An Investigation of the Chemical Composition of Precipitation in and around Kuala Lumpur

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RINGKASAN

Sampel hujan dikumpulkan pada tiga tempat di dalam dan di sekitar Kuala Lumpur dari Mei, 1982 ke Mei, 1983. Sampel-sampel dianalisiskan untuk pH, anion (sulfat, nitrat, klorida dan fluorida) dan kation (kalsium, magnesium, natrium dan kalium). Analisis korelasi dan regresi menunjukkan anion-anion utama kelihatan lebih berkaitan dengan kation-kation daripada ion hidrogen. Pencemar daripada kedua-dua sumber iaitu semulajadi dan oleh manusia nampaknya seolah-olah menentukan komposisi kimia bagi hujan.

SUMMARY

Individual rain event samples were collected at three sites in and around Kuala Lumpur from May, 1982 to May, 1983. The samples were analysed for pH, anions (sulphate, nitrate, chloride and fluoride) and cations (calcium, magnesium, sodium and potassium). Correlation and regression analyses indicated that the major anions appeared to be more closely associated with the cations than the hydrogen ion. Pollutants from both natural and anthropogenic sources appeared to have contributed to the chemical composition of precipitation.

INTRODUCTION

The occurrence of acid precipitation has been well documented in the United States, Canada and Europe for more than a decade (Wisnienski and Keitz, 1983; Likens and Butler, 1981; Summers and Whelpdale, 1976; Martin and Barber, 1978, Ruppert, 1975). Source contributions to acid precipitation and the characterization of its chemical nature have also been investigated (Pratt *et al*, 1983; Freely and Liljestrand, 1983; Mc Naughton, 1981; Richardson and Merva, 1976). It was generally accepted that oxides of sulphur and nitrogen contributed to the acidity of the rain water. Previous work also suggested that acidity and concentrations of ionic components of precipitation have been increasing in certain geographic locations as a result of man's activities. Interest in precipitation chemistry in Malaysia was initiated by reports on the menace of acid rain and the knowledge that there has been increasing emission of pollutants to the atmosphere. The Malaysian Meteorological Service has been monitoring the pH of rainwater in the Klang Valley since 1976. Rainwater samples were collected monthly. The overall pH of rainwater samples in Petaling Jaya and Cameron Highlands were 4.5 and 5.4

respectively(New Straits Times, 13th June, 1983). There is, however, no data on the chemical composition of rainwater. The present work was undertaken to investigate the acidity and chemical composition of rain in and around Kuala Lumpur.

MATERIALS AND METHODS

Individual rain event samples were collected from May, 1982 to May, 1983 at three sites: Kuala Lumpur city centre, Petaling Jaya residential area and Serdang University Complex. The three sites are within 30 km of each other, with Petaling Jaya on the West and Serdang on the south of Kuala Lumpur. Kuala Lumpur has the highest traffic density. There is no industrial polluting source in the immediate neighbourhood of the sampling sites, though there are some industrial activities in Kuala Lumpur and Petaling Jaya.

Sequential static untis were used for collection of rainfall samples through funnels into $250-cm^3$ acid-washed polyethylene bottles (Copper *et al.*, 1976). Only wet precipitation was collected. Following collection, the rainfall samples were taken to the laboratory and pH was measured within 24 hours of the event.

The sample bottles were then sealed and stored in a freezer until subsequent chemical analysis.

The pH measurements were made with a standard pH meter after calibrating at pH 4.00 and 7.00. Chloride and fluoride concentrations were determined using Orion ion-selective electrodes and the digital Orion ion-analyser 901. Nitrate concentrations were determined using the brucine method (Jenkins and Medsker, 1964). Sulphate concentrations were quantified by inductively coupled emission spectrometry (Miles and Cook, 1982), so were the concentrations of calcium, magnesium, sodium and potassium. A labtest Plasmascan 710 was used.

The data were converted to μeq dm^{-3} for statistical analysis. Values below the detection limit for a given constituent were arbitrarily assigned a value of one-half of the detection limit for that component (Pratt et al., 1983). Fluoride and potassium concentrations were not included for statistical analyses as their mean concentrations were not significantly different from their limits of detection.

RESULTS AND DISCUSSION

The means, standard errors and ranges of the major components for precipitation collected from May, 1982 to May, 1983 are given in Table 1. The monthly ranges of these major components are listed in Table 2. Partial data were obtained for nitrate and chloride concentrations as the volume of these liquids was insufficient for all analyses.

The acidity of rain water collected at the three sites are in the order of Petaling Jaya > Serdang > Kuala Lumpur. The relative acidity or alkalinity of rainfall is affected by the presence of both acid-producing and alkali-producing constituents in the rainfall. These constituents may be present in either gaseous or particulate form and may be derived from either natural or anthropogenic sources. In the absence of major pollutants, raindrops falling through the atmosphere will reach an equilibrium with carbon dioxide which dissolves in water to produce an equilibrium pH of 5.7 (Gorham, 1976). The average pH of the rain water are 4.10, 4.30 and 4.80 at Petaling Jaya, Serdang and Kuala Lumpur respectively. These values are below that of 'neutral' rainfall. There is, however, great variation in the pH between events. In Kuala Lumpur, for example, it ranged from 3.1 to 7.3.

In general, the concentrations of the major components are higher in Kuala Lumpur than in Petaling Jaya and Serdang. There is, however, wide variations in the ionic concentrations between events. It has been observed that concentrations of ions may vary within a rain event, between events and between locations (Liljestrand, 1979; Hales, 1981, c.f. Pratt et al., 1983). This is due to differences in the origins of the materials present in the precipitating air mass and differences in the meteorology and atmospheric chemistry within events, between events and between locations.

Concentrations of fluoride in all the events are below 0.1mg dm^{-3}. This is as expected as there are no specific fluoride-emitting industries in the vicinity of the sampling sites.

Sea spray has been cited as one of the major natural sources of sulphate, nitrate, alkali and alkaline earth elements in precipitation (Gorham, 1976; Martin and Barber, 1978). The ratios of SO_4/Na, Cl/Na and Mg/Na in sea spray were quoted as 0.25, 1.8 and 0.12 respectively (Sverdrup et al., c.f. Martin and Barber, 1978). The ratios of SO_4/Na are 3.69, 4.22 and 3.23 in Kuala Lumpur, Petaling Jaya and Serdang respectively. This indicates that a very high percentage of sulphate in rainwater is not of maritime origin. One of the likely sources is the combustion of petroleum fuels and automobile gasoline (Ruppert, 1979). On the other hand, the ratios of Cl/Na are 1.4, 1.5 and 1.3, and the ratios of Mg/Na are 0.18, 0.12 and 0.09 for Kuala Lumpur, Petaling Jaya and Serdang respectively. It thus appears that sea spray is the main source for chloride, magnesium and sodium in the rain water. These elements are strongly correlated with one another (Tables 3 and 4). Strong correlation between these ionic concentrations is probably the result of common resources, though it may also be the result of common scavenging mechanisms or chemical reaction mechanisms.

The ratio of Mg/Ca in sea spray is 3.16 (Eriksson, 1952). The ratios calculated for rainwater samples at Kuala Lumpur, Petaling Jaya and Serdang are around 0.07. This clearly indicates that like sulphate, a high percentage of calcium in rain water does not originate from sea spray. Limestone and cement dust contributes a high percentage of calcium (Gorham, 1976). Combustion of refuse, both domestic and industrial, supplied alkali and alkaline earth metals to the fly dust (Ruppert, 1979). The major source of calcium in precipitation thus appears to be from man made activities.

TABLE 1
Rainfall (mm), pH, H^+ ($\mu eg\ dm^{-3}$) and mean concentrations
($mg\ dm^{-3}$) of the major components in precipitation

Site		Rainfall	pH	H^+	Ca^{2+}	Na^+	Mg^{2+}	SO_4^{-2}	NO_3^-	Cl^-
Kuala Lumpur	Mean	33.34	4.82	15.37	2.75	1.07	.20	3.95	2.21	1.54
	S.E.	3.55	.07	6.78	.20	.11	.02	.22	.17	.44
	Minimum	1.14	3.10	.05	.19	.05	< D.L.	.28	< D.L.	.61
	Maximum	166.40	7.30	294.33	12.23	4.11	1.30	18.39	9.66	5.63
	No. of events/ analysis	120	120	120	112	119	117	114	63	49
Petaling Jaya	Mean	27.54	4.12	76.89	.95	.68	.08	2.87	1.36	1.05
	S.E.	2.24	.07	11.17	.08	.09	.007	.18	.11	.09
	Minimum	.08	3.10	.32	.11	< D.L.	< D.L.	.14	D.L.	.36
	Maximum	96.62	6.50	794.33	4.44	4.45	.38	7.47	3.77	4.95
	No. of events/ analysis	99	99	99	98	98	97	96	62	52
Serdang	Mean	34.18	4.38	42.35	1.25	.96	.09	3.10	1.08	1.22
	S.E.	3.07	.07	6.26	.12	.11	.008	.17	.20	.10
	Minimum	2.44	3.50	.79	.14	< D.L.	< D.L.	.46	< D.L.	.52
	Maximum	117.73	6.10	316.23	5.94	5.54	.40	6.84	9.35	4.20
	No. of events/ analysis	80	80	80	80	80	80	75	51	46

F^- concentrations were < 0.1 $mg\ dm^{-3}$;

H^+ [$ueq\ dm^{-3}$] was calculated from pH values.

D.L. for Na^+ , Mg^{2+} and NO_3^- are 0.002, 0.00004 and 0.04 $mg\ dm^{-3}$ respectively.

For concentrations below D.L., an arbitrary value of ½ D.L. was used in the computation of the mean and S.E.

TABLE 2
Monthly range of rainfall (mm), H^+ (μegdm^{-3}) and major chemical components
(mg dm^{-3}) in precipitation.

	Year	Month	Rainfall	H^+	Ca^{2+}	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-	Cl^-	*Number of events
Kuala Lumpur	1982	May	1.14-119.80	0.14-1.99	2.46-10.49	0.59-2.21	0.12-0.99	3.82-7.56	5.23-8.33	1.94-5.63	6
		June	3.09-153.46	0.05-3.98	2.26-12.23	0.90-8.10	0.16-1.30	2.71-18.39	5.09-9.66	1.80-2.54	9
		July	14.13-166.40	0.13-25.12	3.48-5.33	0.98-2.78	0.16-0.35	4.28-7.97	4.65-7.53	0.89-1.18	6
		Aug.	4.87-134.78	0.13-10.00	2.78-6.11	0.83-2.94	0.13-0.39	3.10-9-39	2.30-5.32	1.51-2.93	10
		Sept.	1.95-137.20	0.50-22.39	0.36-2.15	0.36-2.15	0.08-0.68	1.17-7.85	2.48-4.61	1.34-3.04	7
		Oct.	4.22- 94.02	0.06-39.81	0.69-8.10	0.41-4.11	0.04-0.52	1.24-9.35	1.95-4.74	1.33-2.01	10
		Nov.	6.98-113.35	0.20-794.33	0.55-2.95	0.09-2.90	0.03-0.22	1.01-2.93	< D.L.-2.61	0.65-3.16	13
		Dec.	5.20- 14.13	0.44-4.27	1.71-2.70	0.20-0.79	0.19-0.23	2.82-3.87	0.27-2.57	N.D.	5
	1983	Jan.	2-92- 60.08	0.12-79.43	0.19-1.70	0.05-1.65	0.02-0.27	0.28-4.94	< D.L-2.26	0.70-1.43	7
		Feb.	1.95- 47.09	0.63-39.81	0.62-2.61	0.10-1.31	0.06-0.26	1.34-5.17	< D.L-2.04	1.66	7
		Mar.	3.73- 56.84	0.25-35.48	0.71-4.30	0.10-3.01	0.06-0.46	1.44-6.40	0.22-1.55	0.64-1.18	12
		April	5.68-106.04	0.25-125.90	0.75-4.30	0.15-0.95	<D.L.-0.34	2.21-6.72	0.35-2.30	0.73	10
		May	4.22- 71.78	0.40-22.39	0.69-2.64	0.07-2.22	0.04-0.15	0.82-3.87	0.02-1.73	0.61-1.16	18
Petaling Jaya	1982	May	1.14-69.34	0.40-39.81	0.30-1.38	0.07-0.71	0.02-0.06	1.80-4.32	0.66-0.95	0.96-1.33	5
		June	0.08-69.83	7.94-63.10	0.12-2.12	0.08-1.81	0.01-0.07	0.21-4.37	0.22-1.02	0.71-1.75	6
		July	17.86-64.14	17.78-70.79	0.18-0.88	0.53-0.90	0.03-0.16	0.79-5.06	0.31-1.28	1.09-4.95	5
		Aug.	2.60-73.08	3.16-112.20	0.29-1.77	0.13-2.60	0.03-0.38	2.02-6.19	1.28-3.28	1.40-2.42	10
		Sept.	0.57-96.62	6.31-79.43	0.30-0.88	< D.L.-0.53	0.02-0.10	2.07-4.85	0.71-1.15	0.85-1.74	7
		Oct.	3.17-70.94	0.13-199.53	0.16-1.08	< D.L.-1.88	0.01-0.08	0.84-5.32	0.75-2.04	0.78-1.37	15
		Nov.	2.96-85.25	7.94-398.11	0.11-1.17	< D.L.-0.47	0.08-0.13	1.04-2.81	<D.L.-2.30	0.36-1.37	17
		Dec.	30.04-64.96	14.13-794.33	0.28-1.76	0.08-0.69	0.03-0.11	0.36-1.16	0.53-0.66	0.73-1.37	6
	1983	Jan.	7.47-29.48	0.32-44.67	0.19-4.44	0.01-4.45	0.02-0.23	0.14-7.47	0.84-3.77	0.66-1.22	7
		Feb.	12.34-56.84	3.16-141.25	0.96-3.00	0.29-1.32	0.08-0.28	1.38-7.47	1.86-3.06	0.71-0.94	5
		Mar.	8.77-32.48	12.59-199.53	1.36-2.55	1.11-2.37	0.12-0.23	3.60-5.15	1.86-2.44	1.11-1.21	5
		April.	7.31-81.20	35.48-398.11	0.81-3.51	0.96-2.74	<D.L.-0.19	1.91-6.21	0.31-3.26	0.89-1.20	7
		May	34.75-44.66	31.62-100.00	0.20-1.54	< D.L.-0.70	0.02-0.07	0.53-4.55	<D.L.-1.37	0.55-0.82	4
Serdang	1982	May	2.66-44.22	12.59-39.81	0.32-1.70	0.28-1.51	<D.L.-0.12	2.23-5.07	0.09-0.44	0.67-1.53	4
		June	2.44-71.45	0.40-22.39	0.20-4.10	0.22-2.09	0.02-0.29	1.27-5.07	0.66	0.59-0.78	6
		July	4.89-65.77	3.16-25.12	0.35-4.51	0.28-1.58	0.05-0.40	3.51-4.75	0.44-1.73	1.00-2.70	4
		Aug.	4.87-53.59	0.79-125.89	0.68-3.13	0.29-3.34	0.06-0.30	2.71-5.62	1.11-1.33	1.69-1.77	6
		Sept.	12.84-47.91	5.01-100.00	0.43-3.85	0.17-1.63	0.07-0.21	2.68-4.65	1.02-2.53	1.18-2.34	6
		Oct.	3.90-25.41	0.79-70.79	0.16-5.94	0.20-2.75	0.02-0.26	2.05-6.84	0.27-1.20	0.63-2.18	11
		Nov.	4.87-87.09	15.84-316.23	0.14-1.63	< D.L.-0.93	0.01-0.12	0.46-4.50	0.27-2.44	0.63-1.38	17
		Dec.	20.30-51.96	1.00-50.12	0.40-0.92	0.14-1.74	0.03-0.15	.11	< D.L.-0.84	0.60-0.96	5
	1983	Jan.	10.26-66.26	7.94-112.20	0.73-3.12	1.71-5.34	0.04-0.23	1.	1.33-4.39	1.39-1.65	3
		Feb.	4.96-26.28	1.78-223.87	0.50-0.84	0.84-1.47	0.05-0.10	1.9.	0.58-3.01	1.08-1.11	4
		Mar.	10.23-89.31	0.40-31.62	1.91-3.15	1.14-5.54	0.10-0.15	3.05-4..	0.58-1.99	1.30-4.20	3
		April	45-79-117.73	22.39-50.12	0.90-1.95	0.18-1.54	0.04-0.11	2.82-4.42	0.09-9.35	0.72-1.33	4
		May	10.23-108.30	15.84-125.89	0.48-1.98	0.02-3.29	0.02-0.10	1.23-4.39	< D.L.-3.29	0.52-1.27	7

* The number of events does not necessarily equal to the number of analysis.
  D.L. for Na^+, Mg^{2+} and NO_3^- are 0.002, 0.00004 and 0.04 mg dm^{-3} respectively.
  N.D. — Not Determined

TABLE 3
Matrix of correlation coefficients for the major components
(μeg dm^{-3}) and rainfall (mm) for all the samples.

	Ca^{2+}	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-	Cl^-	Rainfall
H^+	−0.172** (290)	−0.096 (294)	−0.164** (294)	−0.056 (285)	−0.087 (177)	−0.172* (145)	−0.001 (299)
Ca^{2+}		0.520*** (290)	0.888*** (287)	0.717*** (278)	0.669*** (175)	0.529*** (144)	−0.005 (290)
Na^+			0.454*** (293)	0.545*** (285)	0.402*** (177)	0.550*** (145)	−0.122 (297)
Mg^{2+}				0.776*** (283)	0.592*** (175)	0.673*** (144)	−0.135 (294)
SO_4^{2-}					0.608*** (170)	0.603*** (138)	−0.061 (285)
NO_3^-						0.458*** (121)	0.238** ·(177)
Cl^-							0.027 (145)

Level of significance :   * p < 0.05
( ) = number of samples. ** p $\leqslant$ 0.005
                     *** p $\leqslant$ 0.0005

TABLE 4
Correlation Coeff cients for the Major Components, (μeg^{-3}) at
Kuala Lumpur, Petaling Jaya and Serdang separately.

	Relationship		Kuala Lumpur (n)	Petaling Jaya (n)	Serdang (n)
H^+	vs	Ca^{2+}	−0.127 (112)	0.144 (98)	−0.187 (80)
H^+	vs	Na^+	−0.112 (119)	0.033 (98)	−0.106 (80)
H^+	vs	Mg^{2+}	−0.095 (117)	0.021 (97)	−0.189 (80)
H^+	vs	SO_4^{2-}	−0.082 (114)	0.116 (96)	0.013 (75)
H^+	vs	NO_3	−0.224 (64)	0.013 (62)	0.130 (51)
H^+	vs	Cl^-	−0.284* (47)	0.031 (52)	−0.128 (46)
Ca^{2+}	vs	Na^+	0.489*** (112)	0.806*** (98)	0.548*** (80)
Ca^{2+}	vs	Mg^{2+}	0.874*** (111)	0.826*** (96)	0.857*** (80)
Ca^{2+}	vs	SO_4^{2-}	0.765*** (107)	0.713*** (96)	0.714*** (75)
Ca^{2+}	vs	NO_3	0.807*** (62)	0.459*** (62)	0.194 (51)
Ca^{2+}	vs	Cl^-	0.633*** (46)	0.072 (52)	0.660*** (46)
Na^+	vs	Mg^{2+}	0.394*** (117)	0.730*** (96)	0.536*** (80)
Na^+	vs	$SO_4{2-}$	0.509*** (114)	0.610*** (96)	0.567*** (75)
Na^+	vs	NO_3^-	0.723*** (64)	0.375** (62)	0.314* (51)
Na^+	vs	Cl^-	0.693*** (47)	0.289* (52)	0.373* (46)
Mg^{2+}	vs	$SO_4{2-}$	0.799*** (113)	0.774*** (95)	0.744*** (75)
Mg^{2+}	vs	NO_3^-	0.656*** (63)	0.451*** (61)	0.198 (51)
Mg^{2+}	vs	Cl_3^-	0.766*** (47)	0.424** (51)	0.694*** (46)
SO^{2-}	vs	NO^-	0.775*** (62)	0.449*** (61)	0.288* (47)
SO_4^{2-}	vs	Cl^-	0.593*** (44)	0.538*** (51)	0.538*** (43)
$NO3^-$	vs	Cl^-	0.685*** (41)	−0.033 (42)	0.116 (38)

Level of significance: * P < 0.05
           ** P $\leqslant$ 0.005
        *** P $\leqslant$ 0.0005

Fig 1 shows the mean concentrations of several ionic components as a function of pH. The mean concentrations of these ionic components generally increase with increasing pH. The increase is especially notable for calcium. This trend is expected for the cations but not for the anions. Based on the assumption that the acidity of precipitation arises from the presence of H_2SO_4 and HNO_3, one would expect the concentrations of sulphate and nitrate ions to be highest at the lowest pH. However, this is not observed in the present study. This could partially be explained by the extremely high concentrations of calcium which appear to have a buffering effect on acidity. This buffering effect had also been observed earlier (Cooper et al., 1976; Gorham, 1976). Correlations between hydrogen ion and either sulphate or nitrate were low at all pH ranges (Table 5). On the other hand, calcium, magnesium and sodium were highly correlated with sulphate and nitrate.
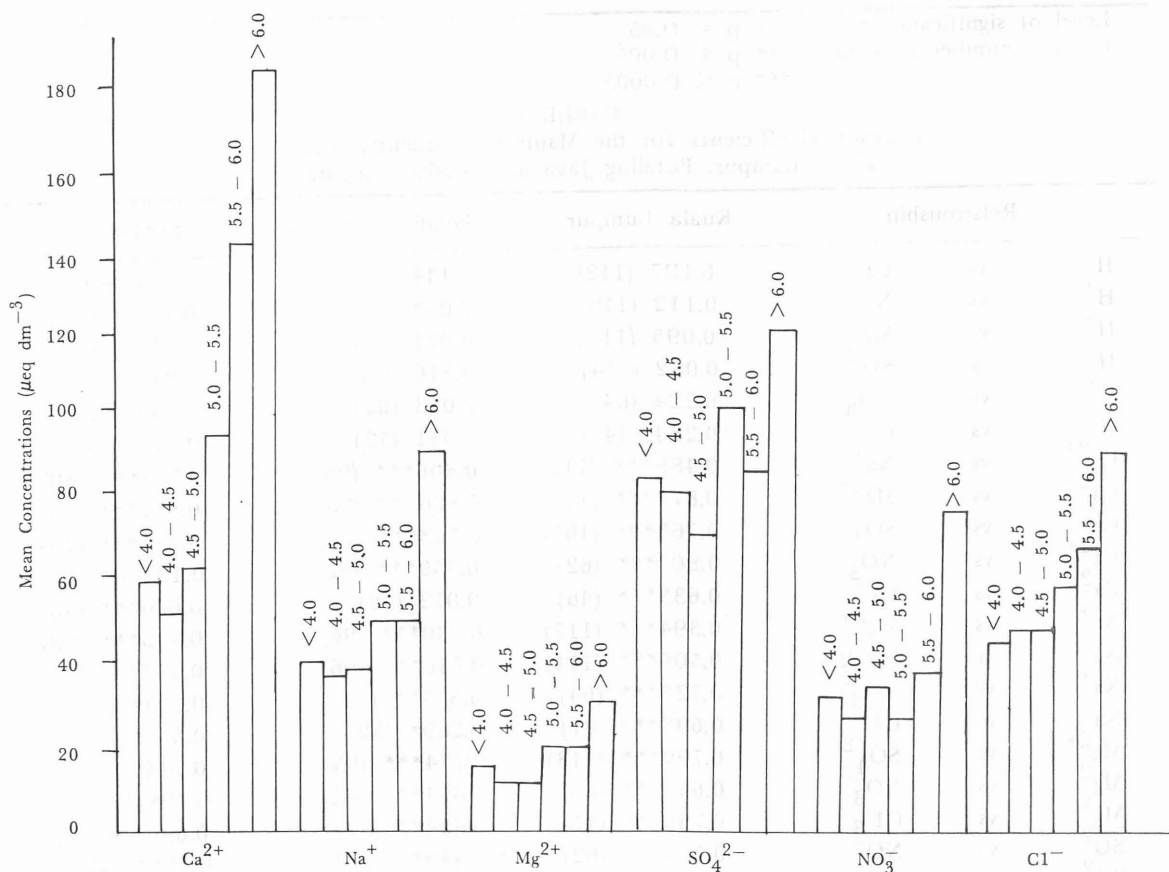

Fig. 1. Mean concentrations of chemical components ($\mu eq\ dm^{-3}$) as a function of pH.

TABLE 5
Correlation coefficients by pH range

	Relationship		< 4.0(n)	$4.0-4.5$(n)	$> 4.5-5.0$(n)	$>5.0-5.5$(n)	$>5.5-6.0$(n)	>6.0(n)
H^+	vs	Ca^{2+}	0.462*(30)	−0.287*(71)	−0.166(67)	−0.211(44)	−0.208(34)	−0.083(44)
H^+	vs	Na^+	0.098(30)	−0.218(71)	0.006(67)	−0.108(45)	−0.059(35)	−0.217(49)
H^+	vs	Mg^{2+}	0.307(29)	−0.211(70)	−0.164(68)	−0.209(45)	−0.233(35)	0.021(47)
H^+	vs	SO_4^{2-}	0.098(30)	−0.130(66)	−0.117(65)	−0.205(44)	−0.161(33)	0.140(47
H^+	vs	NO_3^-	0.167(15)	0.037(50)	0.038(44)	0.012(30)	−0.170(19)	−0.122(19)
H^+	vs	Cl^-	0.119(17)	−0.0.30(45)	0.024(41)	−0.381(16)	−0.015(10)	0.224(15)
Ca^{2+}	vs	Na^+	0.793***(30)	0.442***(71)	0.570***(67)	0.591***(44)	0.507**(34)	0.247(44)
Ca^{2+}	vs	Mg^{2+}	0.770***(29)	0.798***(70)	0.919***(67)	0.901**(44)	0.880***(34)	0.827***(43)
Ca^{2+}	vs	SO_4^{2-}	0.543**(30)	0.678***(66)	0.838***(65)	0.864***(43)	0.788***(32)	0.715***(42)
Ca^{2+}	vs	NO_3^-	0.561*(15)	0.413**(50)	0.595***(44)	0.520**(30)	0.789***(19)	0.688**(17)
Ca^{2+}	vs	Cl^-	0.550*(17)	0.201(46)	0.670***(41)	0.551*(16)	0.811**(10)	0.152(14)
Na^+	vs	Mg^{2+}	0.678***(29)	0.380**(70)	0.551***(67)	0.502***(45)	0.496**(35)	0.152(47)
Na^+	vs	SO_4^{2-}	0.382*(30)	0.457***(66)	0.602***(65)	0.628***(44)	0.650***(33)	0.380(47)
Na^+	vs	NO_3^-	0.707**(15)	0.203(50)	0.348*(44)	0.673***(30)	0.380(19)	0.088(19)
Na^+	vs	Cl^-	0.549*(17)	0.281(46)	0.637***(41)	0.802***(16)	0.634*(10)	0.356(15)
Ng^{2+}	vs	SO_4^{2-}	0.702***(29)	0.807***(66)	0.841***(65)	0.917***(44)	0.731***(33)	0.632***(46)
Mg^{2+}	vs	NO_3^-	0.556*(14)	0.417**(50)	0.574***(44)	0.424*(30)	0.580*(19)	0.522*(18)
Ng^{2+}	vs	Cl^-	0.731**(16)	0.375*(46)	0.703***(41)	0.558*(16)	0.827**(10)	0.644*(15)
SO_4^{2-}	vs	NO_3^-	0.716**(15)	0.399**(47)	0.673**(43)	0.605**(29)	0.660**(18)	0.601*(18)
SO_4^{2-}	vs	Cl^-	0.383(17)	0.523***(44)	0.698***(39)	0.751**(15)	0.538(8)	0.334(15)
NO_3^-	vs	Cl^-	0.257(13)	0.089(40)	0.582***(32)	0.516*(15)	0.886**(9)	0.166(12)

Level of significance =   *P < 0.05
       **P $\leqslant 0.005$
       ***P $\leqslant 0.0005$

The variance in acidity in precipitation has been attributed to sulphate ions alone (Mc Naughton, 1981), nitrate ions alone (Lewis and Grant, 1980) and both the two anions together (Feeley and Liljestrand, 1983; Galloway and Likens, 1981; Richardson and Merva, 1976). However, no significant correlation between hydrogen ions and either sulphate or nitrate ions is noted in the present study (Tables 3, 4 and 5). Kasina (1980) also found no correlation between the increase in sulphate and the decrease in pH of precipitation. Acid components such as sulphate and nitrate ions can be neutralized partly by alkaline substances. Multiple regression analyses were used to determine which cations may be associated with the anions (Table 6). For sulphate, magnesium was the best predictor in the model while calcium was the best predictor for nitrate. This indicates that in the majority of rain events at our sampling sites, most of the sulphate and nitrate were not associated with the hydrogen ion. Instead, they occurred as salts associated with other cations [e.g. $MgSO_4$ and $Ca(NO_3)_2$]. While some of the measured free hydrogen ions were no doubt donated by strong acids of sulphate and nitrate, weak and organic acid could have accounted for the major portion. Similar observations were made by Pratt et al. (1983). Possible explanations are (i) the sampling sites may be recipients of alkaline dust such as from limestone quarries in the region and (ii) as the sampling sites are not in the vicinity of severe pollution sources, air masses seem to have a long atmospheric residence time in which to undergo chemical reactions before deposition in a rain event.

Further work including analysis of dry preciptation will have to be carried out to examine the effect of dustfall on the chemical composition of rain water. Data collected over several years are needed to arrive at meaningful evaluations and correlations between differences in composition with time and type of meteorological event.

TABLE 6

Cationic predictors of sulphate and nitrate concentrations from the stepwise multiple regression model.

Dependent variable	All the three sites	Individual sites		
		Kuala Lumpur	Petaling Jaya	Serdang
$[SO_4^{2-}]$	Mg^{2+}	Mg^{2+}	Mg^{2+}	Mg^{2+}
	Na^+	Ca^{2+}	Ca^{2+}	Na^+
	H^+	H^+		H^+
	Ca^{2+}			
	$R^2 = .61$	$R^2 = .64$	$R^2 = .62$	$R^2 = .63$
$[NO_3^-]$	Ca^{2+}	Ca^{2+}	Ca^{2+}	Na^+
	Mg^{2+}	Na^+		
		Mg^{2+}		
	$R^2 = .47$	$R^2 = .74$	$R^2 = .22$	$R^2 = .10$

The cations are listed in order of importance.

CONCLUSION

Precipitation was collected and analysed for the period of May, 1982 to May, 1983 in and around Kuala Lumpur. Spatial and temporal variations in the concentrations of chemical components in the rain water were observed. There appeared to be contributions of both natural and anthropogenic sources of pollutants to the composition of precipitation. Sulphate and nitrate were the predominant, anions; they appeared to be associated more with metallic cations than with hydrogen ions.

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