WATER QUALITY SURVEY OF VIETNAM

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1. Introduction

From November 18 to 24, 2000, a detailed water quality survey was conducted in Vietnam primarily in the Hanoi area with a cursory survey in Ho Chi Minh City. The survey was performed by a joint team of researchers from Kumamoto University, Japan, and the Vietnam National University in Hanoi. As practicable, various water quality parameters were assessed in the field at sampling locations and preserved samples were transported to Kumamoto University for further analyses. Results of this survey, primarily with respect to Hanoi, are reported here.

2. General

Vietnam, located in Southeast Asia, is tropical in the south and monsoonal in the north with a hot rainy season from mid-May to mid-September and a warm dry season from mid-October to mid-March (CIA, 2000). The largest urban areas are Hanoi (the capital) in the north and Ho Chi Minh City (Saigon) in the south. Hanoi is located on the banks of the Red River (Song Hong) and is imbedded with numerous lakes. Ho Chi Minh City is located on the banks of the Saigon River on the northern edge of the Mekong delta region. Both population centers are in river deltas of low altitude and are subject to extensive flooding in the rainy season.

The public water supply for Hanoi is entirely from groundwater and the Red River has never been known historically to serve as a source for potable water. The total well extraction rate was approximately 500,000 cm^3/d in 1998 and was estimated to be 700,000 cm^3/d in 2000 (Uyen, 2001). The average annual temperature in Hanoi is 23.4°C with 1,680 mm/yr of rainfall occurring on an average of 142 days per year. The Hanoi aquifer consists of

loose and alternating quaternary sediments and the underlying zone, which serves as the source for potable water wells, is 40 to 80 m deep (Nhue, 2001). There is significant continuity between the upper and lower aquifer zones and considerable infiltration of pollutants into the lower zone due to discharges of untreated wastewater is thought to occur. Naturally occurring components such as fluorine, aluminum, acidity, sulfate and brine are also frequently present at relatively high concentrations (Cat, 2001). Studies on various contaminants of anthropogenic sources in the Hanoi aquifer have been conducted by Nhue (2001) and Cat (2001) and a detailed description of the existing wells and water treatment plants has been reported by Nhue (2001).

3. Materials and Methods

Surface water and groundwater samples were collected at designated locations in Hanoi as shown in Figure 1 and described in Table 1. Surface water samples were also collected at three locations in Ho Chi Minh City (see Section 4.2). In the field at the time of sampling, temperature, pH, NO_3^- and NH_4^+ were measured directly using an ion/pH meter (IM-22P, Hach) with selective probes. Additionally, 500 ml samples were collected and acidified to a pH of less than 2.0 with HCl and then sealed and capped and transported to Kumamoto University for determination of all other parameters reported herein.

Total suspended solids (SS) were determined by the standard method; sulfate (SO_4^{2-}) was determined by the turbidimetric method; sulfide (S^{2-}), by the iodometric method; and silica (as silicon dioxide, SiO_2), by the molybdosilicate method (APHA, 1995). Inorganic carbon (IC) and total organic carbon (TOC) were determined with a carbon analyzer (TOC-5050A, Shimadzu). Metals (Fe, Ca, Mg, Na, K and Mn) were determined by atomic adsorption (Z-6100 spectrophotometer, Hitachi). Arsenic (As) was analyzed by a subcontractor using atomic adsorption. Statistical considerations were based on plus/minus one standard deviation (SD) (i.e., the range including 68% of the data, assuming a normal distribution).

4. Results and Discussion

4.1 Hanoi region

Results of analyses performed on samples from various locations in Hanoi are shown in Tables 2, 3 and 4. Samples were from either surface waters (rivers and canals) or groundwater (primarily from the well head or adjacent plumbing) as designated in Table 2. Parameters measured at the time and location of sampling (see Materials and Methods) are included in Table 2. Most non-metallic compounds are shown in Table 3 and metallic elements plus arsenic are shown in Table 4. SS (Table 3) was only determined on surface water samples. The S^{2-} levels (Table 3) were consistently very low; however, the preservation of samples by acidification prior to transport was not proper for this constituent

(APHA, 1995), thus the accuracy of these values will require additional sampling and testing. Mn (Table 4) was below detection at all locations.

Table 1. Name and descriptive characteristics of sampling locations in Hanoi (see Figure 1 for locations).

No.	Name	Characteristics
1	Bach Khoa	Well of water treatment plant, H=68 m, Q=30,000 m3/d
2	Ha Ding 5	Well of Ha Dinh treatment plant, H=65-70 m, Total Q=80,000 m3/d for Ha Dinh system.
3	Ha Ding 6	Well of Ha Dinh treatment plant, H=65-70 m
4	Ha Ding 8	Well of Ha Dinh treatment plant, H=65-70 m
5	Van Dien	River water
6	Lu River (in)	In-flow to Xa Dan Lake from Lu River
7	Lu River (out)	Out-flow from Xa Dan Lake to Lu River
8	Qunyne Mai	Well of water treatment plant, H=68 m, Q=3,000 m3/d
9	Hoan Kiem	Lake water
10	Yen Phu 12	Well of Yen Phu treatment plant, H=70 m, Total Q=80,000 m3/d for Yen Phu system
11	Yen Phu 20	Well of Yen Phu treatment plant, H=68 m
12	Minh Khai	Personal well, H=40 m
13	Dong Tam	Personal well (Dr. Ha's well?), H=40 m
14	Cau Moi	Tributary of Lich River
15	Pha Van No. 1	Well of Phap Van treatment plant, H=65-78 m, Total Q=30,000 m3/d for Phap Van system.
16	Pha Van No. 2	Well of Phap Van treatment plant, H=65-78 m
17	Pha Van No. 3	Well of Phap Van treatment plant, H=65-78 m
18	Kim Nguu	Tributary of Kim Nguu River
19	HUCE	Well of treatment plant at university, H=65 m, Q=360 m3/d
20	Univ. tap	Treated well water in HUCE distribution system.

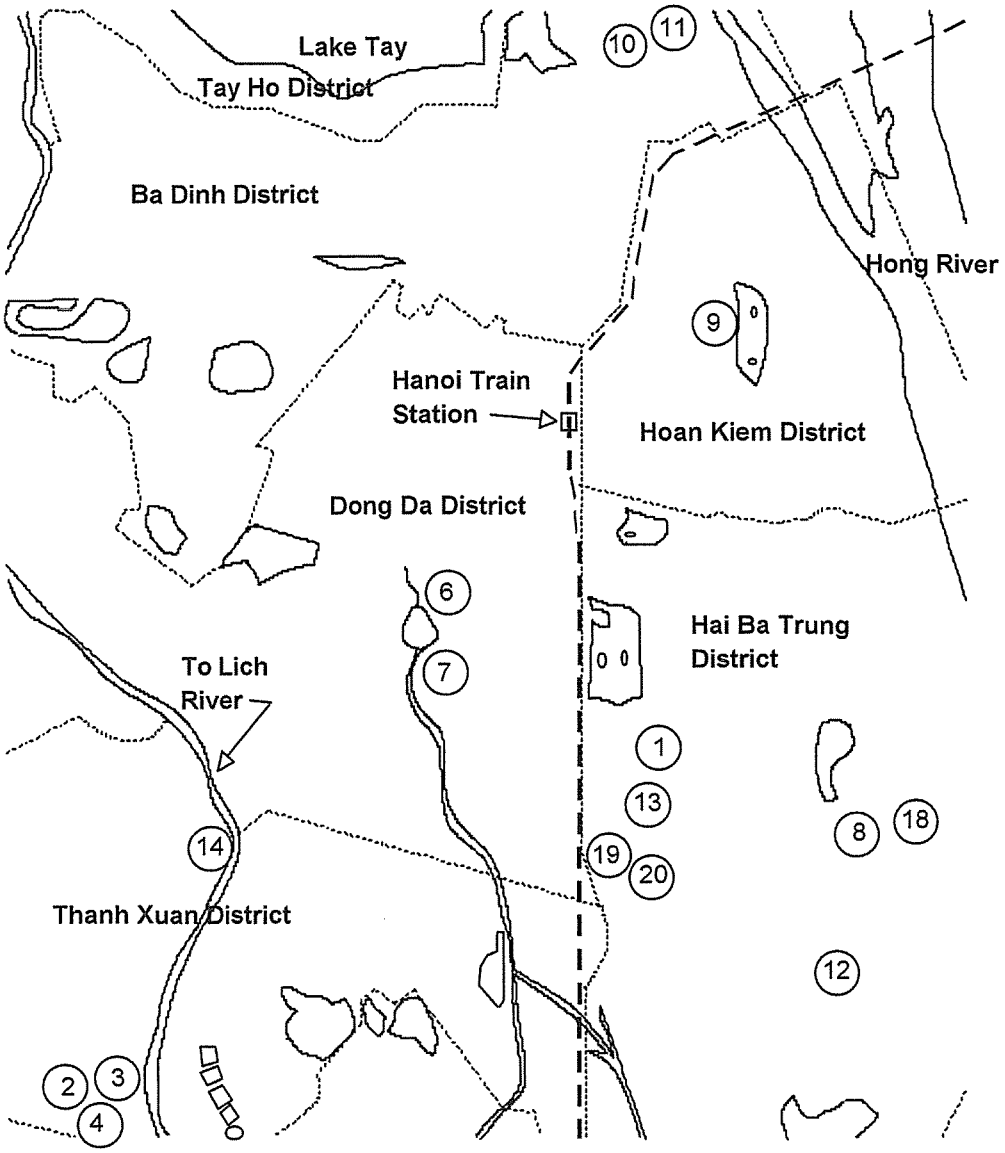

Figure 1. Sampling locations in Hanoi shown in relation to major lakes and tributaries (See Table 1). Locations 5, 13, 15, 16 and 17 are outside of the area of this map.

Table 2. Data from the Hanoi region determined at the time of sampling with source descriptions.

No.	Name	Description	Temp. (°C)	pH	NO_3^- (mg N/L)	NH_4^+ (mg N/L)
1	Bach Khoa	Well	26.1	6.84	1.0	9.6
2	Ha Ding 5	Well	26.0	6.82	0.7	9.6
3	Ha Ding 6	Well	26.3	6.88	0.7	9.0
4	Ha Ding 8	Well	26.0	6.86	0.8	10.2
5	Van Dien	river (?)	21.3	7.80	2.3	10.3
6	Lu River (in)	lagoon inlet	22.3	7.72	1.9	28.8
7	Lu River (out)	lagoon outlet	21.3	8.11	1.5	7.8
8	Qunyne Mai	well	25.3	6.80	0.2	2.8
9	Hoan Kiem	lake	19.9	10.30	1.0	0.2
10	Yen Phu 12	well	25.0	7.38	0.4	0.8
11	Yen Phu 20	well	25.2	7.10	0.8	3.6
12	Minh Khai	well	25.3	6.60	1.1	19.4
13	Dong Tam	well	24.3	6.70	2.2	5.9
14	Cau Moi	river	22.0	7.43	1.6	24.1
15	Pha Van No. 1	well	27.0	6.90	0.7	21.8
16	Pha Van No. 2	well	26.3	6.80	0.6	14.8
17	Pha Van No. 3	well	26.3	6.80	0.6	12.0
18	Kim Nguu	canal	23.4	7.00	2.7	26.4
19	HUCE	well	25.3	6.69	1.8	7.8
20	Univ. tap[a]	Well[a]	20.3	8.06	1.5	0.1

[a] Following treatment in distribution system.

Comparisons between data of well and surface water sources are shown in Table 5 (parts "a" and "b") and Figures 2, 3 and 4. Hoan Kiem Lake (No. 9) was considered atypical of the surface waters and was thus excluded from the composite analysis. Unique features of this stagnant lake included a high pH and very low NH_4^+ as well as a bright green coloration from algal growth. The university tap water (No. 20) was also excluded because following treatment and residence time in the distribution system, categorization with the other well waters which were sampled at the source would be tenuous (as evidenced by temperature, pH, NH_4^+ and Fe in particular).

Table 3. Major inorganic parameters in samples of the Hanoi region (nitrogenous compounds are in Table 2 and arsenic is in Table 4).

No.	Name	SO_4^{2-} (mg/L)	S^{2-} (mg/L)	SiO_2 (mg/L)	IC (mg/L)	TOC (mg/L)	SS[a] (mg/L)
1	Bach Khoa	1.6	0.5	52.8	24.8	1.4	--
2	Ha Ding 5	2.2	0.1	41.3	23.5	2.5	--
3	Ha Ding 6	2.6	0.9	37.9	22.3	1.3	--
4	Ha Ding 8	2.1	0.1	44.6	17.8	1.7	--
5	Van Dien	29.2	0.5	29.3	12.6	4.6	50.
6	Lu River (in)	5.0	1.3	34.9	20.2	5.9	50.
7	Lu River (out)	23.4	0.5	23.0	14.3	3.2	35.
8	Qunyne Mai	4.2	1.3	35.0	13.6	0.5	--
9	Hoan Kiem	1.6	1.4	21.8	1.9	8.3	175.
10	Yen Phu 12	2.1	1.4	22.1	4.6	0.5	--
11	Yen Phu 20	2.6	2.2	45.1	6.3	0.6	--
12	Minh Khai	0.8	0.5	23.7	26.0	2.8	--
13	Dong Tam	14.4	0.9	42.6	25.5	1.7	--
14	Cau Moi	11.7	0.8	90.9	18.1	5.4	25.
15	Pha Van No. 1	2.8	0.0	30.9	20.7	3.2	--
16	Pha Van No. 2	2.4	0.0	44.0	21.1	3.0	--
17	Pha Van No. 3	2.1	1.2	41.4	18.7	2.8	--
18	Kim Nguu	18.2	1.6	41.7	20.9	13.8	80.
19	HUCE	5.2	0.0	53.8	26.6	1.6	--
20	Univ. tap	5.3	0.4	15.8	7.2	0.4	--

[a] SS determined only on surface water (non-well) samples.

The average temperature of the well waters (Table 5a, Figure 2) was significantly higher than that of the surface waters (26°C versus 22°C, respectively). While surface water temperatures would be subject to seasonal trends (autumn in this case), the well water temperatures should reflect constant groundwater conditions. 26°C is a rather high temperature for groundwater and in Japan would qualify as a thermal water or hot spring source (i.e., > 25°C). The pH levels were consistently lower in the well waters than the surface waters (6.9 versus 7.6, respectively), possibly reflecting a mild acidity resulting from contact with subsurface formations. NO_3^- levels were low in both well and surface waters, rarely exceeding 3 mg N/L and in no cases did they approach the regulatory limit of 10 mg N/L for potable water. For surface waters, NH_4^+ levels were relatively high at about 20 mg

N/L versus 10 mg N/L for well waters. The higher NH_4^+ levels in surface waters probably reflect pollution from anthropogenic sources.

Table 4. Metals and arsenic (As) in samples of the Hanoi region.

No.	Name	Fe (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Mn[a] (mg/L)	As (mg/L)
1	Bach Khoa	11.5	25.1	12.4	29.0	3.0	0.0	0.054
2	Ha Ding 5	15.6	25.5	14.8	27.4	3.1	0.0	0.120
3	Ha Ding 6	12.1	23.8	12.7	30.8	3.6	0.0	0.120
4	Ha Ding 8	15.0	23.4	13.5	28.7	3.8	0.0	0.078
5	Van Dien	1.5	33.5	14.0	47.9	21.1	0.0	0.014
6	Lu River (in)	1.2	36.1	12.9	40.2	17.5	0.0	0.013
7	Lu River (out)	0.7	30.8	10.6	31.2	14.0	0.0	0.006
8	Qunyne Mai	4.3	15.2	10.9	9.1	1.7	0.0	0.050
9	Hoan Kiem	1.0	13.7	1.4	8.3	6.1	0.0	0.005
10	Yen Phu 12	2.5	32.8	8.6	7.2	1.9	0.0	0.053
11	Yen Phu 20	9.1	40.5	13.8	18.2	6.7	0.0	0.080
12	Minh Khai	20.5	51.8	15.9	26.2	2.5	0.0	0.088
13	Dong Tam	24.0	45.9	20.8	72.4	2.3	0.0	0.017
14	Cau Moi	1.0	33.1	16.6	44.4	14.8	0.0	0.008
15	Pha Van No. 1	9.5	25.3	13.2	32.6	5.7	0.0	0.070
16	Pha Van No. 2	9.7	21.2	12.0	34.2	5.3	0.0	0.051
17	Pha Van No. 3	9.5	20.9	11.8	36.2	5.4	0.0	0.039
18	Kim Nguu	3.3	37.2	14.3	44.6	20.2	0.0	0.020
19	HUCE	31.6	42.8	18.0	44.0	1.9	0.0	0.020
20	Univ. tap	0.1	26.9	6.3	3.0	1.7	0.0	0.020

[a] Mn below detection in all samples. Detection limit less than 0.05 mg/L.

SO_4^{2-} levels (Table 5a, Figure 3) were about an order of magnitude higher in surface waters than well waters (21 versus 2.6 mg/L, respectively). SiO_2 and IC levels in well and surface waters did not appear to be significantly different. TOC levels, however, were noticeably higher in surface waters (4.8 versus 1.8 mg/L, respectively). In a few cases, a datum stood out in its category as a "flyer" and was thus eliminated from the analyses as displayed in Figure 3 and discussed above. Those cases being: SiO_2 in Cau Moi, which was

about 3 times higher than the surface water average; TOC in the heavily polluted Kim Nguu Canal, which was about 3 times higher than the surface water average; SO_4^{2-} in Dr Ha's well water, which was nearly an order of magnitude higher than average for wells; and SO_4^{2-} in the Lu River-In, which was nearly an order of magnitude lower than the surface water average. The Lu River "-In" and "-Out" designation refers to the inlet and outlet, respectively, of Xa Dan Lake, which serves as a passive treatment lagoon in the river's course. The significance of this feature, however, with respect to the atypical inlet value for SO_4^{2-} is not clear.

Arsenic values were alarmingly high (Table 5b). The average of 0.065 mg/L for well waters is in excess of the commonly accepted drinking water standard of 0.050 mg/L and greatly in excess of the recently proposed standard of 0.010 mg/L by the U.S. congress. The surface waters, though not considered potable water sources, at 0.012 mg/L are also of concern.

Table 5a. Comparisons of well and surface water quality parameters in Hanoi – continued in Table 5b, below. Standard deviations shown in brackets (1 SD).

	Temp. (°C)	pH	NO_3^- (mg N/L)	NH_4^+ (mg N/L)	SO_4^{2-} (mg/L)	SiO_2 (mg/L)	IC (mg/L)	TOC (mg/L)
Well	25.7 (0.7)	6.86 (0.20)	0.89 (0.55)	9.79 (6.15)	2.56 (1.15)	39.6 (9.7)	19.3 (7.2)	1.82 (0.96)
Surface	22.1 (0.9)	7.61 (0.42)	2.00 (0.50)	19.5 (9.7)	20.6 (7.4)	32.2 (8.0)	17.2 (3.6)	4.78 (1.18)

Table 5b. Comparisons of well and surface water quality parameters in Hanoi – continued from Table 5a, above. Standard deviations shown in brackets (1 SD)

	As (mg/L)	Fe (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)
Well	0.0646 (0.0325)	13.4 (8.0)	30.3 (11.3)	13.7 (3.1)	30.4 (16.3)	3.61 (1.66)
Surface	0.0122 (0.0055)	1.54 (1.03)	34.1 (2.5)	13.7 (2.2)	41.7 (6.4)	17.5 (3.2)

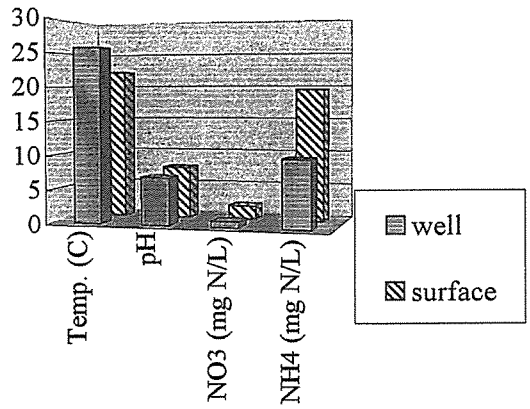

Figure 2. Comparisons of well and surface parameters for temperature, pH, nitrate and ammonium in Hanoi.

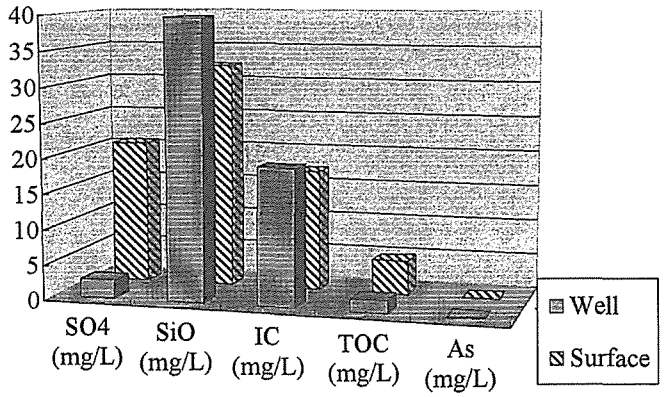

Figure 3. Comparisons of well and surface parameters for sulfate, silica (SiO2), IC, TOC and As in Hanoi.

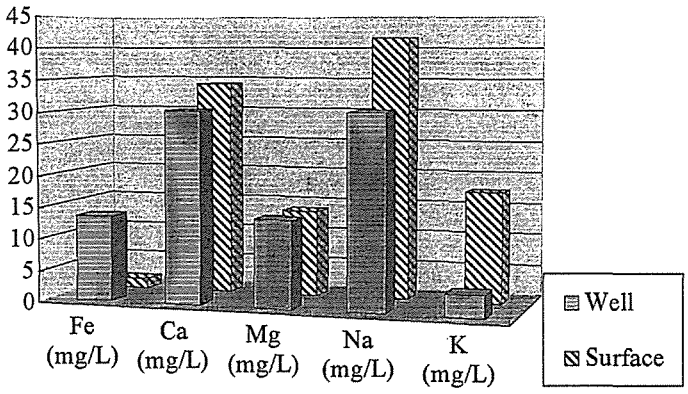

Figure 4. Comparisons of well and surface parameters for Fe, Ca, Mg, Na and K in Hanoi.

The metals as shown in Figure 4 only differed significantly between well and surface water sources in that Fe was higher in well waters and K was higher in surface waters. Na also had a higher average value for surface waters, however, due to considerable scatter in the data, significance is difficult to imply. The higher Fe levels in well waters is assumed to reflect the soluble divalent ferrous form, Fe(II), which would be expected due to anaerobic conditions in the subsurface. Upon exposure to oxygen in surface waters, this form would oxidize to the insoluble, trivalent ferric form, Fe(III), and precipitate out of solution.

The metals shown in Figure 4 are also displayed in pie-chart format in Figures 5 and 6 for well and surface waters, respectively. Total hardness is defined by the American Public Health Association (APHA, 1995) as the sum of Ca and Mg ions (as $CaCO_3$), which in this case would be 132 and 141 mg $CaCO_3$/L for well and surface waters, respectively. If Fe(II) is also considered (which would only be a significant factor for the well waters), the hardness levels would be 156 and 144 mg $CaCO_3$/L for well and surface waters, respectively. By either interpretation, it does not appear that the hardness levels are significantly different. The only other unique factors evident from the data shown in Figures 4, 5 and 6 would be the very low amounts of Fe in the surface waters and the noticeably lesser amounts of the monovalent metals Na and K in the well waters.

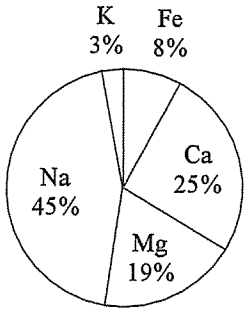

Figure 5. Metals in Hanoi well water (percentages of molar concentrations). Total concentration of the five metals, 2.98 mM.

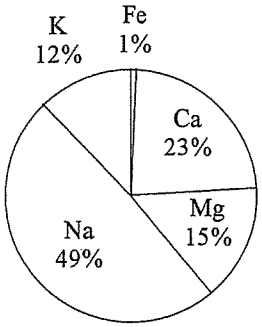

Figure 6. Metals in Hanoi surface water (percentages of molar concentrations). Total concentration of the five metals, 3.70 mM.

4.2 Saigon region

Water quality analyses were only made for surface waters at three locations in Ho Chi Minh City as shown in Tables 6, 7 and 8. Two of the locations, as discussed below, were disturbingly polluted in appearance and odor.

Table 6. Data from Ho Chi Minh City determined at the time and location of sampling with source descriptions.

No.	Name	Description	Temp. (°C)	pH	NO_3^- (mg N/L)	NH_4^+ (mg N/L)
21	Dong Nai	River	27.5	7.04	0.7	0.5
22	Saigon River	River	28.6	6.94	1.5	5.0
23	Dirty Canal	Canal	28.0	6.83	1.7	21.8

Table 7. Major inorganic parameters in samples from Ho Chi Minh City (nitrogenous compounds in Table 6, arsenic (As) not determined).

No.	Name	SO_4^{2-} (mg/L)	S^{2-} (mg/L)	SiO_2 (mg/L)	IC (mg/L)	TOC (mg/L)	SS (mg/L)
21	Dong Nai	3.6	0.4	12.9	2.3	0.8	5
22	Saigon River	12.0	2.0	14.4	10.7	2.4	60
23	Dirty Canal	16.7	2.0	25.9	16.8	4.9	100

Table 8. Metals in samples from Ho Chi Minh City.

No.	Name	Fe (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Mn[a] (mg/L)
21	Dong Nai	0.8	2.2	0.9	3.0	1.3	0.0
22	Saigon River	3.6	13.1	5.0	30.4	6.1	0.0
23	Dirty Canal	3.6	22.8	4.1	40.8	11.6	0.0

[a] Mn below detection in all samples (detection limit less than 0.05 mg/L).

The temperatures of these surface waters in the southern, tropical Saigon region were about 6°C warmer than those of surface waters in Hanoi. The relative degree of pollution among these surface waters was evident from the increasing levels of NH_4^+, TOC and SS from location No. 21 to 22 and ultimately 23 (Tables 6 and 7). Evidently, the higher levels of organic pollutants in the Saigon River and the Dirty Canal (No. 22 and 23, respectively) were enough to maintain anaerobic conditions as evidenced by the relatively high levels of Fe in these samples (Table 8) -- soluble Fe(II) is only present under reducing or anaerobic conditions. Interestingly, though, the total hardness levels of these samples were all within the range of a soft water (i.e., less than 100 mg $CaCO_3$/L). Even including Fe(II), the "Dirty Canal," with the highest hardness level, was only 80 mg $CaCO_3$/L. The hardness of the Saigon River was only 60 mg $CaCO_3$/L and Don Nai was extremely low with only 11 mg $CaCO_3$/L.

5. Conclusions

i) Analyses were performed on samples from surface and groundwater sources at 20 locations in Hanoi. Various parameters were measured in the field and samples were delivered to Kumamoto University, Japan, for further detailed analyses.

ii) NO_3^- levels were consistently below the regulatory limit for potable water. The average NH_4^+ level for surface waters, however, was relatively high at about 20 mg N/L versus 10 mg N/L for well waters.

iii) SO_4^{2-} and TOC were higher in surface waters than in well waters; SiO_2 and IC, however, were not significantly different between different sources.

iv) For potable well waters, the average arsenic level of 0.065 mg/L was alarmingly high, being well above the commonly accepted regulatory limit of 0.050 mg/L.

v) Both surface and well waters had low levels of total hardness (between 130 and 160 mg $CaCO_3$/L). Well waters had higher Fe levels (about 14 mg/L), possibly reflecting anaerobic conditions in the subsurface.

vi) Three surface waters in Ho Chi Minh City were also investigated. All of the sources consisted of soft water (i.e., total hardness well below 100 mg $CaCO_3$/L). Two of the sources had significant levels of soluble Fe, apparently indicating anaerobic conditions resulting from high organic pollutant loadings.

6. Acknowledgement: The authors wish to thank Mr. Taro Kondo for technical assistance in acquiring data in the field.

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