 1.80	5.07 1.65-8.67 3.48	3.4	8.10 1.36-10.38 3.34	8.08 6.52-10.63 1.61	7.78 2.67-14.91 3.77
CO3	Mean Range STDEV	2.3-3.2	2.78 2.30-3.20 0.44	4.02 2.30-5.30 1.156	2.3-4.80		3.24 2.20-4.00 0.73	3.00-5.60	2.44 2.00-2.8 0.30
HCO3	Mean Range STDEV	167.6 98.55-241.6 51.63	6.25 4.39-9.49 1.91	192.60 143.20- 248.60 48.24	120.08 120.10- 187.70 3.48		201.13 130.50-255.50 40.63	236.40 135.60-287.30 56.17	153.54 108.10-182.40 26.73

Note : bdl (below detection limit)
*only 2 samples

Table 3.11: The summary of physical and chemical properties of river water : Sg. Tempurung, Gua Tempurung (SGT1-SGT9)

Chemical Properties	Station ID	**SGT1**	**SGT2**	**SGT7**	**SGT3**	**SGT8**	**SGT4**	**SGT9**	**SGT5**	**SGT6**
	n Statistic	3	5	5	6	3	6	5	4	4
pH	Mean Range STDEV	7.78 7.72-7.89 0.09	7.44 6.53-7.83 0.52	7.26 7-7.71 0.30	7.89 7.32-8.13 0.291	7.58 7.1-8.19 0.55	8.05 7.64-8.42 0.26	7.89 8.11-7.58 0.23	8.09 7.98-8.26 0.12	7.98 7.56-8.23 0.3
Ca	Mean Range STDEV	37.22 36.07-37.83 1.00	27.91 19.56-37 0.86	27.33 20.22-33.06 5.01	30.12 25.35-36.31 4.61	29.61 26.66-31.71 2.63	32.83 26.11-26.59 3.82	32.85 37.21-28.02 4.20	34.75 28.6-40.2 5.1	45.93 31.07-72.26 18.1
Mg	Mean Range STDEV	16.71 15.27-17.53 1.23	4.38 2.49-6.23 1.62	3.89 3.14-5.97 1.17	4.917 3.17-6.88 1.44	4.151 3.40-4.31 0.16	4.522 3.122-6.558 1.3	4.879 3.047-6.758 1.58	3.588 0.427-6.588 2.55	5.67 3.434-8.381 2.23
Na	Mean Range STDEV	1.54 1.13-1.78 0.36	2.56 1.74-3.68	2.14 0.82-4.29 1.33	2.01 1.49-3.29 0.66	2.19 1.72-2.88 0.61	2.14 1.401-4.292 1.09	1.655 2.654-0.728 0.69	1.978 1.217-2.978 0.83	1.46 0.843-1.693 0.41
K	Mean Range STDEV	1.74 1.63-1.81 0.1	1.52 1.39-1.62 0.10	1.318 1.01-1.58 0.25	1.24 0.93-1.58 0.23	1.47 1.40-1.60 0.12	1.282 0.923-4.292 0.25	1.267 0.942-1.475 0.21	1.094 0.704-1.622 0.39	1.18 1.457-0.618 0.39
Fe	Mean Range STDEV	bdl	0.204 0.10-0.32 0.11	0.26-0.281	0.25 0.04-0.69 0.30	0.21 0.16-0.26 0.05	1.885 0.097-0.281 0.09	0.086 0.02-0.138 0.05	0.095-0.429	0.112-0.411
Mn	Mean Range STDEV	0.555	0.096 0.074-0.108 0.019	0.065 0.024-0.101 0.04	0.04 0.01-0.06 0.02	0.038 0.034-0.042 0.004	0.047 0.02-0.101 0.05	0.03 0.044-0.02 0.02	0.054 0.006-0.142 0.08	0.018-0.122
Al	Mean Range STDEV	0.027	0.199 0.121-0.291 0.72	0.215 0.167-0.275 0.05	0.15 0.04-0.21 0.06	0.207 0.151-0.246 0.05	0.153 0.006-0.289 0.13	0.125 0.03-0.289 0.10	0.284 0.042-0.694 0.29	0.299 0.014-0.567 0.23
Pb	Mean Range STDEV	bdl	bdl	0.055-0.06	0.003-0.006	bdl	0.055-0.06	0.001-0.006	0.001-0.007	0.006
Zn	Mean Range STDEV	bdl	0.223 0.019-0.491 0.208	0.307 0.086-0.574 0.247	0.14 0.02-0.26 0.12	0.011-0.165	0.265 0.030-0.574 0.261	0.281 0.113-0.51 0.18	0.023	0.382
Cu	Mean Range STDEV	0.006-0.850	0.017 0.006-0.045 0.018	0.008 0.006-0.013 0.003	0.006-0.007	0.006-0.008	0.004-0.343	0.019 0.007-0.043 0.02	0.011	bdl
As	Mean Range STDEV	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Cd	Mean Range STDEV	bdl	bdl	0.013	0.057		0.008-0.155	0.011	0.009	0.007
Cl	Mean Range STDEV	0.48 0.32-0.64 0.22	0.51 0.41-0.63 0.01	1.35 0.49-3.36 1.21	0.85 0.39-2.04	1.12 0.59-2.06 0.82	0.528 0.218-0.718 0.353	0.750 0.38-1.765 0.57	3.872 0.368-14.05 6.76	4.123 0.353-4.897 7.184
F	Mean Range STDEV	0.43	0.30 0.26-0.36 0.04	0.37 0.21-0.59 0.15	0.35 0.24-0.53 0.12	0.28 0.24-0.32 0.04	0.299 0.232-0.353 0.5	0.29 0.235-0.41 0.08	1.026 0.21-2.566 1.33	0.328-2.765
SO4	Mean Range STDEV	1.57	1.73 0.67-2.06 0.60	2.08 2.05-2.13 0.05	1.99 1.17-2.33 0.47	2.22 2.07-2.49 0.24	2.994 1.987-6.209 1.808	1.984 2.193-1.545 0.30	2.106 2.047-2.167 0.06	2.56 1.797-3.889 1.16
NO3	Mean Range STDEV	0.35	1.23 0.40-2.58 0.90	2.11 1.40-2.89 0.66	1.80 0.46-2.34 0.68	1.97 1.50-2.30 0.42	1.787 0.49-2.757 0.87	2.014 0.475-3.167 0.98	2.027 0.531-2.917 1.06	3.59 0.567-8.909 3.86
CO3	Mean Range STDEV	2.3	1.83 1.3-2.2 0.48	3.00 2.60-3.50 0.47	3.68 0.13-8.70 4.47	3.8-4.1	2.3	3.6	2.63 2.3-3.2 0.5	3.7 2.2-4.9 1.37
HCO3	Mean Range STDEV	251.75 210.27-275 36.01	129.57 95.60-149.42 21.09	127.16 69.80-191.80 46.55	143.42 108.72-201.60 40.55	150.27 147.60-151.60 2.31	143.8 105.18-196.7 31.75	148.73 118.3-173.3 20.38	134.7 111.50-188.4 36.35	188.16 117.53-301.6 79.5

Note: bdl-below detection limit

Table 3.12: The summary of chemical properties of drip sites :Gunung Jebak Puyuh (Gua Straw),Gunung Senyum (Gua Angin),Kaki Bukit (Gua Kelam and Gua Burma) and Bukit Baling (Gua Berlian)

Date	Location	Sample ID	Chemical Properties																
			K	Na	Ca	Mg	Fe	Mn	Al	Cu	Pb	Zn	Cl	F	SO4	CO3	HCO3	NO3	Nitrite
			mg/l																
15/15/08	Gua Straw	GSTRW	0.671	1.356	31.31	2.017	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	2.933	8.7	134	0.843	
15/15/08		GSTRW	0.775	1.48	71.97	1.902	bdl	0.019	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
13/5/2008	Gua Angin	GA3	5.099	3.232	122	16.37	bdl	0.046	bdl	bdl	bdl	bdl	bdl	bdl	bdl	2.3	bdl	0.602	0.074
13/5/2008		GA4	1.034	1.672	54.92	8.392	bdl	bdl	bdl	bdl	bdl	bdl	1.884	bdl	4.574	1.5	150.4	33.401	bdl
14/5/2008		GA2	4.109	2.576	95.09	10.45	bdl	bdl	bdl	bdl	bdl	bdl	3.951	bdl	12.139	3.5	245	bdl	0.296
28/7/2008	Gua Kelam	KE1	1.447	2.178	90.46	2.976	bdl	bdl	bdl	bdl	bdl	0.082	2.836	bdl	2.835	bdl	276	6.524	bdl
28/7/2008		KE2	0.956	2.111	86.7	2.35	bdl	bdl	bdl	bdl	bdl	0.042	2.412	bdl	2.156	bdl	143	3.12	bdl
9/11/2007		KE1	1.456	4.071	102.8	3.467	1.47	0.002	0.001	bdl	0.003	0.053	2.415	bdl	4.321	bdl	231	4.137	bdl
9/11/2007		KE2	0.875	5.017	104.9	2.41	bdl	bdl	bdl	bdl	bdl	0.013	3.21	bdl	1.987	bdl	256	2.145	bdl
8/11/2007	Gua Wang Burma	**BU	1.684	5.149	138.7	4.111	0.361	0.000	0.001	0.010	bdl	0.019	bdl	bdl	bdl	bdl	bdl	bdl	bdl
28/7/2008		SGWB1	2.758	7.057	33.88	1.203	0.197	0.107	0.135	0.003	bdl	0.321	7.271	0.263	1.276	4.4	129	bdl	bdl
28/7/2008		SGWB2	2.424	6.622	29.28	1.009	0.049	bdl	bdl	bdl	bdl	0.066	7.193	0.303	0.966	2.9	93.9	1.339	bdl
29/7/2008		SGWB3	2.422	6.483	28.44	0.982	0.02	bdl	bdl	bdl	bdl	0.062	7.183	0.262	0.092	2.5	119	0.474	bdl
8/11/2007	Gua Berlian	BE1	0.918	1.654	65.31	2.876	bdl	bdl	0.004	bdl	bdl	0.432	1.121	bdl	3.824	0.47506	205.9	1.114	bdl
8/11/2007		BE2	0.873	1.218	69.81	2.761	bdl	bdl	bdl	bdl	bdl	0.34	1.541	0.047	4.231	0.06299	219.4	bdl	bdl
8/11/2007		BE3	0.765	1.429	56.43	3.743	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.09204	192.4	bdl	bdl
8/11/2007		BE4	0.813	1.531	89.43	3.761	bdl	bdl	bdl	bdl	bdl	bdl	0.873	0.015	2.111	8.6	272.6	2.15	bdl
29/7/2008		BE1	0.852	1.523	61.25	2.706	bdl	bdl	0.002	bdl	bdl	0.483	0.993	bdl	3.817	3.4	191.4	1.495	bdl
29/7/2008		BE2	0.708	1.379	61.1	2.665	bdl	bdl	bdl	bdl	bdl	0.27	1.177	0.035	0	1.78575	189.2	0.7	bdl
29/7/2008		BE3	1.143	1.388	60.3	4.502	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	1.60195	200.3	bdl	bdl
29/7/2008		BE4	0.658	1.358	103.7	3.845	bdl	bdl	bdl	bdl	bdl	bdl	1.006	0.032	4.328	12.6	304.2	2.52	bdl

Note : bdl - below detection limit

**insufficient sample

The results also show that most of water samples from Gua Tempurung consist of a broad trace metal elements and range from Fe, Mn, Al, Pb, Cd, Cu, As and Zn. Water samples in Gua Kelam and Gua Wang Burma show the presence of Zn which varies from 0.013 mg/l – 0.082 mg/l and 0.062 mg/l – 0.321 mg/l, respectively.

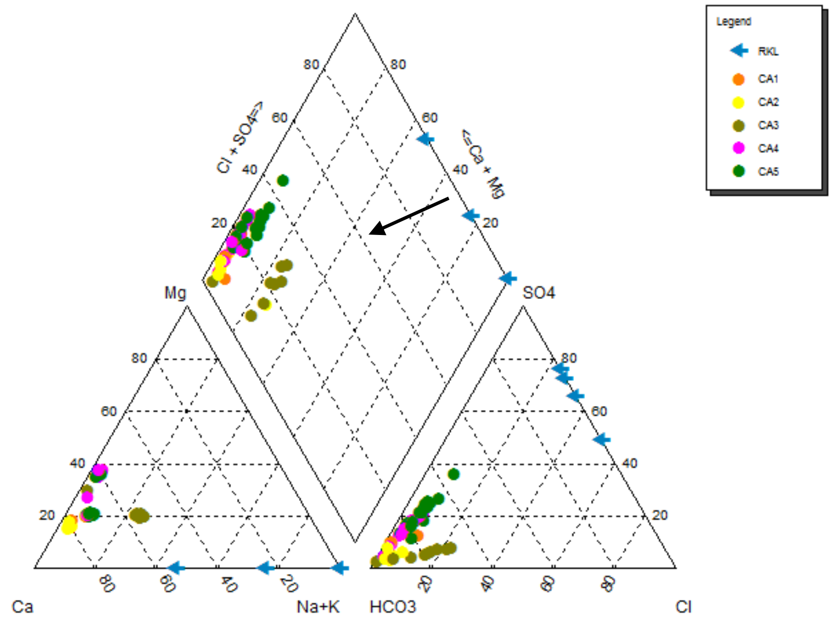
On the other hand, drip water from Batu Caves is high in NO_3 and the mean value range from 6.85mg/l- 70.84mg/l. Gua Tempurung shows the mean value of NO_3 ranging from 1.233 mg/l – 3.59 mg/l (drip, pond and spring) and 5.07 mg/l – 8.1 mg/l, respectively.

3.3.2 Hydrogeochemical Facies

The dominant ions are displayed graphically in Piper Diagram (Figure 3.4). The water samples designate as a Ca-HCO_3 facies, as could be expected in a limestone environment. Otherwise, meteoric water assigns as a Na-SO_4 facies. The arrow in the diagram suggests the alteration of Na-SO_4 facies (meteoric water) to Ca-HCO_3 facies (drip water) as a result of hydrpgeochemistry evolution process acts in the karst system.

3.3.3 Source Rock Deduction

Table 3.13, 3.14 and 3.15 show the results of PHREEQC analysis. The ratios of Ca/ (Ca+ SO_4), Mg/ (Ca+Mg), Cl^-/(Sum Anions), the HCO_3/ (Sum Anions) and TDS determine the water samples originates from carbonate weathering. The results also prove that Ca is derived from calcite and dolomite. However, the HCO_3/ (Sum Anions) ratios show that the a)



b)

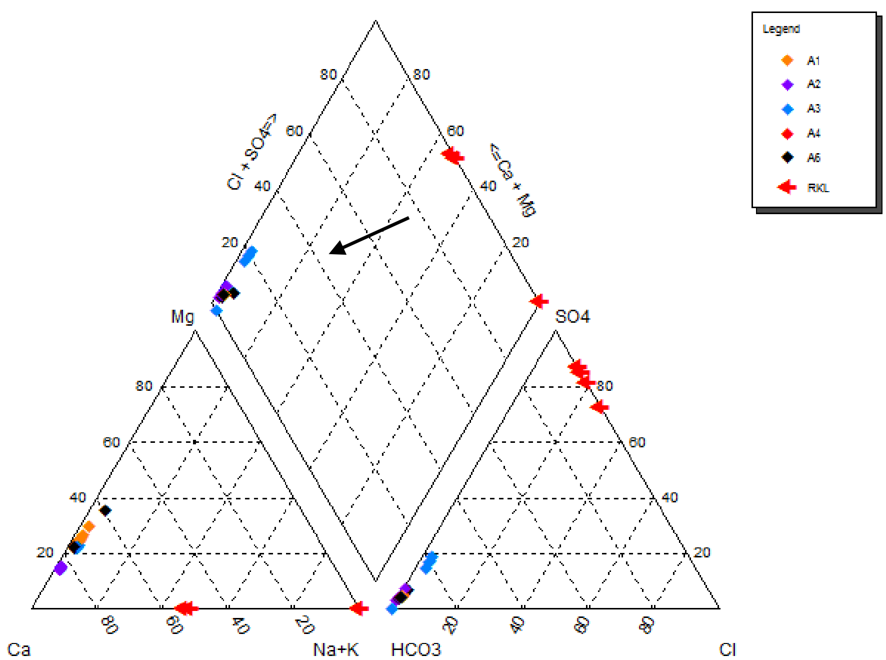
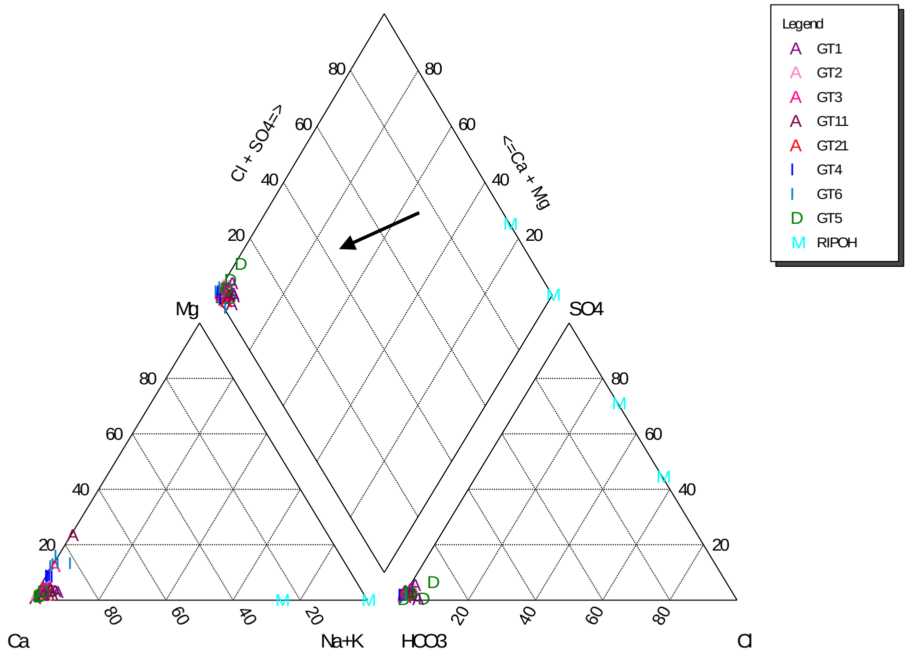


Figure 3.4 a: The Piper Diagram of drip water in Villa Cave, Batu Caves

b: The Piper Diagram of drip water in Dark Cave, Batu Caves c)



d)

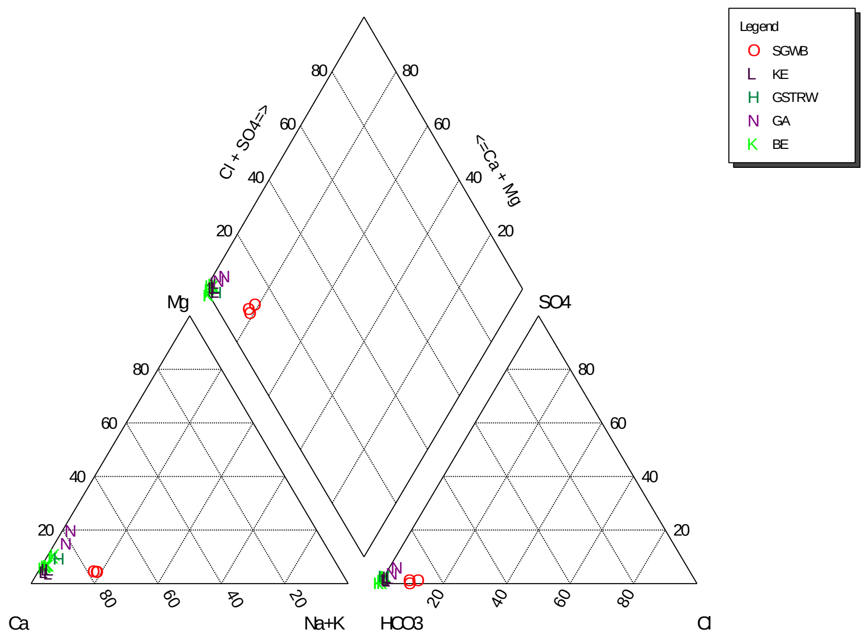


Figure 3.4: c) The Piper Diagram of karst water in Gua Tempurung

d) The Piper Diagram of karst water in Gua Straw, Gua Angin, Gua Berlian, Gua Kelam dan Gua Wang Burma drip water from Villa Cave (CA1, CA2, CA3, CA4 and CA5) and Dark Cave (A3) are indicated brine (August 2008 and January 2008).

3.3.4 $SI_{calcite}$

Overall, the $SI_{calcite}$ ranges from undersaturated to oversaturated with calcite. The results show that 97% of drip water in Dark Cave are reaches oversaturation and ranges from 0.398 - 0.79. Besides, drip water in Villa Cave show that only 70% are reach oversaturated value and range from 1.908 - 1.01.7. Drip water in Gua Tempurung shows that the $SI_{calcite}$ -0.215-0.913. Figure 3.5 represents a rapid change of $SI_{calcite}$ traverse along Gua Tempurung.

Table 3.13 : Source rock deduction analysis for drip water in Villa Cave, Batu Caves

Parameter	Attention Value	Conclusion	Statistic	CA1 n=6	CA2 n=6	CA3 n=9	CA4 n=20	CA5 n=23
Water Type				Ca-HCO3				
(Na+K-Cl)/(Na+K-Cl+Ca)	> 0.2 and < 0.8	Plagioklase weathering possible	Range (%)	-0.062-0.01 (100%)	-0.046-0.251 (100%)	-0.153-0.23 (100%)	-0.035 -0.03 (100%)	-0.025-0.039 (100%)
	< 0.2 or > 0.8	Plagioklase weathering unlikely	Range (%)	na	na	na	na	na
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	Range (%)	0.514-0.549 (60%)	0.817 (33%)	0.566-0.867 (56%)	0.358-0.643 (20%)	0.512-0.648 (61%)
	=0.5	Halite solution	Range (%)	0.509 (20%)	na	0.496-0.51(33%)	na	na
	<0.5, TDS >500	Reverse Softening, seawater	Range (%)	0.261 (20%)	0.28-0.474 (64%)	na	0.353-0.457 (10%)	0.488 (4%)
	<0.5, TDS <500 and >50	Analysis Error	Range (%)	na	na	0.165 (11%)	0.371-0.437 (70%)	0.371-0.437 (35%)
	<0.5, TDS <50	Rainwater	Range (%)	na	na	na	na	na
Mg/(Ca+Mg)	=0.5 and HCO3-/Si>10	Dolomite Weathering	Range (%)	na	na	na	na	na
	<0.5	Limestone-dolomite weathering	Range (%)	0.1607-0.2162 (100%)	0.1771-0.2875 (100%)	0.3188-0.4441 (100%)	0.3620-0.4912 (38%)	0.3675-0.4482 (65%)
	>0.5	Dolomite dissolution, calcite precipitation or seawater	Range (%)	na	na	na	0.5021-0.5629 (62%)	0.5681-0.6188 (35%)
	<0.5 and HCO3-/Si<5	Ferromagnesian Minerals	Range (%)	na	na	na	na	na
	>0.5	Granitic weathering	Range (%)	na	na	na	na	na
TDS	>500	Carbonate weathering or brine or seawater	Range (%)	843 (20%)	80-209	na	513-516 (10%)	63-480 (91%)
	<500	Silicate weathering	Range (%)	94-211 (80%)	574	83-380	69-224 (90%)	796-946 (9%)
Ca/(Ca+SO4)	=0.5	Gypsum dissolution	Range (%)	na	na	na	na	na
	<0.5, and pH <5.5	Pyrite oxidation	Range (%)	na	na	na	na	na
	<0.5, and pH neutral	Calcium removal - ion exchange or calcite precipitation	Range (%)	na	na	na	na	na
	>0.5	Calcium source other than gypsum - carbonate or silicates	Range (%)	0.869-0.95 (100%)	0.758-0.956 (100%)	0.886-0.967 (100%)	0.752-0.947 (100%)	0.78-0.916 (100%)
	pH			6.37-7.99	6.3-8.02	6-8.32	6.4-8.35	6.4-8.23
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	Range (%)	0.018-0.078 (100%)	0.018-0.061 (100%)	0.007-0.218 (100%)	0.015-0.048 (100%)	0.028-0.061 (100%)
	>0.8 and TDS<100	Rainwater	Range (%)	na	na	na	na	na
	<0.8	Rock weathering	Range (%)	na	na	na	na	na
HCO3-/ Sum Anions	>0.8	Silicate or carbonate weathering	Range (%)	0.835-0.855 (40%)	0.825-0.896 (50%)	0.98 (11%)	na	0.344-0.779 (100%)
	<0.8 sulfate high	Gypsum dissolution	Range (%)	na	na	na	na	na
	<0.8 sulfate low	Seawater or brine	Range (%)	0.64-0.78 (60%)	0.684-0.781 (50%)	0.48-0.739 (89%)	0.502-0.791 (100%)	
SI Calcite	>0	Oversaturated with respect to calcite	Range (%)	0.124-0.904 (40%)	0.212-1.01 (50%)	0.115-0.477 (44%)	0.015-0.906 (90%)	0.109-0.578 (74%)
	=0	Saturated with respect to calcite	Range (%)	na	na	na	na	na
	<0	Undersaturated with respect to calcite	Range (%)	-1.447--0.192 (60%)	-1.211--0.661 (50%)	-1.908--0.149 (56%)	-1.167--0.283 (10%)	1.271--0.042 (26%)
Conclusion	The interpretations of this water analysis strongly suggest: -The water samples primarily originate from calcium and bicarbonate, indicating a limestone origin - Sicalcite is indicates undersaturated to oversaturated with calcite - Most of water samples show a possibility of drip water is a brine types							

Note : % = Percentage of attention value/total sample (n)
na = not available

Table 3.14 : Source rock deduction analysis for drip water in Dark Cave, Batu Caves

Parameter	Attention Value	Conclusion	Statistic	A1 n=6	A2 n=6	A3 n=6	A4 n6	A6 n=6
Water Type				Ca-HCO3				
(Na+K-Cl)/ (Na+K-Cl+Ca)	> 0.2 and < 0.8	Plagioklase weathering possible	Range (%)	0.011-0.019 (100%)	0.008-0.016 (100%)	0.006-0.018 (100%)	0.012-0.022 (100%)	0.01-0.039 (100%)
	< 0.2 or > 0.8	Plagioklase weathering unlikely	Range (%)					
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	Range (%)	0.628-0.71 (100%)	0.648-0.967 (100%)	0.545-0.695 (100%)	0.613-0.804 (100%)	0.641-0.724 (100%)
	=0.5	Halite solution	Range (%)	na	na	na	na	na
	<0.5, TDS >500	Reverse Softening, seawater	Range (%)	na	na	na	na	na
	<0.5, TDS <500 and >50	Analysis Error	Range (%)	na	na	na	na	na
	<0.5, TDS <50	Rainwater	Range (%)	na	na	na	na	na
Mg/(Ca+Mg)	=0.5 and HCO3-/Si>10	Dolomite Weathering	Range (%)	na	na	na	na	na
	<0.5	Limestone-dolomite weathering	Range (%)	0.247-0.303 (100%)	0.142-0.152 (100%)	0.221-0.223 (100%)	0.148-0.171 (100%)	0.318-0.369 (100%)
	>0.5	Dolomite dissolution, calcite precipitation or seawater	Range (%)	na	na	na	na	na
	<0.5 and HCO3-/Si<5	Ferromagnesian Minerals	Range (%)	na	na	na	na	na
	>0.5	Granitic weathering	Range (%)	na	na	na	na	na
TDS	>500	Carbonate weathering or brine or seawater	Range (%)	81-371 (100%)	125-552 (100%)	119-171 (83%)	70-300 (100%)	90-268 (100%)
	<500	Silicate weathering	Range (%)	na	na	679 (17%)	na	na
Ca/(Ca+SO4)	=0.5	Gypsum dissolution	Range (%)	na	na	na	na	na
	<0.5, and pH <5.5	Pyrite oxidation	Range (%)	na	na	na	na	na
	<0.5, and pH neutral	Calcium removal - ion exchange or calcite precipitation	Range (%)	na	na	na	na	na
	>0.5	Calcium source other than gypsum - carbonate or silicates	Range (%)	0.94-0.951 (100%)	0.926-0.965 (100%)	0.878-0.935 (100%)	0.903-0.965 (100%)	0.911-0.958 (100%)
	pH			7.64-8.25	7.46-8.1	7.75-8.14	7.8-8.4	7.57-8.15
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	Range (%)	na	na	na	na	na
	>0.8 and TDS<100	Rainwater	Range (%)	na	na	na	na	na
	<0.8	Rock weathering	Range (%)	0.009-0.012 (100%)	0-0.008 (100%)	0.011-0.021 (100%)	0.006-0.017 (100%)	0.008-0.015 (100%)
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	Range (%)	0.86-0.897	0.91-0.956		0.854-0.932 (100%)	0.832-0.924 (100%)
	<0.8 sulfate high	Gypsum dissolution	Range (%)	na	na	na	na	na
	<0.8 sulfate low	Seawater or brine	Range (%)	na	na	0.478-0.757 (100%)	na	na
SI Calcite	>0	Oversaturated with respect to calcite	Range (%)	0.151-0.666 (100%)	0.259-0.867 (100%)	0.222-0.797 (100%)	0.158-0.797 (100%)	0.322-0.657 (63%)
	=0	Saturated with respect to calcite	Range (%)	na	na	na	na	na
	<0	Undersaturated with respect to calcite	Range (%)	na	na	na	na	-0.398 (33%)
Conclusion	The interpretations of this water analysis strongly suggest: -The water is primarily calcium and bicarbonate, indicating a limestone origin - Sicalcite value indicates that water sample is undersaturated to oversaturated with calcite - Only A3 show a posibility of drip water is brine							

Note : % = Percentage of attention value/total sample (n)
na = not available

Table 3.15 : Source rock deduction analysis for drip water in Gua Tempurung

Parameter	Attention Value	Conclusion	Statistic	GT1	GT2	GT3	GT4	GT5	GT6	GT11
Water type				Ca-HCO3						
(Na+K-Cl)/ (Na+K-Cl+Ca)	> 0.2 and < 0.8	Plagioklase weathering possible	Range (%)	-0.024-0.049 (100%)	-0.067-0.026 (100%)	-0.026-0.026 (100%)	0.005-0.03 (100%)	-0.059-0.033 (100%)	-0.018-0.06 (100%)	-0.088-0.017 (100%)
	< 0.2 or > 0.8	Plagioklase weathering unlikely	Range (%)	na	na	na	na	na	na	na
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	Range (%)	0.638-0.943 (80%)	0.717-0.792 (33%)	0.348-0.816 (87%)	0.588-0.976 (100%)	0.637-0.802 (43%)	0.533-0.906 (64%)	0.543-0.625 (43%)
	=0.5	Halite solution	Range (%)	na	0.494-0.496 (50%)	na	na	na	na	na
	<0.5, TDS >500	Reverse Softening, seawater	Range (%)	na	na	na	na	na	na	na
	<0.5, TDS <500 and >50	Analysis Error	Range (%)	0.401 (20%)	0.168 (17%)	0.348 (13%)	na	0.154-0.45 (57%)	0.063-0.271 (33%)	0.143-0.406 (57%)
	<0.5, TDS <50	Rainwater	Range (%)	na	na	na	na	na	na	na
Mg/(Ca+Mg)	=0.5 and HCO3-/Si>10	Dolomite Weathering	Range (%)	na	na	na	na	na	na	na
	<0.5	Limestone-dolomite weathering	Range (%)	0.0004-0.0009 (100%)	0.0080-0.0198 (100%)	0.0300-0.1232 (100%)	0.0833-0.0924 (100%)	0.0129-0.0358 (100%)	0.0459-0.1611 (100%)	0.0064-0.2362 (100%)
	>0.5	Dolomite dissolution, calcite precipitation or seawater	Range (%)	na	na	na	na	na	na	na
	<0.5 and HCO3-/Si<5	Ferromagnesian Minerals	Range (%)	na	na	na	na	na	na	na
	>0.5	Granitic weathering	Range (%)	na	na	na	na	na	na	na
TDS	>500	Carbonate weathering or brine or seawater	Range (%)	83-101 (100%)	63-104 (100%)	38 - 126 (100%)	41-156 (100%)	63-121 (100%)	96-165 (100%)	64-116 (100%)
	<500	Silicate weathering	Range (%)	na	na	na	na	na	na	na
Ca/(Ca+SO4)	=0.5	Gypsum dissolution	Range (%)	na	na	na	na	na	na	na
	<0.5, and pH <5.5	Pyrite oxidation	Range (%)	na	na	na	na	na	na	na
	<0.5, and pH neutral	Calcium removal - ion exchange or calcite precipitation	Range (%)	na	na	na	na	na	na	na
	>0.5	Calcium source other than gypsum - carbonate or silicates	Range (%)	0.95-0.995 (100%)	0.963-0.974 (100%)	0.977-0.982 (100%)	0.975-0.984 (100%)	0.949-0.996 (100%)	0.975-0.982 (100%)	0.98-0.985 (100%)
	pH		Range (%)	7.62-8.09	8.01-8.21	7.53-8.31	7.35-7.92	7.56-8.29	7.5-8.14	7.74-7.98
Cl-/ Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	Range (%)	na	na	na	na	na	na	na
	>0.8 and TDS<100	Rainwater	Range (%)	na	na	na	na	na	na	na
	<0.8	Rock weathering	Range (%)	0.002-0.053 (100%)	0.009-0.077 (100%)	0.005-0.957 (100%)	0.001-0.009 (100%)	0.007-0.064 (100%)	0.005-0.02 (100%)	0.008-0.007 (100%)
HCO3-/ Sum Anions	>0.8	Silicate or carbonate weathering	Range (%)	0.839-0.924 (100%)	0.903-0.96 (100%)	0.916-0.957 (100%)	0.93-0.944 (100%)	0.834-0.942 (100%)	0.923-0.961 (100%)	0.872-0.953 (100%)
	<0.8 sulfate high	Gypsum dissolution	Range (%)	na	na	na	na	na	na	na
	<0.8 sulfate low	Seawater or brine	Range (%)	na	na	na	na	na	na	na
SI Calcite	>0	Oversaturated with respect to calcite	Range (%)	0.218-0.573 (100%)	0.277-0.834 (100%)	0.263-0.913 (100%)	0.618 (83%)	0.425-0.775 (86%)	0.39-0.904 (83%)	0.271-0.869 (72%)
	=0	Saturated with respect to calcite	Range (%)	na	na	na	na	na	na	na
	<0	Undersaturated with respect to calcite	Range (%)	na	na	na	-0.211 (17%)	-0.089 (14%)	-0.11 (17%)	-0.081- -0.215 (28%)
Conclusion	The analysis strongly suggest that : - Carbonate weathering and limestone origin with minor dolomite, possibly with some ion exchange - All drip water is reach oversaturated, otherwise spring and pond are varies from undersaturated to oversaturated									

Note : % = Percentage of attention value/total sample (n)
na = not available

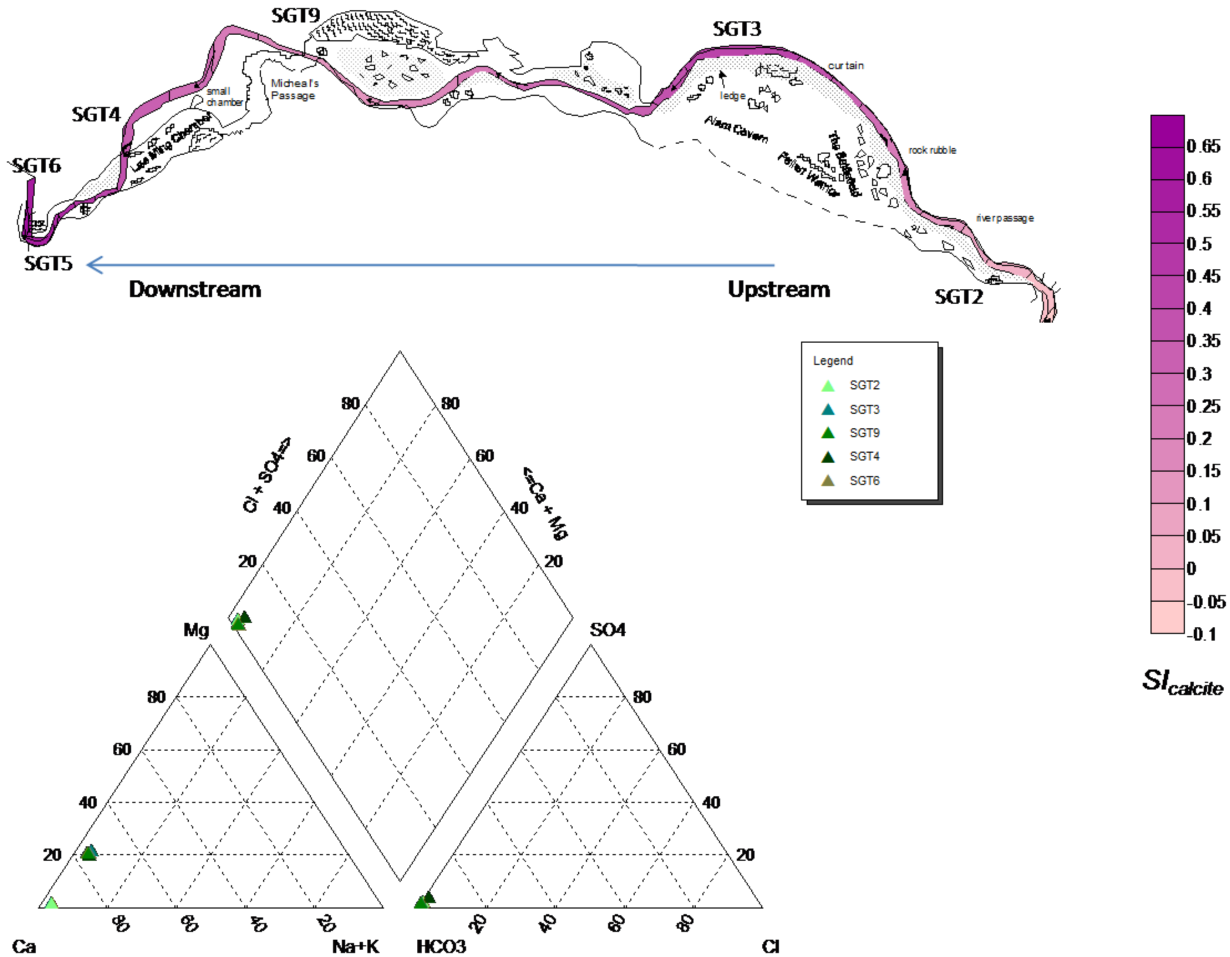


Figure 3.5a: The variability of chemical properties throughout Sungai Gua Tempurung (May 2008)

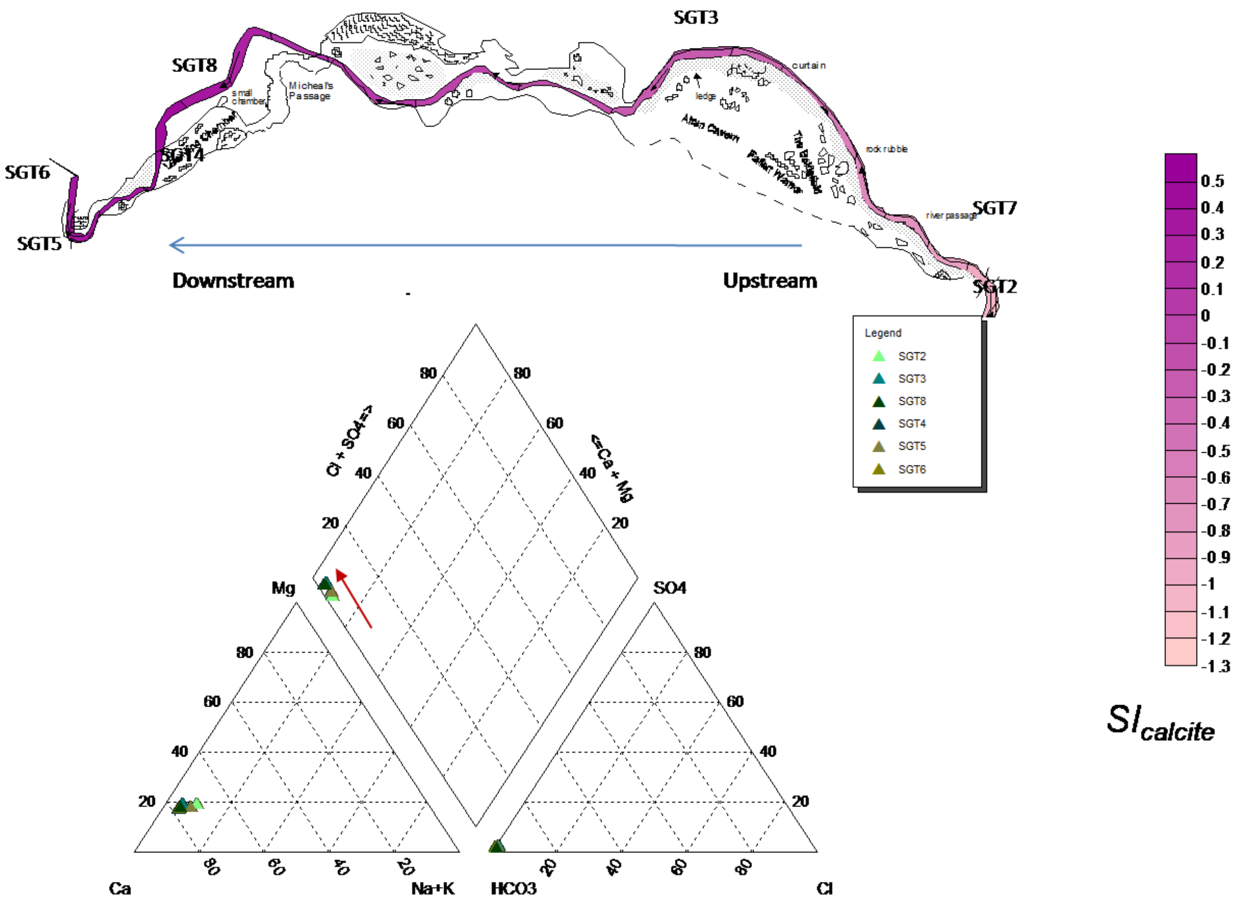


Figure 3.5b: The variability of chemical properties throughout Sungai Gua Tempurung (October 2008)

3.4 DISCUSSION

3.4.1 Drip water hydrology

Figure 3.6 and 3.7 show the time series of drip rate, conductivity and rainfall. The seasonal flow indicates that high variability drip with moderate discharge. This suggest that the seasonal flow is intermittently responding to water input and subject to underflow during large rainfall input flow through poorly connected macropores and causing a high variable head of hydraulic pressure. The hydraulic pressure is decline coincidently with the decrease of water input. This implies a longer water residence time and allows sufficient time for water rock interaction process in the reservoir.

On the other hand, seepages flows demonstrate medium variability drip and constantly flow. This suggests that the drip water flows through well-connected matrix and fractures. The well connected matrix allows the water consistently infiltrates through the reservoir with a constant hydraulic pressure.

Generally, the graph pattern shows that the drip rates and conductivity increase coincidently with high rainfall event vice versa. Figure 3.7 is well illustrating this phenomenon, low water input (March and May, 2008) trigger a small amount of water accumulation in reservoir. Therefore, the hydraulic pressures become low as a result of

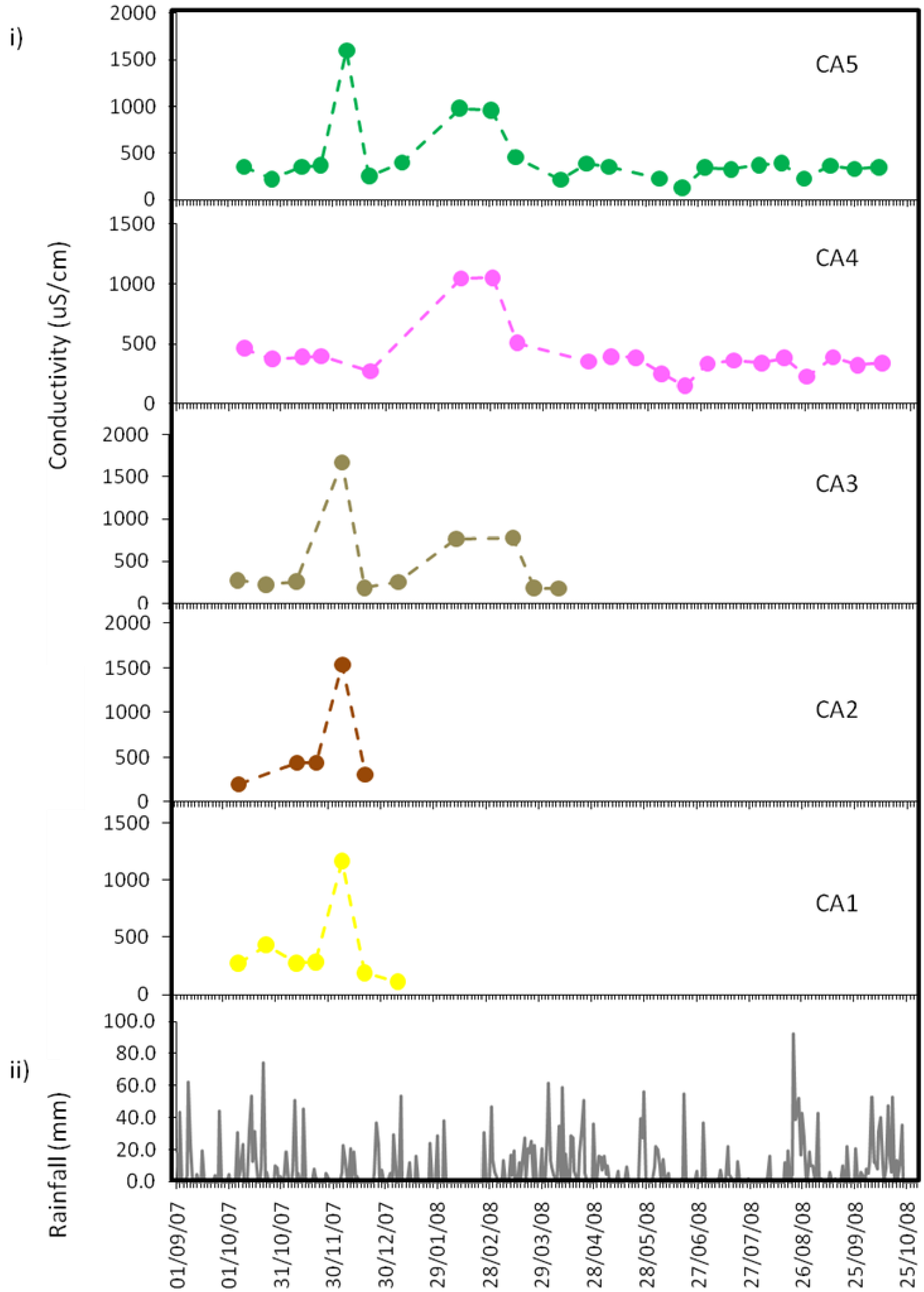


Figure 3.6a: i)The conductivity pattern of drip water in Villa Cave
ii) Rainfall events

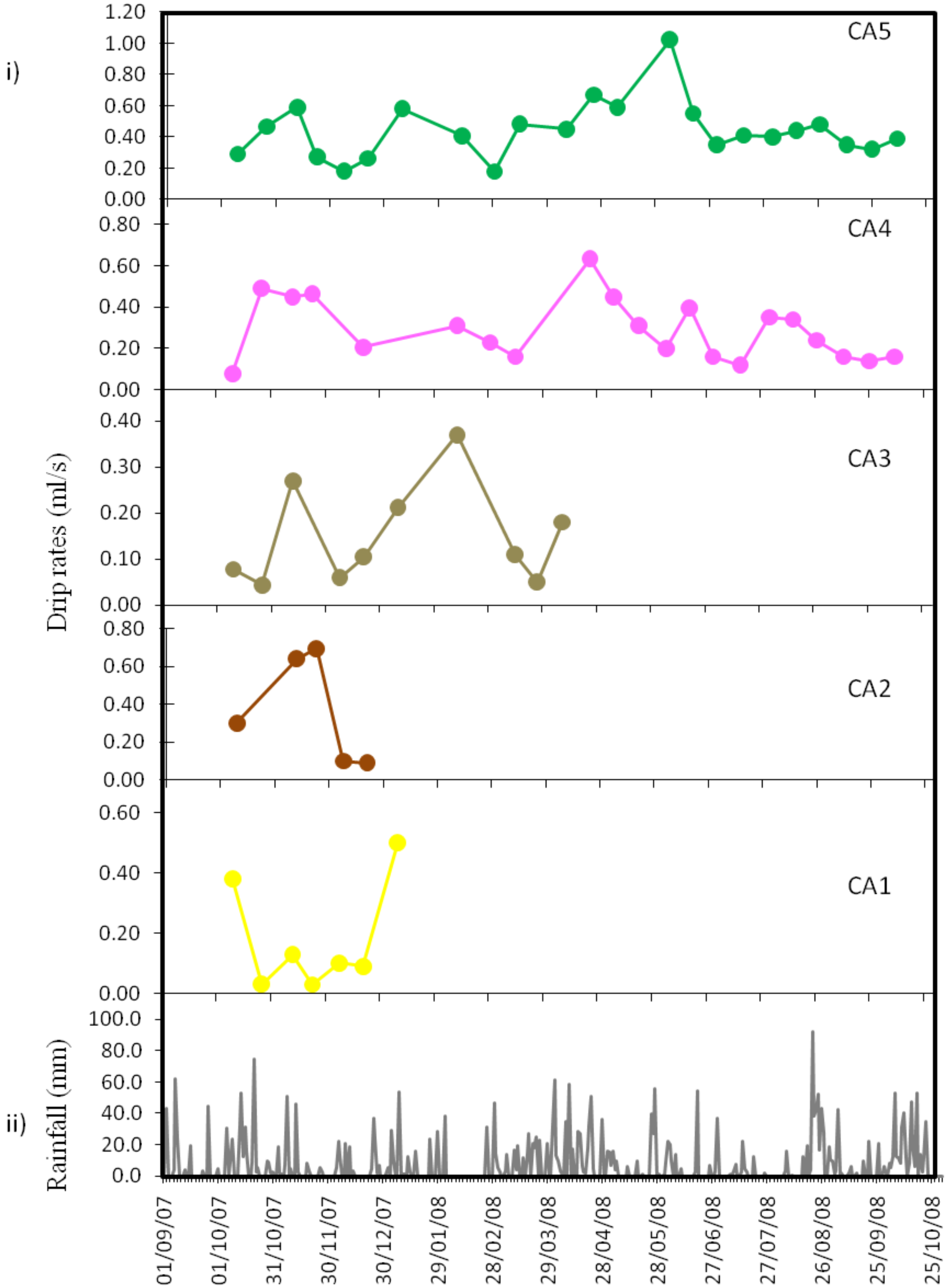


Figure 4.6b: i) The drip rates pattern of drip water in Villa Cave
: ii) Rainfall events

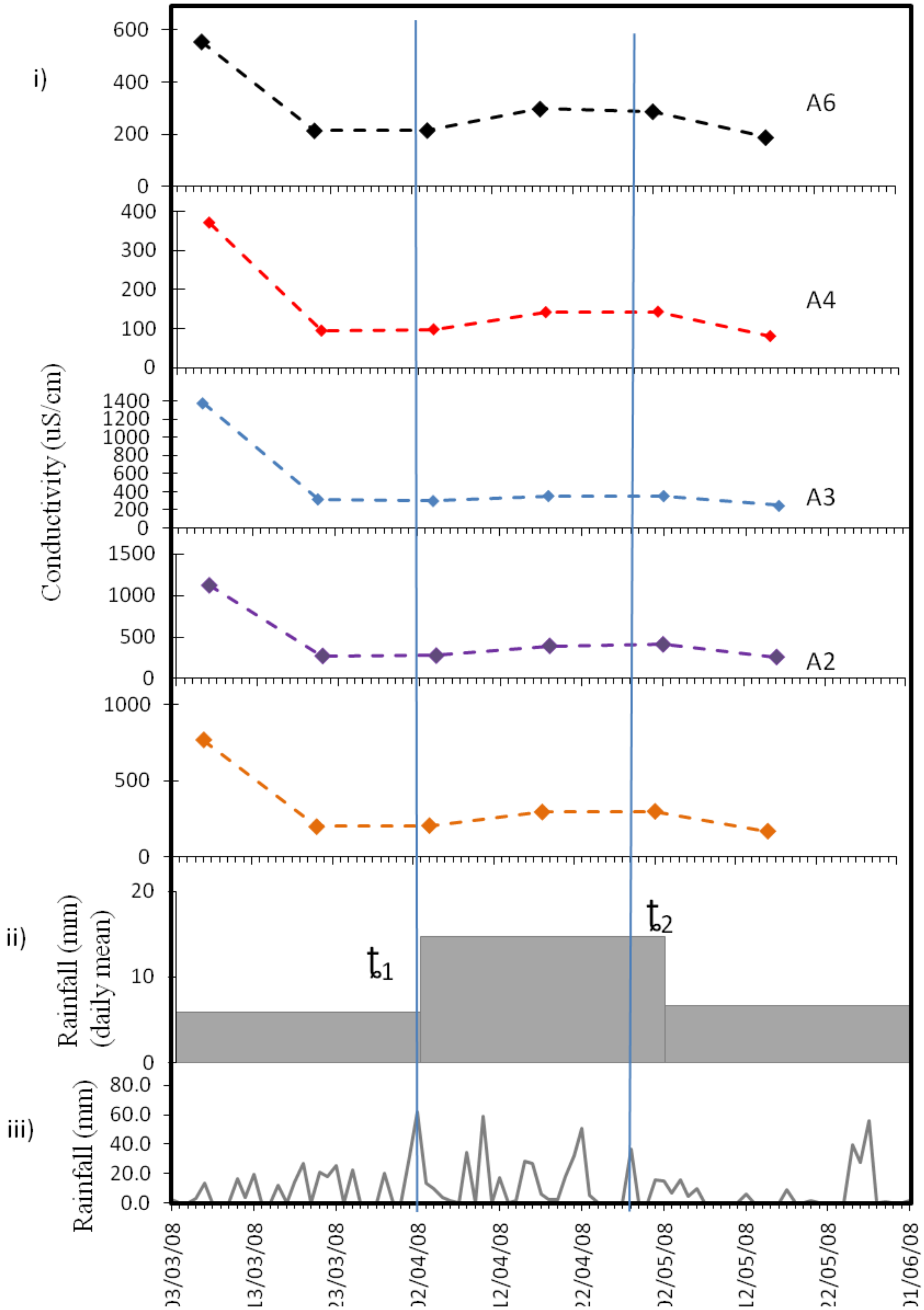


Figure 3.7a : i) The conductivity pattern of drip water in Dark Cave
ii) Rainfall events (Mean Daily)
iii) Rainfall events

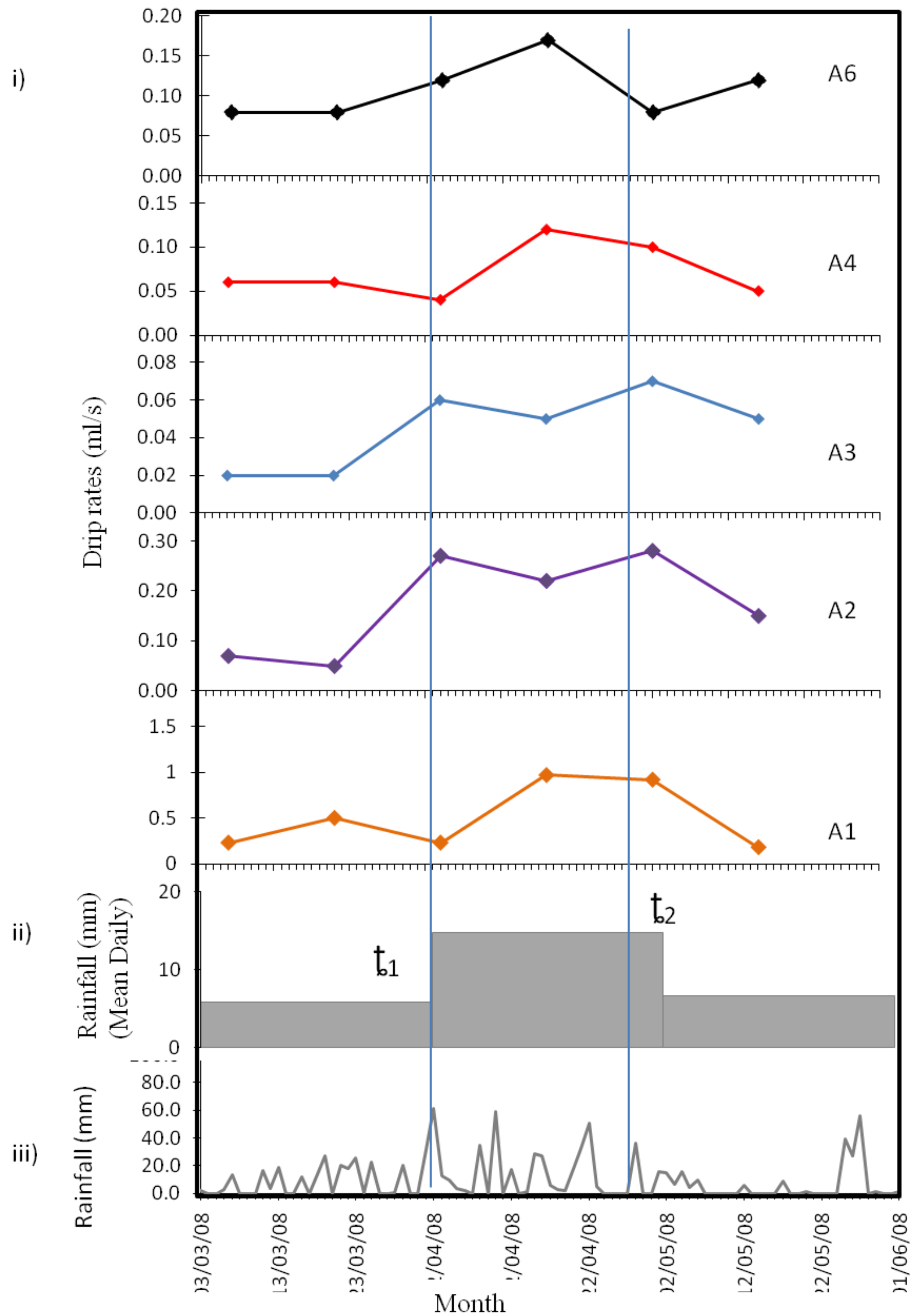


Figure 3.7b i) The drip rates pattern of drip water in Dark Cave
ii) Rainfall events (Mean Daily)
iii) Rainfall events

slow water infiltration in pores and microfissures and the drip rates is decline. In contrast, drip rate is elevated on April due to rapid water infiltration during rainfall events and increased the hydraulic pressures in karst system. Thus the drip rate is increased.

The time-lag indicates the filling/feeding time of water infiltrates through microfissures and pores in karst (Fernandez-Cortes et al., 2008). By referring A3 and A2 drip sites, the sharp increase in drip rate and conductivity, on 4/4/2008 ($\square_1$) and 2/5/2008 ($\square_2$) and the occurrences of rainfall excess is on 2/4/2008 and 30/4/2010, identify that the time lag is short which varies from 2 to 3 days. However, is should be noted that the sampling is not perform during water excess, therefore the time-lag mighty be less than 2 to 3 days.

The time-lag study indicates a short time for water to fill in karst system, approximately 2 to 3 days. In contrast, monitoring study of drip rates in Southern Spain revealed that the average filling time is 26 (±10 days) (Fernandez-Cortes et al., 2008). The moist environment in Peninsular Malaysia suggests that the hydraulic pressure is considered constant and stable throughout the year as a response to rapid water input. This suggests that each of karst system is correspondingly complex respond to the climatic condition.

3.4.2 Geochemistry

The chemical properties demonstrate that the karst water in Peninsular Malaysia is strongly influenced by the host rock composition. The sources rock deduction analysis concluded that the karst water is derived from limestone-dolomite weathering process. However, the ratios show that a wide range of chemistry content could be due to the variance of karst host rock in Peninsular Malaysia. Generally, the karst host rock in Peninsular Malaysia comprises of white or pale grey coarse to fine grained marble (Gobbet and Hutchison, 1967). Gua Tempurung show broad metal trace element originates from tin ore in the karst host rock which is consists of SiO, TiO, FeO, MnO, CaO and NaO (Ismail, 1994). Furthermore, water samples from Jebak Puyuh and Gunung Senyum show the greater value of Mg compared to other water samples. This may be due to high impurities of the host rock (Yong, 2004 and Jonathan, 2004

For preliminary study, the unique characteristic and consistent data from Batu Caves may represent better discussion to understanding the acts of geochemistry process in Peninsular Malaysia. The thicknesses cover of Dark Cave wis approximately 400 m (Salleh, 2008). Meanwhile, Villa Cave limestone cover is around 750 m (Lekshaman, 2008). The results show that the increase of TDS, Ca and NO_3 in Villa Cave must be significant due to the travel distance of flow route taken in karst system and influence the chemical properties. This suggests that drip water in Villa Cave may experience relatively longer flow routes which increases surface reaction rather than Dark Cave and increases the water rock interaction process (Tooth et al., 2003).

The high concentration of NO_3 could be derived from guano (Ford and William, 2007). Bullock (1971) indentified approximately nine species of bats roost in this caves and some parts of the cave floor are covered with thick guano. On the other hand, in Villa Cave the presence of bat habitat is only observed at the entrance. This suggests that the drip water in the Dark Cave which is reacting with guano may directly infiltrates through the Villa Cave and effect the chemical composition.

Despite of greater NO_3 element, the source rock deduction indicates that the HCO_3^-/ (Sum Anions) ratio designates the water samples from Villa Cave (CA1, CA2, CA3, CA4 and CA5) and Dark Cave (A3) are brine which is impossibly present in limestone environment. Theoretically, the brine water types present as a result of saltwater intrusion, oil-field contamination or contamination by deicing salts (Hounslow, 1995). This could be due to the contribution of abundant NO_3 in this karst system and extensively alter the chemical composition of karst water. This is supported by the fact that the reaction between guano and calcite produce hydroxyapatite (Ford and William, 2007). Theoretically the water rock interaction process will be increase as a result of a long travel distance of flow route, therefore the $SI_{calcite}$ value of karst water from Villa Cave is expected to be high compared to Dark Cave. However, the results that 97% of drip water in Dark Cave are saturated. Besides, only 70% in Villa Cave are reached oversaturated value. This also consistent with Tooth (2000) explained that the chemical properties in karst system is subjected to the human activities either in or above the cave.

Moreover, the variations in karst water chemistry can be used to determine the water rock interaction acts in karst system. Variations in Ca and Mg/Ca show a significant negative correlation at each site and to parallel Prior Calcite Precipitation (PCP) vector (Figure 3.8). This demonstrates that Ca tends to decrease during PCP occurrences and increase the Mg. This is strongly supported by the facts that the dissolution rate is declined due to solution tends to reach saturation associated with pH value above 6 and proves the PCP occurrences in this karst system (Figure 3.9). On the other hand, Figure 3.10 shows a negative correlation of $SI_{calcite}$ and drip rates.

Since the lowest drip rates are subjected to the low water input, suggesting that the PCP tends to occur during low water input due to the increase of evapotranspiration in karst system and trigger the calcite precipitation. In addition, the Mg/Ca also implies the significant of dilution and dissolution process in the karst system (Tooth et al., 2003 and Baker et al., 2006). The trend show that during high water input (high drip rates) the Mg/Ca ratios tends to decrease. This could be due to the occurrences of dilution process increase during high water input as a result of new/young water present in karst reservoir. This is consistent with previous research claimed that the PCP tends to increase during summer coincidently with low water input (Tooth et al., 2003 and Baldini et al., 2006).

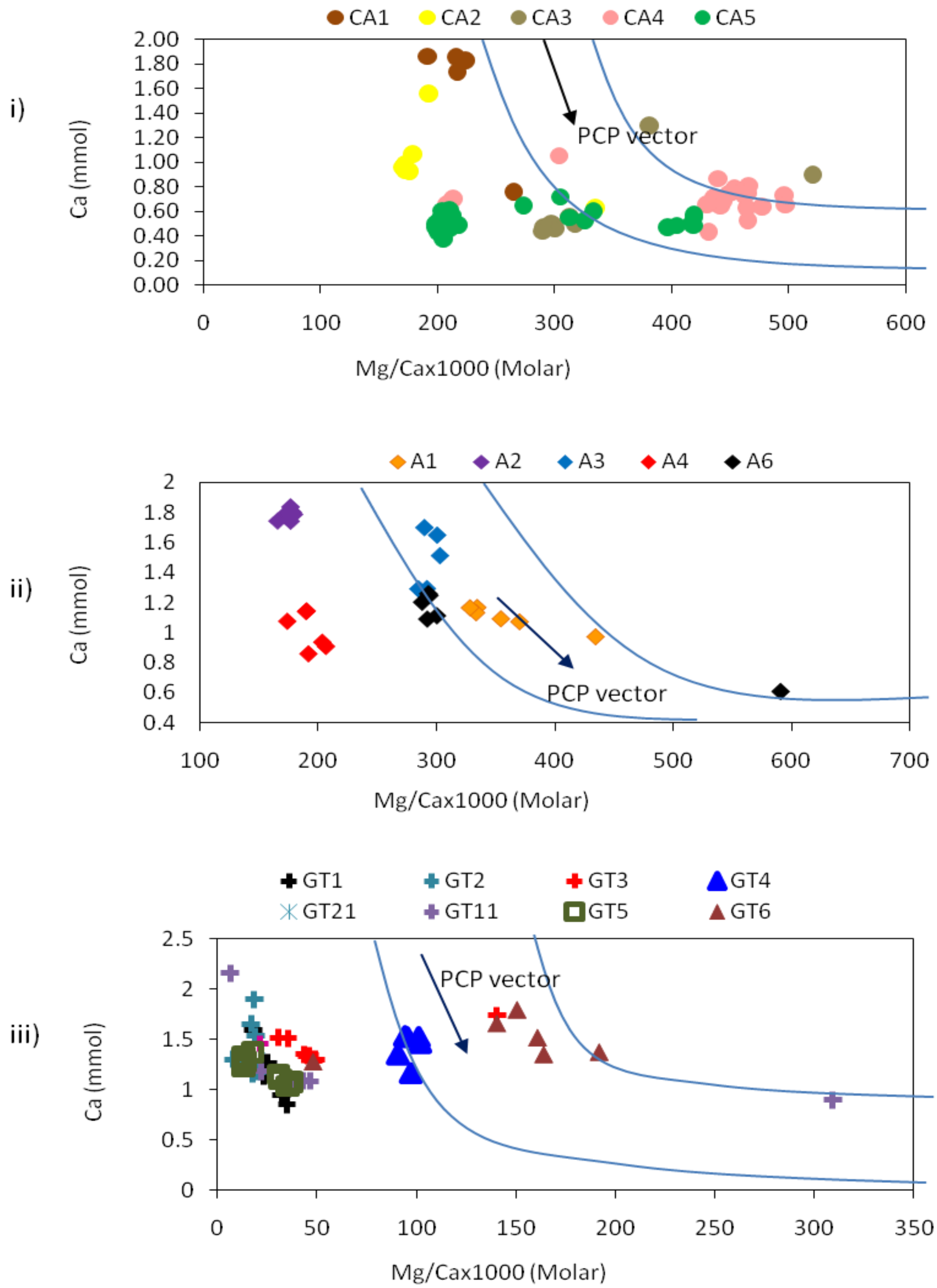


Figure 3.8: Ca against Mg/Ca to isolate the effects of calcite precipitation
i) Villa Cave, Batu Caves
ii) Dark Cave, Batu Caves
iii) Gua Tempurung

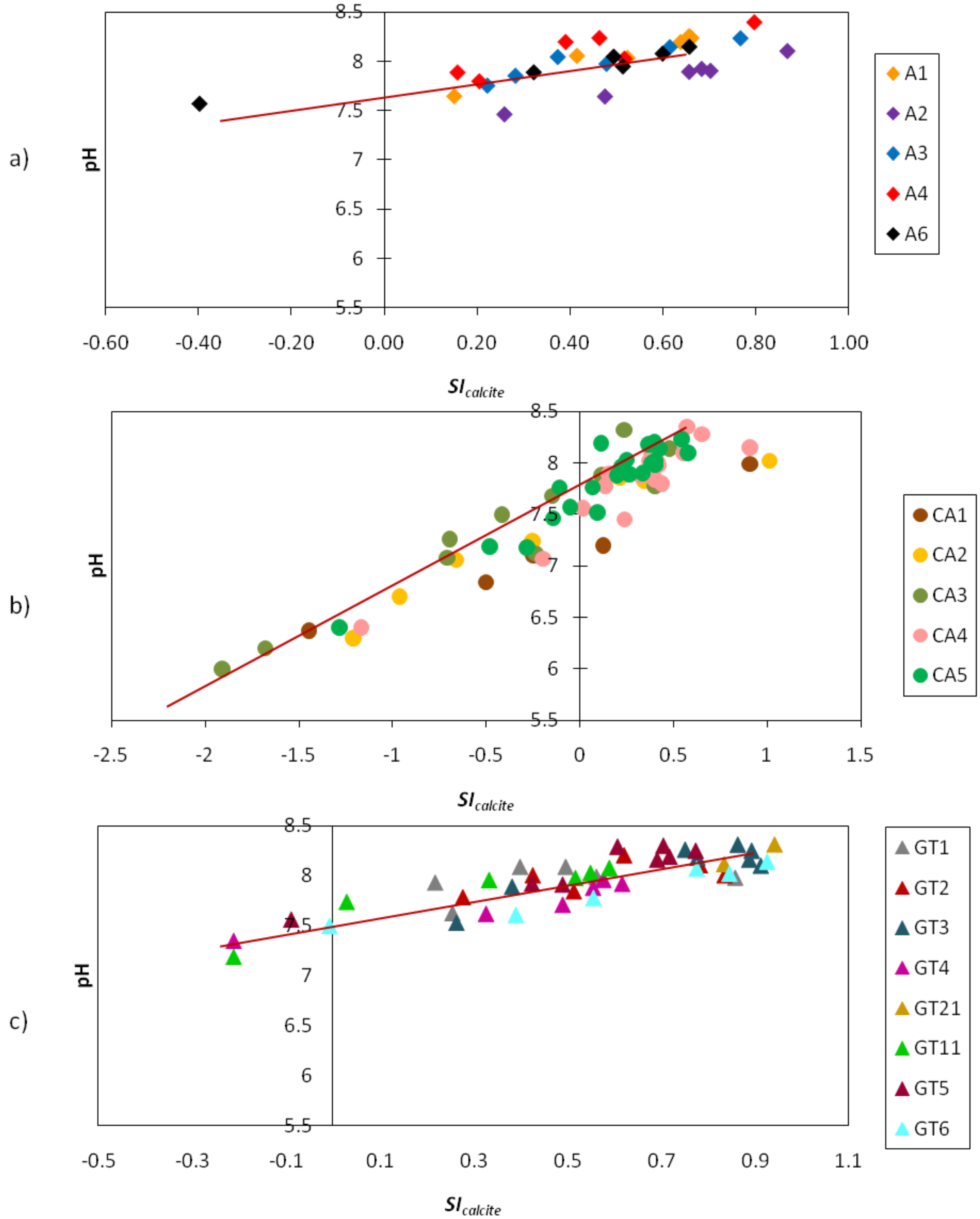


Figure 3.9: The relationship of pH value and $SI_{calcite}$

a) Villa Cave, Batu Caves

b) Dark Cave, Batu Caves

c) Gua Tempurung

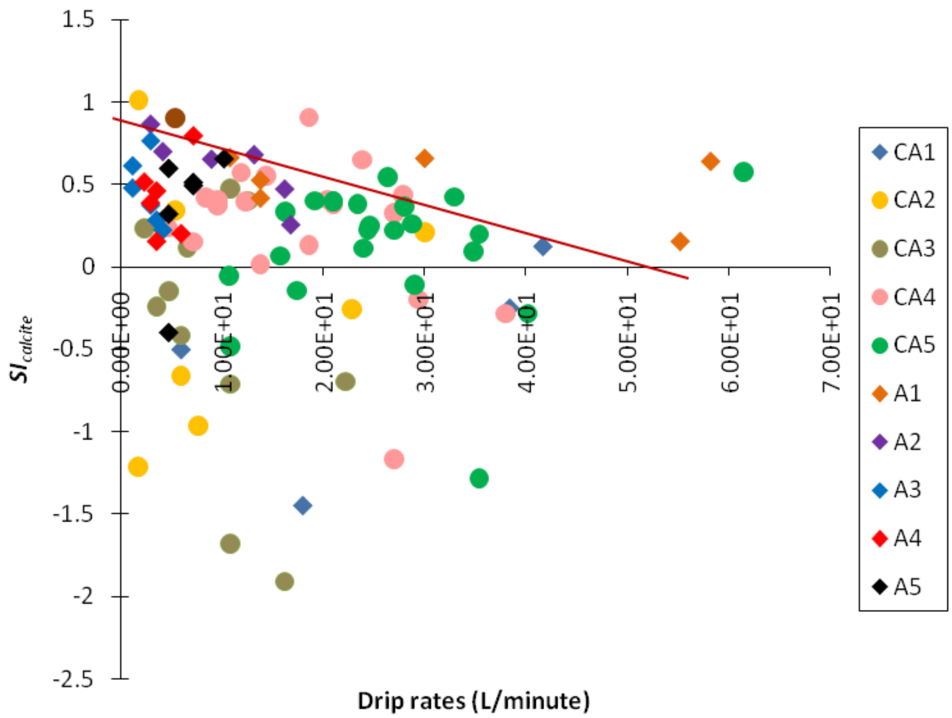


Figure 3.10: The correlation of $SI_{calcite}$ ratios and drip rates (Batu Caves).

3.4.3 Comparison between Drip Sites Characteristic

There are significant differences in Ca concentrations among drip water sites and also between drip waters and other types of karst water. However monitoring study only performed at Batu Caves and Gua Tempurng, the details explanation for water rock interaction processes for other sites are limited. Piper Diagram demonstrates that the ionic exchange processes play a major role in karst system and control the chemical properties. All drip water designates as a Ca-HCO3 facies as a result of the Na ion is replaced by Ca and SO4 is exchange with HCO3. However it should be noted that the drip water from Batu Caves is slightly scattered especially CA3 (see Figure 3.5). Since SO4 and Na are high in Batu Caves, this suggests that CA3 may experience a small potential of ionic exchange process and decrease the Ca concentration. This demonstrates that the variance of flow path taken in the karst system and characteristic influence the chemical properties of drip water.

In contrast, Mg/Ca ratios plotted for Gua Tempurung and the different behavior are observed. Each of drip (GT1, GT2, GT3, GT21 and GT11) and pond (GT5) site has a narrower range in Mg/Ca and falls distinctly to the left of the calcite precipitation vector (see Figure 3.9). All drip sites and pond align with the PCP vector. At GT4 and GT6 (spring) show a pronounced lateral spread and high in Mg. GT4 flows throughout the year and form a huge flowstone, however GT6, the discharge is subjected to high water excess. High volumes of water discharge from spring suggests that the karst water originates from a huge reservoir or vadose zone drains freely under gravity. This proposed that in the vadose zone the potential of surface reaction is reduced due to high water volume in the vadose zone and influences the potential of PCP in the reservoir. This strongly support previous researcher which concluded that the behavior of drip water is varies according to the delivery potential and mechanism to each drip sites (McDonald et al., 2007 and Baldini et al., 2006).

3.4.4 Hydrogeochemical Evolution

The present study underscores the necessity of thoroughly understanding a cave drip water hydrogeochemistry in selected caves in Peninsular Malaysia. The preliminary and relatively details study of drip rates in Batu Caves is considered the hydrogeochemistry evolution in karst system. Figure 3.11 illustrates a simplified conceptual model of karst system. It is divided into three zone, the upper zone, intermediate zone and lower zone. All karst water is assumed to be fed from matrix soil water flow in the absence of recharge. The acidic meteoric water which consists of low chemical properties infiltrates this soil zone and reacts with CO_2 and produces H_2CO_3. The upper zone is subjected to the open system condition and carbonate dissolution processes act actively. In addition, this zone is also characterized by low water storage capacity due to high porosity of weathered soil. Then, the water composition infiltrates through intermediate zone.

In the intermediate zone, dissolution and dilution process are dominantly control on the karst system. The processes increase during high water input, as a result of young water infiltrates through the matrix soil and fracture. The meteoric water infiltrates through the intermediate zone shows the significant the evolution of Na-SO_4 facies for

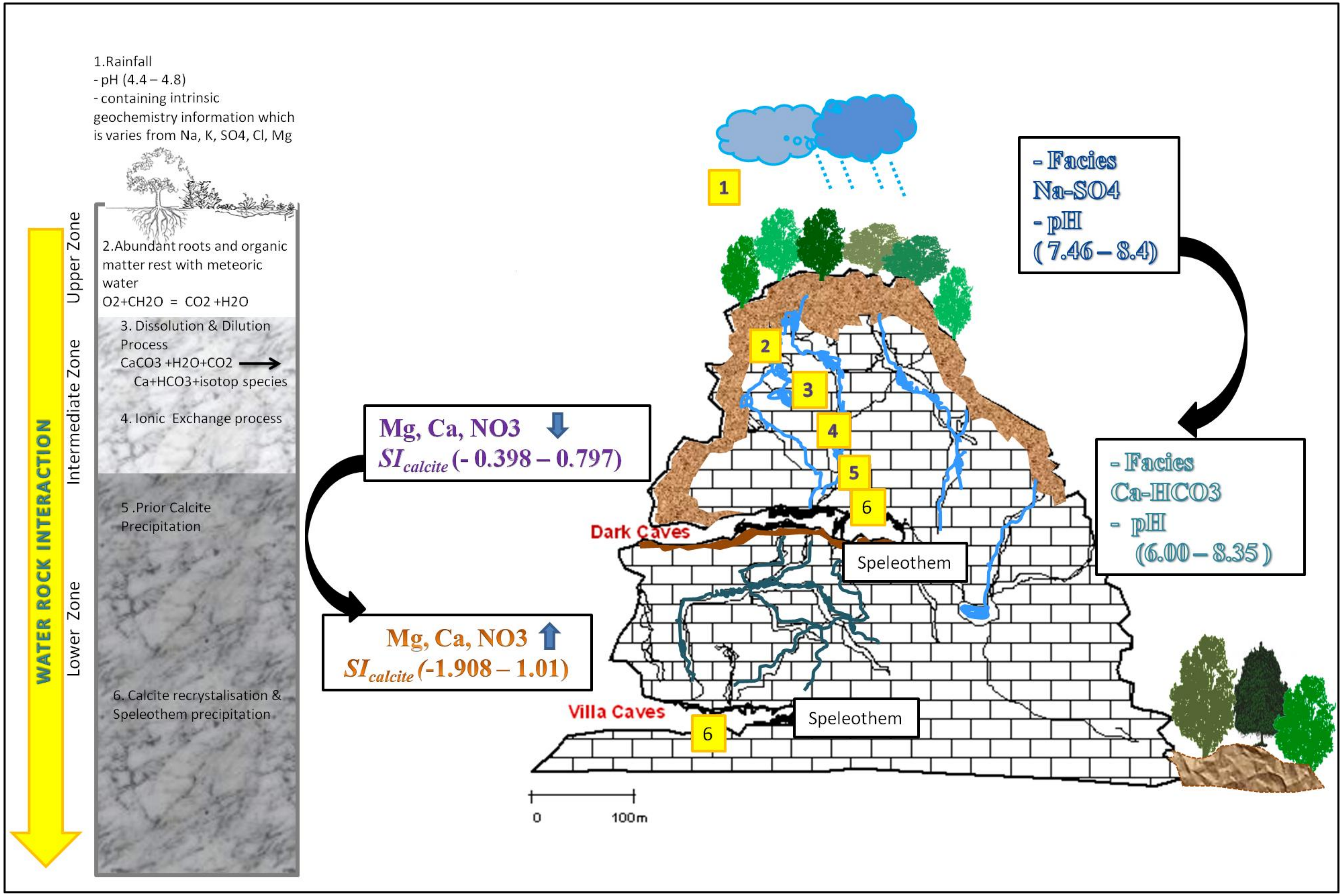


Figure 3.11: The conceptual model of hydrogeochemistry evolution in karst system.

meteoric water to Ca-HCO_3 facies (see Figure 4.4). The evolution implies the significant of ionic exchange process in karst system. The chemistry content of meteoric water is high in Na and SO_4. On the other hand, a karst reservoir is dominated by Ca and HCO3 ions, as a result of dissolution of calcite. When meteoric water infiltrates through the karst reservoir, an exchange of ions takes place. The Na ion is replaced by Ca and SO4 is exchanged with HCO3, a Ca-HCO_3 as result.

Monitoring of water input and drip rates indicate that the drip water can be classified into two group based on hydrological response which are medium variable drip (seepages flow) and high variable drip (seasonal flow). The seepages flow and seasonal flow conveniently indentify end-member in spectrum of possible flow regimes types (see Figure 4.2). The drip rate tends to increase associated with high rainfall (high water input) event vice versa. The volume of water input control the delivery potential of water infiltrates through the lower zone. The hydraulic pressure is perpendicular with volume of water input.

Then, PCP plays a dominant process in the lower zone. The $SI_{calcite}$ value shows that most drip water is saturated with calcite. Besides, the high pH value also shows the significant of the declined of dissolution rate in the zone. The high $SI_{calcite}$ value in Dark Cave designates the potential of speleothem deposition. This proves by the fact that Dark Cave is extensively covered with speleothem such as stalagmites, stalactites and pond which is proved growing secondary deposits.

In addition, the flow routes taken and the travel distance of karst water must be taken into account control the hydrogeochemistry evolution in karst system. The variant of limestone cover of Dark Cave and Villa Cave differentiate the chemical properties of karst water. Moreover, the individual characteristics of flow routes taken also show a strong factor controlling the mechanism of hydrogeochemistry process in the karst system. CA3 shows distinguish chemical properties and the wide range of water samples from Gua Tempurung, differentiate the chemical properties of karst water.