

Rain and Lake Waters in Taiwan: Composition and Acidity

CHEN-TUNG A. CHEN¹, BING-JYE WANG¹, HUI-CHIEN HSU¹ and JIA-JANG HUNG¹

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ABSTRACT

Ten automatic samplers were used to collect dry deposits and rain water in the highly industrialized region of southwestern Taiwan between December 1985 and July 1989. During the dry season, rain water sometimes appeared basic because it contained a large amount of basic minerals such as calcium carbonate released by several local cement plants. During the wet season, however, the rain became increasingly acidic with its lowest pH value of 3.823.

Water samples collected from 137 lakes and reservoirs in Taiwan and its six largest offshore islands were analyzed. According to the rock and soil compositions, the present authors divided Taiwan into three regions. Zone I consists mainly of igneous rocks with lakes generally of low buffering capacity. The major cations are Na^+ ($0.280 \pm 0.335\text{meq/l}$; 50.3%), Mg^{+2} ($0.120 \pm 0.168\text{meq/l}$; 21.5%), Ca^{+2} ($0.112 \pm 0.094\text{meq/l}$; 20.0%), K^+ ($0.032 \pm 0.022\text{meq/l}$; 5.7%) and H^+ ($0.014 \pm 0.015\text{meq/l}$; 2.5%). The major anions are Cl^- ($0.269 \pm 0.329\text{meq/l}$; 46.0%), HCO_3^- (0.204 ± 0.438 ; 34.8%), SO_4^{-2} ($0.104 \pm 0.043\text{meq/l}$; 17.7%), NO_3^- ($0.007 \pm 0.008\text{meq/l}$; 1.3%), PO_4^{-3} ($0.001 \pm 0.003\text{meq/l}$; 0.18%) and OH^- ($0.0001 \pm 0.0002\text{meq/l}$; 0.02%).

Zone II consists mainly of non-calcareous sedimentary and metamorphic rocks with lakes of medium buffering capacity. The major cations are Ca^{+2} ($0.729 \pm 0.801\text{meq/l}$; 52.2%), Mg^{+2} ($0.437 \pm 0.464\text{meq/l}$; 31.3%), Na^+ ($0.203 \pm 0.226\text{meq/l}$; 14.5%), K^+ ($0.019 \pm 0.017\text{meq/l}$; 1.4%) and NH_4^+ ($0.008 \pm 0.015\text{meq/l}$; 0.6%). The major anions are HCO_3^- ($0.888 \pm 0.933\text{meq/l}$; 52.2%), SO_4^{-2} ($0.527 \pm 0.687\text{meq/l}$; 31.0%), $\text{C}_2\text{H}_5\text{COO}^-$ ($0.212 \pm 0.507\text{meq/l}$; 12.5%), Cl^- ($0.056 \pm 0.083\text{meq/l}$; 3.3%), NO_3^- ($0.013 \pm 0.019\text{meq/l}$; 0.8%) and PO_4^{-3} ($0.003 \pm 0.008\text{meq/l}$; 0.2%). Zone III consists mostly of gravel, sand, clay, limestone and the alluvium zone with lakes of high buffering capacity. The major cations are Ca^{+2} ($0.909 \pm 0.953\text{meq/l}$; 41.6%), Na^+ (0.630

¹ Institute of Marine Geology, National Sun Yat-Sen University, Kaohsiung, Taiwan, R.O.C.

± 1.077 meq/l; 28.8%), Mg^{+2} (0.550 ± 0.487 meq/l; 25.2%), K^+ (0.050 ± 0.052 meq/l; 2.3%) and NH_4^+ (0.045 ± 0.125 meq/l; 2.1%). The major anions are HCO_3^- (1.267 ± 1.142 meq/l; 50.5%), Cl^- (0.485 ± 1.222 meq/l; 19.3%), SO_4^{-2} (0.482 ± 0.420 meq/l; 19.2%), $C_2H_5COO^-$ (0.230 ± 0.416 meq/l; 9.2%), NO_3^- (0.041 ± 0.094 meq/l; 1.6%) and PO_4^{-3} (0.005 ± 0.019 meq/l; 0.2%). Overall, Ca^{+2} (0.825 meq/l, 44.0%), Mg^{+2} (0.500 meq/l, 26.6%), Na^+ (0.476 meq/l, 25.4%), K^+ (0.039 meq/l, 2.1%) and NH_4^+ (0.022 meq/l, 1.2%) are the major cations, while HCO_3^- (1.105 meq/l, 50.7%), SO_4^{-2} (0.486 meq/l, 22.3%), Cl^- (0.334 meq/l, 15.3%), $C_2H_5COO^-$ (0.220 meq/l, 10.1%), NO_3^- (0.031 meq/l, 1.4%) and PO_4^{-3} (0.004 meq/l, 0.2%) are the major anions for lakes in Taiwan.

Many lakes in Zones I and II, especially those above 2000m in elevation, are acidic. In general, low-elevation lakes are high in pH and alkalinity and are related to the soil and rock type or man-made eutrophication from the inputs of fertilizers, pesticides and other agricultural chemicals. These lakes are not likely to be acidified in the near future.

The authors also measured the concentrations of 41 minor and trace elements: Al, Au, B, Be, Bi, Cd, Co, Cr, Cu, Dy, Er, Eu, Fe, Gd, Ge, Hg, In, Lu, Mn, Mo, Nb, Nd, Ni, Pb, Pd, Pr, Sc, Sm, Sr, Ta, Tb, Te, Ti, Tm, V, Y, Yb, Zn and Zr in composite rain and lake water samples. These result are presented.

(Key words: Rain water, Lake water, Composition, pH, Alkalinity, Heavy metals)

1. INTRODUCTION

Lately acid rain has attracted much attention and concern worldwide. In Taiwan, the adverse effects of acid rain, the offspring of rapid industrialization, have also been felt and discussed. Lakes are showing both direct and indirect responses to the acidification of water by acid rain. Directly, acid water affects the growth of organisms in lakes, changes the ecosystem (Scheuhammer, 1991), affects the growth of crops if used for irrigation, and speeds up the corrosion of generators and metal pipes if used to generate electricity (Likens and Bormann, 1974; Likens *et al.*, 1979; Glass *et al.*, 1982; Kramer and Tessier, 1982). More circuitously, the release of heavy metals by acidification originally adsorbed on sediments results in high concentrations of heavy metals in the lake biota. Similarly, the heavy metal concentrations in crops also increases if acidified water is used for irrigation. These processes pose serious health problems regardless of whether the acidified lakes constitute the source of drinking water, or whether man consumes food which has been irrigated with acid water and has accumulated high concentrations of heavy metals (Morel and Morgan, 1972; Scheider *et al.*, 1979; Davis *et al.*, 1982; Kilham, 1982; Campbell and Stokes, 1985).

The process of lake acidification that leads to the adverse effects, such as those mentioned above, obviously should be investigated thoroughly. Unfortunately, because of the lack of historical data, the writers do not know clearly whether the lakes in Taiwan have changed or will soon change in terms of their acidity (Chen *et al.*, 1992). The acidity of rain and lake waters in Taiwan and the sensitivity of these lakes to acid rain based on pH and alkalinity data are reported here. These data are hereby used to reveal spatial variations and could be

used as a baseline for future temporal comparisons. Additionally, possible future changes in lake acidity based on studies of total dissolved salt, rock and soil types (Henriksen, 1979) are also estimated in this paper.

2. MATERIAL AND METHODS

Ten automatic dry/wet samplers were used to collect dry deposits and rain water in southwestern Taiwan between December 1985 and July 1989 (Figure 1). These dry deposits were collected periodically and examined by a scanning electron microscope (JEOL JSM-35 CFSEM) and by X-ray diffraction (Diano 8536 XRD). Over two hundred wet samples were collected and analyzed within 24 hours after the rain. The measurements made included pH, alkalinity, conductivity, density, SO_4^{-2} , Cl^- , NO_3^- , Ca^{+2} , Mg^{+2} , K^+ , Na^+ and NH_4^+ . NIST(National Institute of Standards and Technology, USA) pH 4.004 and 7.415 buffers were used to calibrate the Radiometer PHM 85 system, precise to ± 0.003 units. Alkalinity was

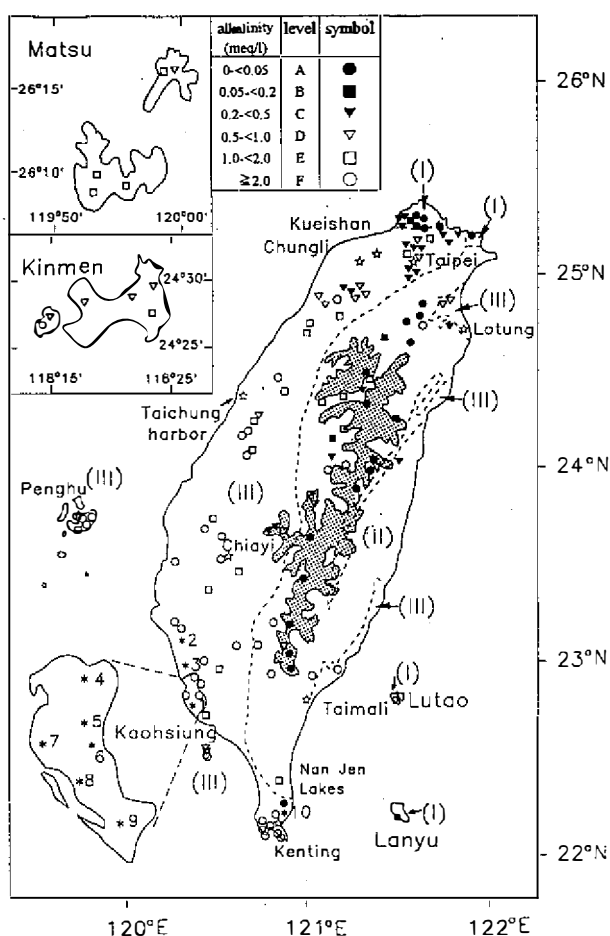


Fig. 1. Locations of automatic rain water samplers (*), numbered 1 through 10 in southwest Taiwan, and lakes sampled all over Taiwan. Zones I through III are described in the text. (hatched area represents elevations > 2000 m)

measured by the Gran Titration (Chen, 1988) and density by a vibrating tube densitometer (Chen *et al.*, 1980). A Dionex 2000i Ion Chromatography was used to measure K^+ , Na^+ , NH_4^+ , Ca^{+2} , Mg^{+2} , F^- , Cl^- , NO_3^- , Br^- and SO_4^{-2} , while a Perkin Elmer 2380 AA was also used to measure Ca^{+2} , Mg^{+2} , K^+ and Na^+ . Nutrients were measured by the Flow Injection Analysis. Certified ERA (Environmental Resource Associate) rain water samples (2694I and 2694II) were used as references. The relative error is less than 6% (Chen and Hung, 1987; Chen *et al.*, 1987; Hung and Chen, 1989). A Millipore-double distillation system was used to provide pure water for reagent preparation and for blank detection.

Over six hundred lake water samples were collected from 137 lakes (Figure 1) either with a bucket (for small ponds) or with a Nansen bottle when boats were available. In remote areas without access to a boat, the authors used a remote-controlled vessel, which could be controlled to obtain samples from as deep as 15 m. Normally, samples were collected at three depths at two locations in each lake with temperatures and pH being measured immediately. Afterwards, once samples were filtered with a 0.45μ m Nalgene filter, they were stored in amber plastic bottles at $4^\circ C$, and shipped back to the laboratory for further analyses of the above mentioned parameters. The filter paper was pre-rinsed with the sample before being used for filtration. The parameters measured were the same as those for rain water. Reliability of the data was further checked by correlating the sum of the cations with the sum of the anions. A linear correlation was found ($r=0.96$, $n=507$) with a slope of 0.96, thus differing only slightly from the expected value of 1 (Figure 2).

A composite rain water sample consisting of all of the samples collected between May, 1986 and June, 1988 was pre-concentrated 20 times by evaporation at sub-boiling temperature. This sample was used to measure minor and trace elements by the Inductively Coupled Plasma (ICP) at National Tsin Hwa University (Hsu and Chen, 1993). Similarly, a composite of lake water samples collected between September, 1985 to July, 1987 was pre-concentrated 20 times before measurements were taken by the ICP. Such pre-concentration

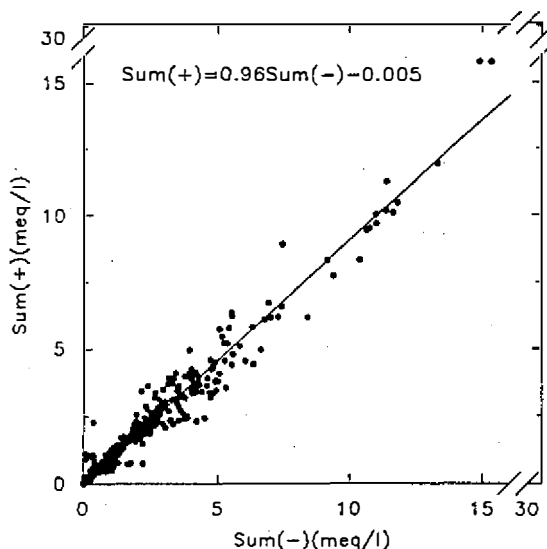


Fig. 2. The sum of cations [sum(+)] correlated with the sum of anions [sum(-)] for lake waters.

was necessary because of limitations in the detectability of the ICP. Detailed sampling and analytical procedures were described elsewhere (Chen and Hung, 1987; Chen *et al.*, 1987; Hung and Chen, 1989).

3. RESULTS AND DISCUSSION

3.1. Rain Waters

Dry deposits consist mostly of quartz, gypsum and aragonite probably coming from several cement plants in the sampling area. A one to fifty weight dilution of dry deposits with deionized/distilled water (pH=5.66) results in solutions with pH values ranging from 7.34 to 10.23 (Chen and Hung, 1987).

The pH range and the numerical means of rain waters collected each month are also shown in Figure 3. The pH of rain waters collected covers a wide range due to the large differences in local conditions. pH values are sometimes quite high in the dry season, perhaps because the samples contain a relatively large amount of airborne mineral particles. A pH value as high as 10.635 is recorded, reflecting high aragonite contents. In general, the higher the alkalinity or conductivity, the higher the pH values appear. Additionally, the rain water becomes relatively more acidic during the wet season (May-Sept.), and there is some indication that it is less acidic at the onset of a rain. This phenomenon also suggests that basic particles contribute to part of the rain water samples. Later during a precipitation event, the water becomes more acidic because basic particles have previously been removed from the atmosphere (Chen and Hung, 1987).

Rain brought in by three typhoons in 1986 are less acidic. The mean pH values for normal rains in June through September in 1986 are slightly more acidic than the mean pH values for all rains combined (Figure 3). The reverse is true, however, in 1987 and 1988.

Of the areas studied, Hsiaogun (site 9) seems to be the most affected by the acid rain because it is adjacent to the heavy industrial area concentrated in southern Kaohsiung. Rain waters there are frequently below pH 5. The amount of nitrate is inversely correlated with pH (Figure 4); thus, nitrate apparently is a heavy contributor of acid rain at Hsiaogun. The pH also correlates inversely with excess sulfate (the amount of sulfate in rain water after correction for sea salts) (Figure 4), suggesting that excess sulfate also contributes to the formation of acid rain at this site. The effect of sulfate is potentially large because of its higher concentration than nitrate.

Based on limited data, the study indicates rain waters collected outside the Kaohsiung area generally have a pH value greater than 5.0. The sulfate and nitrate concentrations are also lower in the less industrialized region. These results reflect the relation between acid rain and air pollution.

In Table 1, the average rain water composition of 10 stations in Taiwan from 1990 to 1994 (Jeng, 1993) is listed. The pH values are all lower than 5.0 except at the Kenting National Park at the southern tip of Taiwan and at the off-shore island of Penghu (Figure. 1).

The hydrogen ion is the fourth most abundant of the cations. Sulfate and nitrate, respectively, are the second and third most abundant anions. The average sulfate to nitrate ratio is roughly 3.5, with a higher ratio (5.0) in the heavy industrial area of Hsiaogun and a lower ratio (2.8) in the metropolitan area of Taipei. This difference probably reflects the relative abundance of automobiles in Taipei.

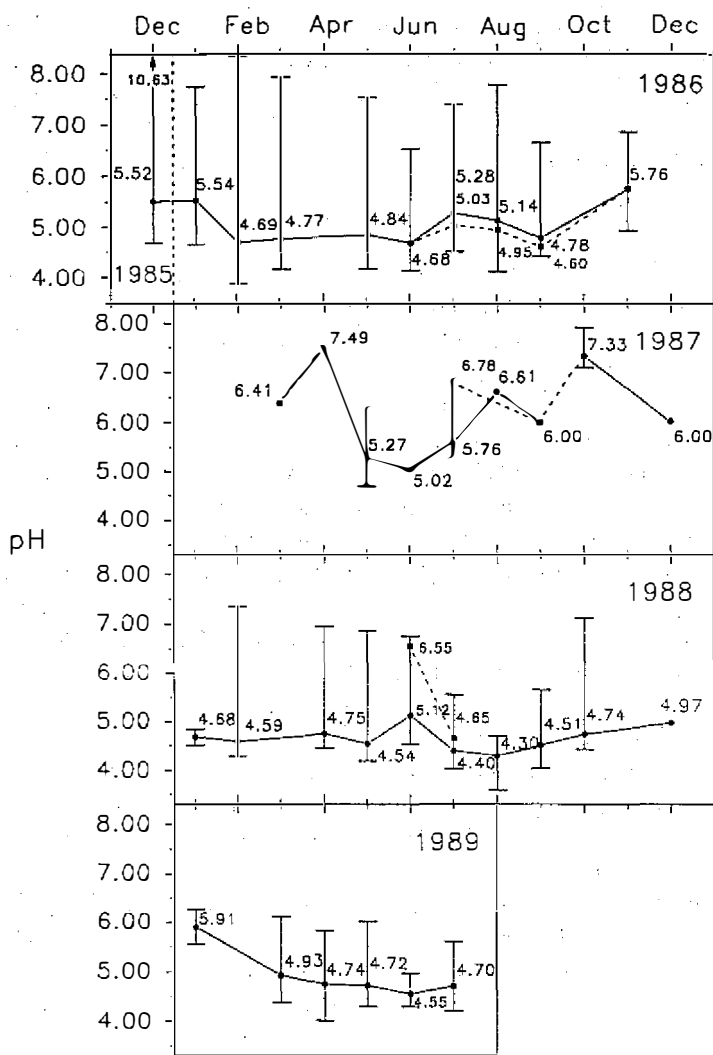


Fig. 3. The numerical mean and the pH ranges of rain waters collected in southwest Taiwan. Dash lines represent values excluding rains brought in by typhoons.

3.2. Lake Waters

Lakes in Taiwan are divided into six categories based on alkalinity according to the classification of Zimmerman and Harvey (1978) (Figure 1): A (<0.05 meq/l); B ($0.05 \sim \leq 0.2$ meq/l); C ($0.2 \sim \leq 0.5$ meq/l); D ($0.5 \sim \leq 1.0$ meq/l); E ($1.0 \sim \leq 2.0$ meq/l) and F (>2.0 meq/l).

As a first approximation, Taiwan is also divide into three major zones in this study according to the geologic compositions and geographic factors. Zone I includes the Tatu and Keelung volcano groups, the five offshore islands in northern Taiwan and Lutao and Lanyu. They consist mainly of igneous rocks such as andesite and andesitic pyroclastics. These rocks have low buffering capacity, and the lakes in this region should have

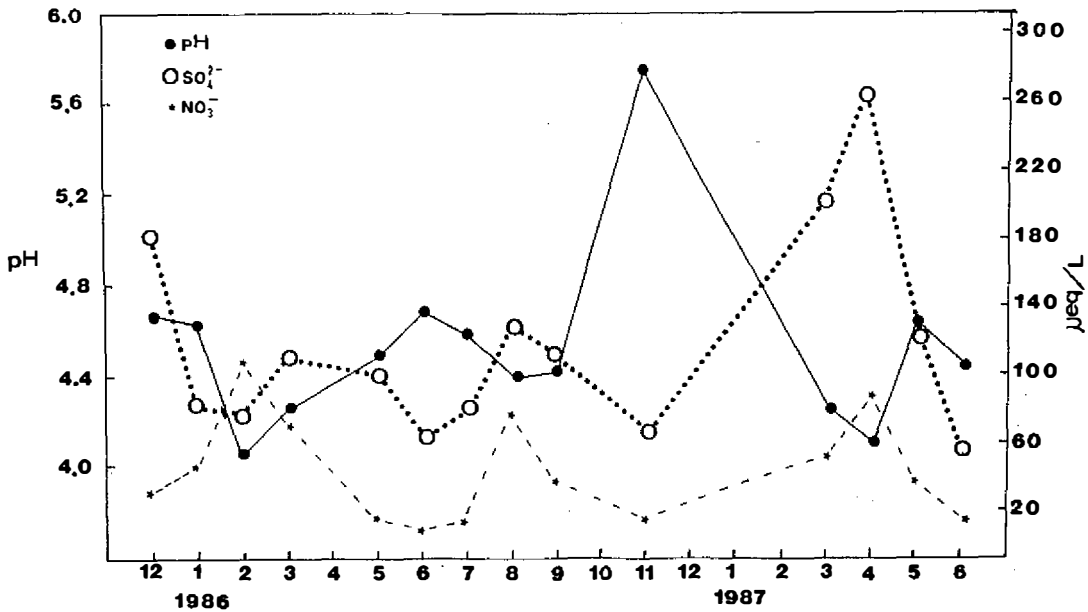


Fig. 4. The monthly average of pH, nitrate and excess sulfate concentrations at Hsiaogun between December, 1985 and June, 1987.

Table 1. Average rain water compositions of 10 stations in Taiwan from 1990~1994. (data taken from Jeng, 1993)

Item Station	No. of Observations	pH	Cation						Anion					
			Na ⁺	Ca ²⁺	NH ₄ ⁺	H ⁺	K ⁺	Mg ²⁺	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	HCO ₃ ⁻	CH ₃ COO ⁻	C ₂ H ₃ COO ⁻
			meq/l						μeq/l					
Taipei	208	4.15	0.101	0.077	0.049	0.073	0.025	0.026	0.148	0.119	0.043	3.55	0.43	0.07
Kueishan	132	4.26	0.109	0.038	0.033	0.054	0.025	0.030	0.117	0.135	0.035	3.32	1.09	0.38
Chungli	135	4.32	0.140	0.084	0.040	0.045	0.072	0.038	0.213	0.162	0.041	3.20	0.53	0.26
Hsiaogun	100	4.38	0.078	0.034	0.049	0.043	0.010	0.035	0.062	0.101	0.020	5.10	0.45	0.34
Kenting	93	5.37	0.203	0.045	0.011	0.005	0.017	0.061	0.208	0.058	0.011	6.04	0.13	0.34
Taimali	212	4.83	0.086	0.018	0.023	0.019	0.060	0.023	0.149	0.052	0.020	1.15	0.98	0.42
Lotung	97	4.55	0.174	0.036	0.044	0.026	0.031	0.037	0.184	0.091	0.025	3.95	0.14	0.03
Taichung	129	4.58	0.082	0.043	0.058	0.032	0.017	0.024	0.103	0.129	0.035	3.60	0.33	0.16
Chiayi	80	4.96	0.022	0.014	0.053	0.008	0.017	0.019	0.047	0.060	0.022	1.39	0.31	0.07
Penghu	46	5.17	0.280	0.053	0.023	0.003	0.025	0.049	0.287	0.083	0.020	0.73	0.09	0.13
Average		4.45	0.115	0.046	0.039	0.036	0.033	0.032	0.146	0.101	0.029	3.18	0.53	0.24

low alkalinities and potentially low pH values. Noteworthy, there are still hot springs, fumaroles and solfataras in the Tatun volcano group, and those could be the sources of acidity in the environment. Eleven lakes are sampled in Zone I. Five are classified as A, one as B. The five small ponds sampled on Lutao off southeastern Taiwan, however, are classified as E, perhaps because of the local pollution and eutrophication. Na⁺ (0.280 ± 0.335 meq/l; 50.3%), Mg²⁺ (0.120 ± 0.168 meq/l; 21.5%), Ca²⁺ (0.112 ± 0.094 meq/l; 20.0%), K⁺ (0.032 ± 0.022 meq/l; 5.7%) and H⁺ (0.014 ± 0.015 meq/l; 2.5%) are the major cations and Cl⁻ (0.269 ± 0.329 meq/l; 46.0%), HCO₃⁻ (0.204 ± 0.438 meq/l; 34.8%),

SO_4^{-2} ($0.104 \pm 0.043 \text{ meq/l}$; 17.7%), NO_3^- ($0.007 \pm 0.008 \text{ meq/l}$; 1.3%), PO_4^{-3} ($0.001 \pm 0.003 \text{ meq/l}$; 0.18%) and OH^- ($0.0001 \pm 0.0002 \text{ meq/l}$; 0.02%) are the major anions (Table 2). The average salt content is 1.169 meq/l, while the average alkalinity is 0.204 meq/l. Further acidification of some of these lakes is possible because of the low buffering capacity of those lake waters and the surrounding rocks and sediments.

The boundaries of Zone II extend from Santiaochiao in northern Taiwan southward along the Central Ridge to Mutanshan Mt. of the Hengchun Peninsula. Zone II consists mainly of non-calcareous sedimentary and metamorphic rocks such as mudstone, sandstone, tuffaceous sandstone, shale, coaly shale, sandy shale, gravel, conglomerate, agglomerate, argillite, slate, phyllite and schists. These rocks have buffering capacities between igneous rocks (Zone I) and calcareous rocks (Zone III). The lakes in this region show a wide variety of alkalinity and pH values with the average salt content being 3.128 meq/l and the average alkalinity 0.914 meq/l. The major cations are Ca^{+2} ($0.729 \pm 0.801 \text{ meq/l}$; 52.2%), Mg^{+2} ($0.437 \pm 0.464 \text{ meq/l}$; 31.3%), Na^+ ($0.203 \pm 0.226 \text{ meq/l}$; 14.5%), K^+ ($0.019 \pm 0.017 \text{ meq/l}$; 1.4%) and NH_4^+ ($0.008 \pm 0.015 \text{ meq/l}$; 0.6%). The major anions are HCO_3^- ($0.888 \pm 0.933 \text{ meq/l}$; 52.2%), SO_4^{-2} ($0.527 \pm 0.687 \text{ meq/l}$; 31.0%), $\text{C}_2\text{H}_5\text{COO}^-$ ($0.212 \pm 0.507 \text{ meq/l}$; 12.5%), Cl^- ($0.056 \pm 0.083 \text{ meq/l}$; 3.3%), NO_3^- ($0.013 \pm 0.019 \text{ meq/l}$; 0.8%) and PO_4^{-3} ($0.003 \pm 0.008 \text{ meq/l}$; 0.2%) (Table 2). Many high elevation lakes in Zone II (above 2000 m; hatched area in Figure 1) are either acid-sensitive or might soon become acid-sensitive (Figure 1). Since little local pollution occurs near these lakes, acid rain and local geochemistry are possible causes of the acidification.

Zone III includes the western foothills, coastal plains, coastal terraces, the Penghu islands, the Ilan plain and the metamorphosed limestone near Tailuko and Taitung. It consists mainly of gravel, sand, clay, limestone and the alluvium zone. Most lakes here have an alkalinity higher than 1.0 meq/l, and the waters are generally slightly basic (pH

Table 2. The major cation and anion contents (C, meq/l), deviation (δ , meq/l), percentage(%), and number of observations (N) of lakes in Taiwan.

I T E M	Cation					Anion					
	1	2	3	4	5	1	2	3	4	5	6
Zone I	Na^+	Mg^{+2}	Ca^{+2}	K^+	H^+	Cl^-	HCO_3^-	SO_4^{-2}	NO_3^-	PO_4^{-3}	OH^-
C	0.280	0.120	0.112	0.032	0.014	0.269	0.204	0.104	0.007	0.001	0.0001
δ	0.335	0.168	0.094	0.022	0.015	0.329	0.438	0.043	0.008	0.003	0.0002
%	50.3	21.5	20.0	5.7	2.5	46.0	34.8	17.7	1.3	0.18	0.02
N	14	14	14	14	14	14	14	14	14	14	14
Zone II	Ca^{+2}	Mg^{+2}	Na^+	K^+	NH_4^+	HCO_3^-	SO_4^{-2}	$\text{C}_2\text{H}_5\text{COO}^-$	Cl^-	NO_3^-	PO_4^{-3}
C	0.729	0.437	0.203	0.019	0.008	0.888	0.527	0.212	0.056	0.013	0.003
δ	0.801	0.464	0.226	0.017	0.015	0.933	0.687	0.507	0.083	0.019	0.008
%	52.2	31.3	14.5	1.4	0.6	52.2	31.0	12.5	3.3	0.8	0.2
N	164	164	164	164	28	161	163	42	164	164	164
Zone III	Ca^{+2}	Na^+	Mg^{+2}	K^+	NH_4^+	HCO_3^-	Cl^-	SO_4^{-2}	$\text{C}_2\text{H}_5\text{COO}^-$	NO_3^-	PO_4^{-3}
C	0.909	0.630	0.550	0.050	0.045	1.267	0.485	0.482	0.230	0.041	0.005
δ	0.953	1.077	0.487	0.052	0.125	1.142	1.222	0.420	0.416	0.094	0.019
%	41.6	28.8	25.2	2.3	2.1	50.5	19.3	19.2	9.2	1.6	0.2
N	309	307	309	307	18	294	308	309	35	311	311

between 7.0 and 9.0). A few lakes are heavily polluted. The average salt content and alkalinity are 4.783 meq/l and 1.255 meq/l, respectively. The major cations are Ca^{+2} (0.909 ± 0.953 meq/l; 41.6%), Na^+ (0.630 ± 1.077 meq/l; 28.8%), Mg^{+2} (0.550 ± 0.487 meq/l; 25.2%), K^+ (0.050 ± 0.052 meq/l; 2.3%) and NH_4^+ (0.045 ± 0.125 meq/l; 2.1%). The major anions are HCO_3^- (1.267 ± 1.142 meq/l; 50.5%), Cl^- (0.485 ± 1.222 meq/l; 19.3%), SO_4^{-2} (0.482 ± 0.420 meq/l; 19.2%), $\text{C}_2\text{H}_5\text{COO}^-$ (0.230 ± 0.416 meq/l; 9.2%), NO_3^- (0.041 ± 0.094 meq/l; 1.6%) and PO_4^{-3} (0.005 ± 0.019 meq/l; 0.2%) (Table 2). Owing to the high alkalinity values, it is not believed that any one of these lakes is in danger of acidification in the foreseeable future.

Of particular interest is the Nan Jen Lake group in Kenting National Park. These lakes did not exist prior to 1980, but the waters contain mainly NaCl which probably comes from rain water and sea spray. It is not known to what extent this group of lakes is in equilibrium (or in a steady state) with their bottom sediments or the surrounding rocks and soils (acidic laterite). A more intensive study of these lakes is currently in progress.

Overall, 28% of all lakes in Taiwan are classified as class F, 21% E, 17% D, 15% A, 14% C, and 5% B. The average salt content is 4.075 meq/l, while the average alkalinity is 1.112 meq/l. The major cations are Ca^{+2} (0.825 meq/l, 44.0%), Mg^{+2} (0.500 meq/l, 26.6%), Na^+ (0.476 meq/l, 25.4%), K^+ (0.039 meq/l, 2.1%) and NH_4^+ (0.022 meq/l, 1.2%). The major anions are HCO_3^- (1.105 meq/l, 50.7%), SO_4^{-2} (0.486 meq/l, 22.3%), Cl^- (0.334 meq/l, 15.3%), $\text{C}_2\text{H}_5\text{COO}^-$ (0.220 meq/l, 10.1%), NO_3^- (0.031 meq/l, 1.4%) and PO_4^{-3} (0.004 meq/l, 0.2%). Bicarbonate seems to contribute most to the alkalinity, and calcium concentration correlates well with alkalinity ($r=0.89$, $n=481$; Figure 5).

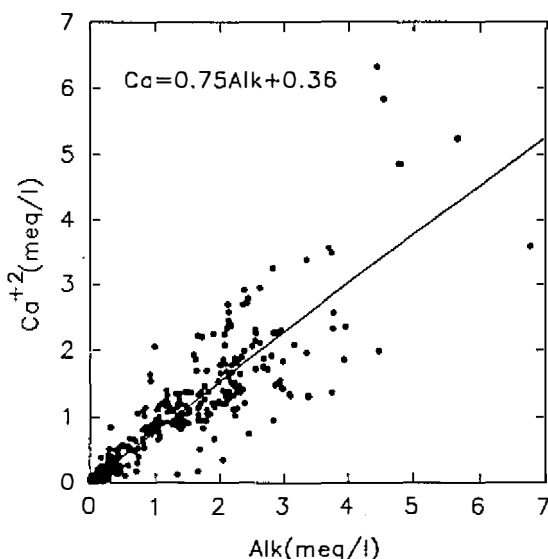


Fig. 5. Calcium correlated with alkalinity for lake waters.

Because of limitations in the detectability of ICP detection, a large sample had to be used in this study in order to pre-concentrate it for minor and trace element analysis by the ICP. As a result, composite samples were necessary leading to the possibility of bias in the data. Concentrations of certain trace metals in twenty-six events of rain water in 1990 which

were pre-concentrated and measured with graphite furnace atomic absorption spectrophotometry (Perkin-Elmer 5100PC HGA-600), however, show spatial and temporal variations in southwestern Taiwan (Lin and Hung, 1992). With the exception of Al, metal concentrations of composite rain water (1986-1988), nevertheless, are covered by the range of samples in 1990. Since both the ICP and the atomic absorption methods give similar results, the data may be considered at least semi-quantitative. It is understood that these data (Table 3) are the only ones available in Taiwan, and a long-term observation may still be necessary

Table 3. Trace element concentrations (ppb) in composite rain and lake waters.

element	rain water ^a	rain water ^b	lake water ^a
Al	95.40	4.1~40.1(17.4)	20.80
Au	<1		<1
B	28.85		90.15
Ba	14		44
Be	<0.02		0.03
Bi	<3		<3
Cd	0.56	0.1~1.3(0.22)	0.31
Co	0.84		<0.06
Cr	0.23		0.17
Cu	2.91	0.6~5.7(2.7)	1.22
Dy	<0.1		<0.1
Er	0.25		0.39
Eu	0.10		<0.01
Fe	8.99	1.2~39.6(10.2)	9.18
Gd	<1		<1
Ge	<1		<1
Hg	<4		<4
In	<3		<3
Lu	<0.5		<0.5
Mn	7.73	1.6~13.4(3.7)	4.88
Mo	<3		13.31
Nb	<1		<1
Nd	<1		<1
Ni	1.54		1.69
Pb	4.71	1.0~5.6(2.9)	<0.2
Pd	5.20		<1
Pr	0.92		2.26
Sc	<0.1		<0.1
Si	265.50		3246.50
Sm	<1		<1
Sr	<9		<130
Ta	<1		<1
Tb	0.04		0.59
Te	<10		<10
Ti	0.35		0.23
Tm	<0.08		0.10
V	0.67		<0.04
Y	<0.02		<0.02
Yb	<0.02		0.02
Zn	37.31	5.2~40.9(16.5)	7.31
Zr	<0.09		0.09

a: Taken from Hsu and Chen, 1993

b: Taken from Lin and Hung, 1992; values in parentheses are mean concentrations.

to see the typical trace-element composition of rain water in Taiwan. Besides, the authors are particularly interested in V which may be a proxy for paleoclimate (Chen *et al.*, 1993). The concentration is much lower in lake water than in rain water, perhaps reflecting active biological removal in a lake. Since most concentrations are below 1 ppb, more detailed work is needed to show how reliable or how representative these values are.

4. CONCLUSIONS

Ten stations for automatic dry/wet precipitation samples were established in southwestern Taiwan between December 1985 and July 1989. The chemical analysis of rainwater includes pH, conductivity, alkalinity, density, SO_4^{-2} , Cl^- , NO_3^- , Ca^{+2} , Mg^{+2} , K^+ , Na^+ and NH_4^+ . The lowest pH value of the event rainwaters occurring in the stations of the Greater Kaohsiung area was 3.823, which was much lower than those found in the less industrialized neighborhood stations, where the pH values of event rain waters were generally greater than 5.0. The concentrations of nitrate and sulfate of rain waters in the Greater Kaohsiung area were also higher than those found in the neighborhood stations, showing a strong correlation between rain water acidification and air pollution.

Samples were also collected from 137 lakes all over Taiwan. The results show that lake alkalinity is low in regions of igneous rocks but high for the sedimentary zone in western Taiwan, and variable for the eastern region with metamorphic rocks. Several alpine lakes without local pollution are acid-sensitive ones. In general, low-elevation lakes are high in pH and alkalinity and are related to the soil and rock types or man-made eutrophication from the inputs of fertilizers, pesticides and other agricultural chemicals. These lakes are not in any danger of acidification in the near future. Concentrations of 41 minor and trace elements in composite rain and lake samples are reported.

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