QUALITY OF GROUNDWATER FROM OPEN-WELLS IN RURAL AND PERI-URBAN AREAS OF UNGUJA ISLAND, ZANZIBAR, TANZANIA

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ABSTRACT Water quality is one among the most important environmental issues these decades. Heavy metals receive a particular concern among the wide diversity of chemicals causing environmental degradation including groundwater. Nitrate, as well, is an indicator of human-induced groundwater contamination. This study investigated the levels of toxic heavy metals such as Cd, Cu, Pb, Co and Cr, and nitrate (NO_3^-) contained in the water from 116 open-wells in rural and peri-urban areas of Unguja Island, Zanzibar. The average values of the heavy metals were as follows: 1.359 ± 3.419 μg L^{-1} for Cr; 0.052 ± 0.109 μg L^{-1} for Co; 0.238 ± 0.533 μg L^{-1} for Cu, 0.001 ± 0.004 μg L^{-1} for Cd; and 0.003 ± 0.026 μg L^{-1} for Pb. Referring to Water quality standard in Japan (MHLW), Water quality guideline by WHO and Quality of Drinking Water Supplies (EWURA), the results suggest no serious acute problem of heavy metal contamination so far. The average value of the nitrate (NO_3^-) was 36.1 ± 58.85 mg L^{-1}. The nitrate contamination, some of which exceeded the values of permissible standards for safe drinking waters by MHLW and WHO, however, should not be underestimated.

Key Words: Water quality; Groundwater; Heavy metals; Nitrate; Zanzibar.

INTRODUCTION

Groundwater is a major source of available drinking water worldwide which is estimated for about 95% by Bowell et al. (1996) and about 91% by WHO (2005). In Tanzania mainland, more than 25% of the domestic water consumption comes from groundwater sources (Elisante & Muzuka, 2017). In Zanzibar, however, the dependency on groundwater is more than 95%, since it is the major available water source which meets the requirements of the growing population and economic sectors such as agriculture and tourism (Hansson, 2010; Sikat, 2011).

Contamination of groundwater is one of the major concerns for human health in Africa and beyond (Elisante & Muzuka, 2017). Groundwater may be contaminated with diversified contaminants, including heavy metals, from its natural surrounding through the contact with soils, sediments and rocks in a given geological setting (Islam et al., 2013), as well as those arising from anthropogenic activities (Salem et al., 2000; Siepak et al., 2004; Momodu and Anyakora, 2010; Gaur

et al., 2014; Mohamed et al., 2014). Heavy metal toxicity leads to various public health concerns such as brain damage, mental retardation, kidney damage, renal dysfunction, lung cancer, bone fractures, chronic bronchitis, asthma, hypertension, myocardic dysfunctions, weight and mental retardation of new born babies and death of infants and unborn foetus (Salem et al., 2000; Hu, 2002; Mudgal et al., 2010; Malassa et al., 2013; Neeti et al., 2013; Verma and Dwivedi, 2013). Nitrate is another notorious contaminant for groundwater through various sources such water-soil interaction during percolation, agricultural activities, domestic sewages, leakage from fuel filling stations, industrial effluent, repair garages and so on (Huang et al., 2007). Zanzibar has frequently faced outbreak of waterborne diseases such as cholera. WHO (2016) reported 3,057 cholera cases with 51 deaths in Zanzibar, including 1,818 cases with 38 deaths in Unguja Island and 1,239 cases with 13 deaths in Pemba Island. Therefore, assessing the current status of water quality and levels of contamination is important for possible intervention regarding to the public health in the context of hygiene and disease control.

Despite of the deterioration of water quality and associated public health implications in Zanzibar (e.g., WHO, 2016), there are a few published studies concerning groundwater quality regarding to toxic metals and nitrate which mainly based on urban environment setting (Hansson, 2010; Mohamed et al., 2013; 2014). Moreover, less cases in rural and peri-urban areas were reported. This study, therefore, aimed to determine the concentration level of some heavy metals and nitrate in groundwater from 116 open-wells covering in rural and peri-urban areas of the entire Unguja Island, though not in Pemba Island this time, Zanzibar.

MATERIALS AND METHOD

I. Study Area

Zanzibar, a semi-autonomous region of the United Republic of Tanzania, is archipelago consisting of two large islands, i.e., Unguja and Pemba, and many small islands in Indian Ocean. Unguja Island where this study was conducted is mainly low lying topography with its highest point of 120 m above sea level. Unguja Island is divided into five districts: North A, North B, Central, West and South.

The archipelago is a land block arose above the sea from the ancient Miocene Ruvu/Rufiji delta origin (Hansson, 2010; Sikat, 2011). The soils are roughly divided into three types: a shallow and immature soil derived from rugged coral limestone and lagoonal sediment, classified as Chromic Cambisols (FAO, 1988), covering the entire South District and eastern (coastal) part of the Central, North B and North A District; a moderately weathered sandy soil derived from uplifted lagoonal sediments (mixture of sand and coral rug), classified as Ferralic Arenosols (FAO, 1988), covering hilly area of North B, West and Central District; and an immature sandy soil derived from lagoonal sediments, classified as Cambic Arenosols (FAO, 1988), covering coastal area and inland plain of North A, North B and Central District. The average high and low temperature is 31°C and 24°C,

respectively. The annual rainfall is around 1,400 mm during rainy months between March and May under the southwest monsoon (locally known as *Kusi*) and in November with sporadic shower under the northeast monsoon (*Kaskazi*). In observation, rainfalls in terms of occasions and amounts are more in the northern part of the island than the south.

Regarding groundwater, the sources are rainwater and aquifers. The main aquifers lie on the central part of the island referred as corridor, existing deep in the layer of Quaternary lime stone, Quaternary sand and Miocene sand (Sikat, 2011). These aquifers are said to be recharged partly by deep aquifers from Tanzania mainland (Hansson, 2010). In the southeast part of the island, groundwater is obtained from the fresh water lens covering deep-lying sea water which mainly recharged by rain water infiltrated through rugged lime stone, caves and underground water channels (Hansson, 2010).

II. Sampling and Analyses

Water sample was collected from 116 open-wells located in rural and peri-urban areas of Unguja Island (Fig. 1) in October, 2014 and February, 2015. Due to the development of tap-water system, the use of open-well tends to decline, however, it is still maintained as shown in Photo 1 through Photo 6, for example.

Before sampling, the position (latitude and longitude) was recorded by GPS receiver. Temperature and the level of water surface, i.e., the distance from the top of a wall of open-well and the water surface, was measured, respectively. Each of collected water sample was passed through a plastic disposal filter (ADVANTAC CS020 AN; cellulose acetate type membrane filter with a diameter of 0.2 μm) to fill a 100 ml polythene bottle on site. After transported to the Research Institute for Humanity and Nature, Kyoto, the electric conductivity and pH was measured with LAQUA twin EC meter (Horiba Inc., Kyoto) and LAQUA twin pH meter (Horiba Inc.). Heavy metals were determined using Agilent 7500cx ICP-MS (Agilent Technologies Inc., Tokyo) at the Research Institute for Humanity and Nature (RIHN), Kyoto, as well as nitrate by ion chromatography using Dionex ICS-3000 (Thermo Fisher Scientific Inc., Yokohama).

RESULTS AND DISCUSION

The information of the sampling sites and some selected properties of groundwater are shown in Table 1. Due to the level of water surface, the water sources of open-wells seem to be rain water. The water in the open-well located closer to coast tends to show higher E.C. (electric conductivity), suggesting the influence of sea water. The pH is alkaline with the average of 7.8 which attributed to the soil materials and surface geology such as rugged limestone and corals. The analytical data of the dissolved ions are shown in Table 2, and that of the dissolved metals in Table 3–5.

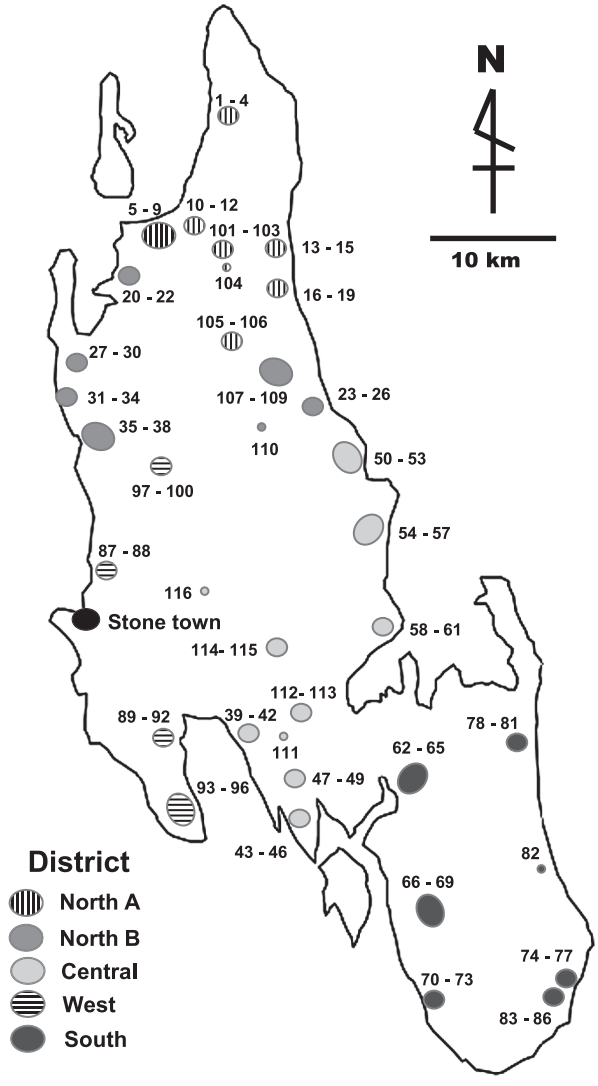

Fig. 1. Location of the open-wells for water sampling, Unguja Island, Zanzibar.

I. Levels of Some Selected Toxic Heavy Metals in Groundwater

Among the huge data set, some heavy metals such as Cr, Co, Cu, Cd and Pb are selected to discuss about the potential risk. The average values of the metals were as follows: 1.359 ± 3.419 μg L^{-1} (ranged from not detected-ND to 28.267 μg L^{-1}) for Cr; 0.052 ± 0.109 μg L^{-1} (ND to 0.851 μg L^{-1}) for Co; 0.238 ± 0.533 μg L^{-1} (ND to 5.172 μg L^{-1}) for Cu, 0.001 ± 0.004 μg L^{-1} (ND to 0.034 μg L^{-1}) for Cd; and 0.003 ± 0.026 μg L^{-1} (ND to 0.278 μg L^{-1}) for Pb. These results suggest no serious acute health effects caused by the heavy

Table 1. Sampling site and some selected properties of ground water

Site No.	District/Ward	GPS reading Latitude	(hddd.ddddd°) Longitude	Water level (m)	Water temp. (°C)	E.C. (μS cm^{-1})	pH (H_2O)
1	North A (Kaskazini A)/Kidoti	–5.59971	39.29961	23.5	26.7	710	7.4
2		–5.80014	39.29914	22.0	27.7	1,260	7.4
3		–5.80281	39.30208	31.1	27.3	510	7.6
4		–5.79707	39.30113	26.1	28.3	670	7.5
5	North A (Kaskazini A)/Mkokotoni	–5.87986	39.25506	7.1	27.4	430	8.1
6		–5.87838	39.25573	6.7	28.0	670	7.6
7		–5.87503	39.25518	3.6	26.5	1,360	8.1
8		–5.87676	39.26883	1.7	26.2	660	7.8
9		–5.87672	39.26881	17.5	27.1	1,200	7.6
10	North A (Kaskazini A)/Kivunge	–5.87700	39.28246	21.6	27.6	940	7.5
11		–5.87626	39.28151	21.4	27.4	2,200	7.3
12		–5.87852	39.27971	18.4	27.7	630	7.5
13	North A (Kaskazini A)/Matemwe	–5.89832	39.35420	4.1	28.5	7,700	8.0
14		–5.89765	39.35386	3.9	28.3	13,000	8.0
15		–5.89682	39.35428	4.1	30.2	13,800	8.0
16	North A (Kaskazini A)/Pwani Mchangani	–5.92307	39.35686	3.7	30.1	3,800	8.0
17		–5.92397	39.35708	3.8	33.0	4,400	7.8
18		–5.92655	39.35823	3.2	28.7	8,600	8.1
19		–5.92524	39.35775	4.3	28.7	7,900	7.8
20	North B (Kaskazini B)/Muwanda	–5.91547	39.22386	0.0	24.9	1,360	7.9
21		–5.91203	39.22689	0.3	26.9	101	6.1
22		–5.91575	39.22575	2.8	26.2	600	7.3
23	North B (Kaskazini B)/Kiwengwa	–5.99724	39.38069	4.3	28.2	4,300	7.8
24		–5.99971	39.38187	4.9	27.2	3,500	7.8
25		–6.00159	39.38211	5.7	27.2	8,600	8.0
26		–6.00293	39.38089	7.8	26.9	4,400	7.8
27	North B (Kaskazini B)/Makoba	–5.95503	39.19877	15.0	27.7	640	7.4
28		–5.95433	39.19390	24.9	28.2	650	7.8
29		–5.95236	39.19533	14.0	28.1	690	7.3
30		–5.95027	39.19494	17.7	28.2	790	7.4
31	North B (Kaskazini B)/Mangapwani	–5.99524	39.18653	12.6	27.3	490	7.4
32		–5.99063	39.18615	14.8	27.0	2,100	7.3
33		–5.99037	39.18854	16.6	28.2	10,200	7.4
34		–5.99014	39.19540	17.7	27.5	710	7.4
35	North B (Kaskazini B)/Kiombamvua	–6.02456	39.21108	3.0	26.9	290	7.8
36		–6.01953	39.20458	17.4	27.4	480	7.4
37		–6.02251	39.20799	15.3	27.9	520	7.5
38		–6.02604	39.20876	5.0	27.5	240	7.4
39	Central (Kati)/Bungi	–6.24203	39.32868	13.8	27.9	730	7.7
40		–6.24247	39.33146	13.6	25.4	510	7.9
41		–6.24376	39.33045	13.1	26.3	510	7.6
42		–6.24871	39.33233	11.6	26.8	650	7.5

Table 1. (continued)

Site No.	District/Ward	GPS reading Latitude	(hddd.ddddd°) Longitude	Water level (m)	Water temp. (°C)	E.C. (μS cm^{-1})	pH (H_2O)
43	Central (Kati)/Unguja Ukuu Kaepwani	–6.30916	39.37296	7.2	26.9	1,150	7.4
44		–6.30813	39.37142	9.2	27.6	1,620	7.5
45		–6.30557	39.37784	5.5	27.5	5,900	8.0
46		–6.30434	39.37726	6.9	27.7	7,100	7.6
47	Central (Kati)/Unguja Ukuu Kaebona	–6.28055	39.37731	15.4	26.1	560	7.5
48		–6.28120	39.37753	15.7	26.4	650	7.4
49		–6.27329	39.37670	18.0	26.1	540	8.0
50	Central (Kati)/Pongwe	–6.05864	39.41414	5.4	27.2	3,600	7.8
51		–6.05869	39.41491	3.1	27.2	8,000	7.9
52		–6.04279	39.40599	3.6	27.5	8,300	8.0
53		–6.04159	39.40678	3.6	27.7	14,500	7.9
54	Central (Kati)/Uroa	–6.10086	39.41516	7.5	27.0	2,100	8.0
55		–6.10320	39.40705	11.9	26.3	1,210	7.8
56		–6.09507	39.42222	7.5	27.5	6,900	8.0
57		–6.09208	39.42155	5.2	27.4	8,000	8.0
58	Central (Kati)/Chwaka	–6.16689	39.43659	3.6	27.4	3,300	8.1
59		–6.16598	39.43567	4.3	27.5	7,400	8.0
60		–6.16618	39.43470	4.3	27.1	11,200	8.0
61		–6.16534	39.43388	2.7	N/A	1,270	7.6
62	South (Kusini)/Kitogani	–6.28567	39.43625	3.4	27.9	2,500	7.6
63		–6.28869	39.43842	6.4	26.9	1,920	7.7
64		–6.28881	39.44046	9.3	26.6	1,000	7.7
65		–6.28001	39.45169	0.0	23.4	640	7.9
66	South (Kusini)/Muyuni C	–6.38277	39.47117	20.3	26.6	350	8.3
67		–6.37971	39.46966	16.8	26.5	380	8.1
68		–6.37719	39.46435	26.3	28.0	680	8.8
69		–6.37281	39.46481	29.1	27.1	780	8.0
70	South (Kusini)/Kizimkazi Dimbani	–6.43608	39.46241	5.9	27.9	970	7.8
71		–6.43262	39.46296	6.2	27.4	1,650	8.1
72		–6.43068	39.46345	7.7	26.5	1,150	8.4
73		–6.43215	39.46595	13.5	26.2	780	8.3
74	South (Kusini)/Tasani	–6.42553	39.55702	22.3	28.8	740	7.8
75		–6.42664	39.55864	17.0	28.5	1,870	7.5
76		–6.42383	39.56186	19.1	29.1	760	7.9
77		–6.42243	39.55684	20.4	27.8	1,110	8.2
78	South (Kusini)/Bwejuu	–6.24114	39.53381	3.6	28.3	1,710	8.4
79		–6.24020	39.53292	3.8	28.3	2,000	8.4
80		–6.24057	39.53175	6.3	27.5	2,700	8.3
81		–6.24135	39.53280	5.3	32.7	1,070	8.5
82	South (Kusini)/Jambiani Kikadini	–6.33326	39.54936	2.2	27.2	6,100	8.3
83	South (Kusini)/Mzuri	–6.42374	39.55427	19.2	27.9	780	7.8
84		–6.42786	39.55369	24.1	28.7	780	8.4

Table 1. (continued)

Site No.	District/Ward	GPS reading Latitude	(hddd.ddddd°) Longitude	Water level (m)	Water temp. (°C)	E.C. (μS cm^{-1})	pH (H_2O)
85		–6.42955	39.55255	24.5	27.4	610	8.4
86		–6.42737	39.55194	25.8	28.0	600	7.8
87	West (Magharibi)/Bububu	–6.12896	39.21786	8.5	28.2	380	8.1
88	West (Magharibi)/Mtoni	–6.12883	39.21807	12.0	28.1	1,440	7.9
89	West (Magharibi)/Kombeni	–6.25209	39.26525	13.0	28.1	710	7.7
90		–6.24897	39.27246	11.6	27.4	790	7.9
91		–6.24921	39.27465	12.4	27.7	1,450	7.9
92		–6.25006	39.27449	13.3	27.5	1,340	7.9
93	West (Magharibi)/Bweleo	–6.29871	39.29074	10.7	29.4	6,000	8.0
94		–6.30192	39.29191	8.5	27.1	1,610	7.8
95		–6.28896	39.28279	10.4	27.8	2,900	8.4
96		–6.29862	39.29212	9.8	N/A	8,400	8.0
97	West (Magharibi)/Bumbwisudi	–6.04878	39.26310	9.4	26.2	270	8.4
98		–6.05496	39.26421	7.5	27.0	430	8.5
99		–6.05696	39.26414	6.6	26.2	390	7.9
100		–6.06024	39.26384	5.9	26.0	61	7.2
101	North A (Kaskazini A)/Chutama	–5.89450	39.29225	13.6	27.7	670	7.4
102		–5.89491	39.29483	15.7	27.3	810	7.4
103		–5.89744	39.29664	23.8	27.5	460	7.6
104	North A (Kaskazini A)/Moga	–5.90358	39.29453	10.2	27.2	720	7.6
105	North A (Kaskazini A)/Kuyasini Ngaba	–5.97231	39.30681	11.2	28.0	730	7.5
106		–5.97233	39.30564	4.9	27.6	670	7.5
107	North B (Kaskazini B)/Upenja	–5.99247	39.35275	33.4	28.4	400	8.1
108		–5.99494	39.34647	28.7	27.3	600	7.8
109		–5.98706	39.33319	23.2	28.0	330	8.3
110	North B (Kaskazini B)/Kilombero	–6.02608	39.33800	26.5	27.8	1,140	7.9
111	Central (Kati)/Cheju-Kibonda Meji	–6.23472	39.35728	12.5	27.0	450	7.9
112	Central (Kati)/Cheju-Chuchumile	–6.21331	39.37486	5.6	26.6	1,030	7.7
113	Central (Kati)/Cheju-Mgeninani	–6.21181	39.37994	15.7	26.1	420	7.8
114	Central (Kati)/Mseweni	–6.18975	39.35661	20.6	27.5	400	8.1
115	Central (Kati)/Ndijani Mseweni	–6.18839	39.35881	21.4	27.0	310	8.2
116	Central (Kati)/Ubago	–6.14283	39.30297	11.7	27.1	600	8.0

Source) Analysis by Tanaka.

Table 2. Dissolved ion (mg L^{-1}) analyzed by Ion Chromatography (ICS-3000)

Site No.	F	Cl	NO2	Br	NO3	SO4	PO4	Na	K	Mg	Ca
1	0.09	70.14	0.00	0.21	42.71	13.73	0.03	30.52	1.93	4.21	76.11
2	0.17	152.29	0.00	0.61	107.00	11.97	0.00	58.66	2.49	7.52	137.01
3	0.06	31.59	0.00	0.09	38.32	2.43	0.00	10.50	1.09	2.93	66.89
4	0.10	64.62	0.00	0.18	36.30	5.92	0.00	28.82	6.29	9.66	62.19
5	0.19	25.34	0.00	0.04	0.56	14.76	0.03	23.49	1.69	4.72	47.58
6	0.12	39.39	0.00	0.10	0.46	15.71	0.00	66.85	1.35	10.59	39.09
7	0.07	81.17	0.15	0.23	52.47	65.54	5.35	104.22	25.51	15.56	118.98
8	0.09	24.41	0.00	0.06	0.15	18.53	0.00	38.64	8.41	5.60	63.92
9	0.14	108.33	0.00	0.28	1.59	47.57	0.00	132.66	4.87	21.29	53.74
10	0.06	86.97	0.00	0.20	125.26	18.47	0.04	52.25	1.11	4.03	96.99
11	0.03	238.28	0.00	0.35	319.63	21.35	0.00	157.66	2.11	4.58	201.05
12	0.12	39.21	0.00	0.08	65.39	6.84	0.01	19.67	1.00	8.52	69.27
13	0.00	1543.41	0.00	6.74	41.88	247.06	0.00	1139.68	47.03	144.28	124.12
14	0.61	2769.32	0.00	11.91	149.76	570.28	0.00	2120.64	104.94	243.80	171.03
15	0.00	2852.61	0.00	12.46	87.30	520.45	0.00	2144.57	101.53	257.85	160.56
16	0.05	544.03	0.07	2.28	160.83	157.75	0.00	452.04	61.94	75.17	86.24
17	0.00	677.16	0.00	2.89	224.42	193.51	0.00	546.84	84.99	81.30	95.94
18	0.00	1614.88	0.00	7.30	13.15	349.08	0.00	1276.23	57.15	154.18	143.33
19	0.00	1397.39	0.00	5.89	51.89	395.59	0.00	1165.88	53.09	162.64	123.06
20	0.01	30.84	0.09	0.08	4.12	31.69	0.00	32.63	4.57	6.59	20.82
21	0.01	15.97	0.00	0.01	0.78	10.87	0.00	9.48	0.27	1.14	3.77
22	0.02	76.79	0.00	0.14	53.59	23.65	0.02	49.77	15.00	5.80	28.30
23	0.00	754.44	0.00	3.23	39.68	162.30	0.00	579.42	24.61	81.84	96.47
24	0.00	544.49	0.00	2.32	37.90	139.07	0.00	447.45	28.74	72.53	90.32
25	0.12	1710.78	0.00	7.52	10.35	313.63	0.00	1285.42	47.21	152.67	138.25
26	0.12	795.57	0.00	3.48	10.30	126.47	0.00	589.88	21.19	67.95	109.25
27	0.08	52.65	0.00	0.14	5.84	7.91	0.00	26.40	1.20	2.04	72.93
28	0.04	28.93	0.00	0.07	16.19	12.29	0.00	26.66	1.53	1.23	78.88
29	0.08	47.41	0.00	0.09	37.92	9.37	0.00	23.38	1.17	2.17	85.60
30	0.05	55.75	0.00	0.14	78.23	20.79	0.00	46.67	1.91	1.85	72.44
31	0.09	17.45	0.00	0.04	1.11	2.77	0.00	18.66	1.36	2.00	59.33
32	0.16	372.91	0.00	1.52	4.33	15.12	0.00	80.79	3.61	25.96	226.16
33	0.06	0.00	0.00	9.93	2.23	329.66	0.00	1477.40	44.94	165.20	230.42
34	0.08	59.43	0.00	0.10	56.60	5.74	0.00	17.12	2.13	2.81	89.95
35	0.02	17.90	0.00	0.05	15.40	11.60	0.03	19.26	2.32	3.85	24.79
36	0.06	12.71	0.00	0.03	5.31	3.55	0.00	12.81	1.51	3.15	64.31
37	0.06	16.96	0.00	0.03	10.76	5.81	0.00	15.47	1.90	8.87	57.23
38	0.01	34.02	0.00	0.05	9.17	3.07	0.00	20.85	0.39	2.28	14.33
39	0.09	103.82	0.00	0.32	4.79	13.53	0.00	59.06	1.87	11.11	46.79
40	0.02	22.90	0.00	0.09	28.58	0.67	0.05	15.31	3.05	2.29	79.81
41	0.07	36.53	0.01	0.10	3.96	3.64	0.00	18.29	1.13	6.67	57.32
42	0.08	63.45	0.00	0.19	2.36	6.80	0.00	34.04	1.81	9.31	59.32

Table 2. (continued)

Site No.	F	Cl	NO_2	Br	NO_3	SO_4	PO_4	Na	K	Mg	Ca
43	0.06	141.83	0.00	0.58	2.94	17.46	0.00	87.91	2.80	8.75	93.40
44	0.05	238.87	0.00	0.99	10.17	31.42	0.00	148.55	3.75	21.73	93.82
45	0.06	1100.81	0.00	4.66	0.00	186.33	0.00	829.25	31.84	100.32	126.12
46	0.15	1378.40	0.00	5.90	2.13	231.77	0.00	1032.15	30.10	121.07	139.35
47	0.05	38.92	0.00	0.08	6.96	6.02	0.00	24.31	0.97	3.69	54.94
48	0.05	71.89	0.00	0.19	2.16	0.66	0.00	18.75	1.94	4.13	74.31
49	0.03	13.92	0.00	0.02	18.74	2.22	1.96	13.86	4.10	3.78	77.35
50	0.00	558.70	0.04	2.33	120.04	131.84	0.00	443.38	45.40	57.24	109.37
51	0.28	1572.20	0.00	6.81	38.10	278.20	0.00	1181.10	54.60	139.27	135.69
52	0.40	1602.92	0.00	7.08	35.44	284.74	0.00	1196.53	53.41	144.21	149.36
53	0.00	3085.85	0.00	13.44	14.31	549.34	0.00	2300.21	83.91	266.91	192.49
54	0.09	316.06	0.10	1.34	3.58	35.30	0.00	223.68	6.54	25.22	106.23
55	0.08	158.55	0.13	0.67	5.28	17.14	0.00	110.62	3.36	13.82	81.47
56	0.12	1335.90	0.00	5.77	3.58	215.46	0.00	991.59	34.38	116.25	143.07
57	0.14	1602.98	0.00	7.01	2.41	266.53	0.00	1181.19	41.33	140.92	152.77
58	0.00	727.12	0.04	3.05	52.51	171.30	0.00	558.25	40.81	71.43	86.20
59	0.22	1389.71	0.79	5.97	54.07	271.32	0.00	1041.56	50.36	134.75	145.87
60	0.32	2281.65	0.13	9.77	43.52	435.13	0.00	1700.54	75.81	205.85	168.65
61	0.05	102.15	0.00	0.53	0.57	83.44	0.00	128.48	13.87	24.45	63.11
62	0.10	413.42	0.00	1.63	1.60	67.82	0.00	304.53	7.83	23.75	101.99
63	0.02	262.32	0.09	1.09	74.83	50.19	0.00	212.94	16.82	27.58	78.07
64	0.09	106.22	0.00	0.41	14.98	20.95	0.00	86.21	6.99	12.21	65.12
65	0.04	78.05	0.00	0.24	3.85	7.35	0.00	43.49	1.44	4.82	56.41
66	0.05	17.58	0.00	0.05	5.86	3.03	0.12	14.69	1.53	0.93	44.74
67	0.03	5.60	0.00	0.03	4.93	0.32	0.14	4.92	4.24	3.25	56.41
68	0.28	38.77	0.00	0.09	0.99	25.17	0.00	85.02	3.37	20.77	12.02
69	0.16	19.84	0.00	0.06	74.07	6.32	9.40	20.44	14.56	13.97	90.21
70	0.09	129.81	0.00	0.39	8.92	18.16	0.00	56.67	6.03	17.66	68.35
71	0.31	124.21	0.11	0.35	53.98	101.51	0.06	205.52	12.59	26.30	62.48
72	0.08	126.92	0.00	0.42	0.20	27.45	0.14	91.47	4.55	6.96	103.10
73	0.04	110.41	0.00	0.34	33.28	13.21	0.01	64.36	3.10	6.52	53.05
74	0.23	74.58	0.00	0.18	8.80	34.99	0.00	63.26	2.31	16.68	43.80
75	0.04	151.74	0.00	0.45	331.59	60.96	0.00	127.77	3.92	9.76	172.29
76	0.31	65.90	0.00	0.20	2.15	9.28	0.00	48.05	1.99	21.15	49.46
77	0.08	77.39	0.00	0.20	8.12	0.38	1.25	60.72	14.73	10.92	122.88
78	0.00	187.70	0.00	0.78	67.77	55.49	0.00	161.28	14.57	59.13	58.11
79	0.00	184.69	0.05	0.73	191.83	101.41	0.00	194.97	43.51	38.49	83.34
80	0.00	394.60	0.00	1.61	80.82	71.84	0.00	302.79	32.59	31.41	107.58
81	0.57	118.02	0.02	0.44	30.28	32.59	0.00	100.83	9.67	17.89	52.72
82	0.07	1136.77	0.00	4.77	0.27	192.26	0.00	846.76	29.29	93.64	120.70
83	0.04	82.86	0.00	0.16	56.10	10.85	0.00	35.82	1.15	3.86	80.84
84	0.33	49.80	0.00	0.15	16.80	33.28	0.04	24.44	4.53	20.05	83.05

Table 2. (continued)

Site No.	F	Cl	NO_2	Br	NO_3	SO_4	PO_4	Na	K	Mg	Ca
85	0.16	33.88	0.00	0.09	7.65	30.93	0.02	36.58	1.43	4.57	63.96
86	0.10	30.59	0.00	0.08	52.89	11.33	0.00	28.14	0.81	2.87	63.87
87	0.05	23.19	0.00	0.04	41.67	14.12	0.00	12.58	1.31	1.79	43.69
88	0.02	77.31	0.09	0.18	228.10	74.01	0.00	70.44	13.37	12.27	153.07
89	0.06	62.92	0.00	0.19	9.42	7.36	0.00	39.25	1.99	6.40	67.90
90	0.05	123.66	0.00	0.37	6.19	8.02	0.00	65.23	1.66	7.48	72.13
91	0.07	242.85	0.00	1.03	3.61	30.38	0.00	172.48	4.62	18.76	88.43
92	0.06	216.61	0.00	0.92	4.21	25.81	0.00	152.38	3.91	16.92	87.53
93	0.15	1363.65	0.00	5.82	16.74	184.55	0.00	945.68	27.24	104.23	178.38
94	0.00	301.53	0.00	1.30	4.94	11.68	0.00	124.48	1.55	6.86	157.54
95	0.00	594.66	0.28	2.61	9.49	70.39	0.00	377.65	8.46	42.69	156.04
96	0.07	1909.60	0.28	8.39	63.67	303.22	0.00	1369.49	56.60	156.60	205.63
97	0.02	13.99	0.00	0.04	6.96	0.99	0.00	16.68	1.56	2.05	34.61
98	0.19	12.48	0.00	0.03	1.27	4.87	0.22	25.12	0.99	10.97	51.17
99	0.08	5.96	0.00	0.02	0.67	5.92	0.00	10.73	1.51	7.68	54.52
100	0.02	9.22	0.00	0.02	7.09	1.19	0.00	6.51	1.86	0.60	2.03
101	0.12	37.26	0.00	0.09	43.75	3.71	0.00	16.83	3.30	4.74	94.58
102	0.10	65.29	0.02	0.14	75.31	10.73	0.00	40.00	0.53	2.61	101.05
103	0.10	12.33	0.00	0.05	8.13	0.44	0.00	4.56	0.46	1.64	65.50
104	0.11	61.87	0.00	0.11	13.99	17.02	0.00	35.79	1.02	8.17	84.48
105	0.08	36.67	0.00	0.05	26.04	14.81	0.00	24.04	1.49	7.72	90.64
106	0.06	42.10	0.00	0.06	23.32	11.22	0.00	24.98	0.61	6.58	88.99
107	0.04	10.66	0.00	0.05	4.32	2.24	0.00	9.28	1.77	3.46	55.80
108	0.05	47.03	0.00	0.12	4.62	15.60	0.00	41.59	1.65	5.82	65.11
109	0.03	11.64	0.00	0.08	8.75	0.68	0.01	5.30	1.01	1.56	59.76
110	0.20	95.34	0.00	0.26	1.33	83.91	0.00	117.39	1.51	21.52	89.14
111	0.03	10.61	0.00	0.03	10.24	1.20	0.10	6.33	1.39	1.26	85.44
112	0.88	18.03	0.00	0.06	1.35	257.06	0.00	37.27	3.39	33.49	131.55
113	0.03	9.07	0.01	0.03	9.00	2.49	0.24	6.16	10.41	2.39	72.57
114	0.05	21.66	0.00	0.03	0.15	6.78	0.02	10.64	1.23	2.94	67.94
115	0.05	14.08	0.00	0.06	1.84	7.07	0.04	8.93	0.47	0.98	54.16
116	0.07	7.74	0.00	0.02	2.36	1.69	0.00	7.46	0.62	6.13	87.97

Source) Analysis by K.C. Shin (Research Institute for Humanity and Nature)

Note) Water quality standard in Japan (mg L^{-1}; MHLW, 2008): F > 0.8; Cl > 200; NO_3 > 10.
Water quality guideline (mg L^{-1}; WHO, 2011): F > 1.5; Cl > 5; NO_2 > 3; Br > 0.01; NO_3 > 50.
Quality of drinking water (mg L^{-1}; EWURA, 2014): F > 4.0; Cl > 800; NO_3 > 75.0; SO_4 > 600; Mg > 100; Ca > 300.

Table 3. Dissolved metal (μg L^{-1}) analyzed by ICP-MS (ICP-MS 7500cx)

Site No.	Li	B	Na	Mg	Al	Si	P	K	Ca	Sc	Ti
1	0.83	24.57	25617.96	3864.22	1.10	8918.33	0.46	1939.10	61942.76	0.09	0.20
2	0.69	30.22	51272.78	7123.13	0.63	7206.22	0.00	2651.47	111905.81	0.07	0.21
3	0.47	20.97	9074.85	2594.51	1.59	3878.34	0.00	1116.18	54908.17	0.05	0.10
4	2.63	48.58	25064.69	8539.22	0.74	11525.81	0.00	5790.74	51857.88	0.08	0.33
5	0.74	17.92	20447.17	4424.42	3.38	6929.17	13.61	1715.16	40205.84	0.06	0.19
6	1.53	42.70	58365.19	9522.76	0.82	12634.50	0.00	1440.87	34034.74	0.08	0.31
7	0.65	67.96	92907.61	14653.93	2.57	11884.73	1763.10	23702.08	103863.95	0.07	0.54
8	0.48	25.61	34612.69	5341.98	1.57	7287.97	0.00	7956.89	53962.03	0.04	0.21
9	8.42	44.39	119701.40	19740.65	1.32	17025.21	0.00	4929.90	46867.09	0.14	0.35
10	0.82	21.01	46824.28	3950.50	0.92	3747.62	0.00	1206.73	81901.41	0.05	0.11
11	1.24	24.35	142069.24	4361.87	1.29	4168.61	0.00	2267.94	168066.34	0.04	0.00
12	0.59	19.92	17617.14	7896.39	0.43	4412.55	0.00	1079.69	59032.66	0.03	0.10
13	12.67	368.38	1018592.65	130804.98	6.03	1662.11	12.79	45807.70	115620.54	0.00	0.11
14	28.70	753.30	2023364.38	239729.54	7.86	2458.32	0.00	107632.68	174201.76	0.04	0.00
15	25.60	784.94	2064338.05	253231.28	13.88	2881.79	0.00	104790.45	165314.98	0.00	1.36
16	7.97	282.81	414462.60	70245.57	6.37	6349.53	0.00	59774.10	84351.37	0.03	0.17
17	8.40	304.21	503429.35	75565.65	6.47	5266.65	0.00	81897.51	90983.76	0.03	0.09
18	16.77	589.16	1192138.52	145627.33	8.32	2206.49	0.00	57947.99	134156.33	0.04	1.59
19	20.03	647.77	1082098.68	149655.51	4.95	7355.99	0.00	52694.98	113531.75	0.07	0.00
20	0.08	37.44	30726.70	6298.41	3.19	2687.55	0.00	4740.17	20531.92	0.02	0.15
21	0.27	14.50	8713.19	1129.51	93.42	5461.81	0.00	298.03	3379.63	0.04	0.12
22	1.00	49.07	46465.04	5789.87	9.38	4898.61	1.61	14656.76	28150.35	0.03	0.12
23	8.62	232.82	540857.78	76439.37	5.56	3556.58	0.00	24504.06	89603.80	0.01	0.12
24	7.30	188.81	422161.37	68764.05	3.52	3188.79	0.00	28843.92	84776.16	0.04	0.09
25	16.30	433.01	1255261.82	150531.73	7.48	5213.09	0.00	49671.58	144371.18	0.00	0.45
26	5.44	211.83	566776.39	65892.78	7.32	4744.62	0.00	22079.67	106475.80	0.05	0.21
27	0.18	19.48	25378.84	2058.17	0.28	6638.02	0.00	1420.74	64928.54	0.05	0.19
28	1.76	14.01	25436.92	1293.01	2.26	4760.64	0.00	1773.02	68484.29	0.03	0.14
29	0.94	21.08	21709.26	2134.21	0.49	5641.27	0.00	1321.07	74203.19	0.05	0.13
30	1.19	22.57	44010.61	1868.39	0.50	4404.39	0.00	2087.16	64029.71	0.03	0.17
31	1.13	19.34	17505.98	1992.67	0.34	11021.61	0.00	1510.16	52498.18	0.07	0.30
32	1.38	35.44	72838.54	24142.55	1.38	9928.74	0.00	3993.23	186225.58	0.12	0.27
33	17.94	427.42	1329979.43	149028.51	1.95	12581.30	0.00	41615.54	197785.90	0.11	0.45
34	1.49	20.33	17012.06	2903.68	0.50	5141.47	0.00	2374.70	82496.24	0.05	0.13
35	0.73	15.57	17827.85	3826.34	3.42	5543.85	4.53	2399.76	23453.99	0.02	0.12
36	1.83	19.94	12322.03	3073.29	0.47	8842.05	0.00	1692.74	56665.80	0.07	0.21
37	3.17	17.08	14515.83	8472.05	0.57	7474.41	0.00	2047.90	50164.24	0.05	0.21
38	4.73	15.89	19229.45	2205.87	1.97	4749.96	0.00	439.79	13648.70	0.02	0.09
39	1.56	29.14	53825.67	10449.71	1.11	4232.47	0.00	2055.59	41575.30	0.03	0.09
40	0.46	20.70	16297.76	2613.03	0.89	2214.63	35.12	3582.46	78160.17	0.02	0.08
41	1.31	22.13	19489.65	7555.40	2.00	4176.57	0.00	1554.59	62002.57	0.04	0.11
42	1.90	29.62	35944.86	10293.39	1.58	4740.56	0.00	2349.83	63803.40	0.03	0.10

Table 3. (continued)

Site No.	Li	B	Na	Mg	Al	Si	P	K	Ca	Sc	Ti
43	5.16	43.06	90586.13	9770.61	0.18	11964.34	0.00	3572.24	90023.28	0.08	0.38
44	4.05	70.50	149091.68	22541.14	1.75	2616.62	0.00	4640.75	87105.49	0.07	0.22
45	12.30	380.21	882774.64	111297.25	4.81	2529.75	18.58	37295.65	139498.70	0.11	0.14
46	12.27	447.38	1078330.15	129905.48	5.10	2140.88	0.00	35120.64	149204.40	0.11	0.25
47	1.26	20.22	26308.16	4332.30	2.21	3748.35	0.00	1342.84	65654.24	0.04	0.12
48	1.92	16.02	20344.19	4852.60	0.86	4408.37	0.00	2415.50	83310.15	0.04	0.11
49	0.53	23.24	15049.21	4445.94	7.36	4646.85	903.48	4810.13	75874.90	0.04	0.16
50	7.03	274.37	459834.72	60639.93	2.79	5421.85	0.00	48665.50	116029.55	0.07	0.31
51	18.79	604.90	1231235.23	147111.18	2.20	3233.74	0.00	61965.06	144099.42	0.02	0.05
52	23.54	604.83	1236946.77	151257.01	1.06	3243.67	0.00	58915.20	157020.95	0.10	0.00
53	38.39	1089.93	2462661.76	288667.14	4.64	3294.57	0.00	97395.61	209947.58	0.30	1.12
54	5.61	104.52	226853.31	26885.20	1.82	4285.95	0.00	7640.69	111369.93	0.06	0.14
55	3.28	64.64	114260.46	15230.65	3.14	3960.87	0.00	4358.62	79308.27	0.05	0.27
56	15.22	451.44	1011928.46	123357.50	3.43	3964.55	0.00	39416.04	150158.72	0.13	0.19
57	15.42	553.49	1213039.95	146835.56	2.51	4124.97	0.00	45272.87	157921.65	0.10	0.28
58	12.26	357.19	571053.21	74613.33	17.66	1276.26	9.32	43322.17	90365.47	0.04	0.06
59	23.55	627.32	1055404.92	138321.51	1.24	4610.87	0.00	54145.20	150711.56	0.09	0.30
60	33.33	958.14	1673766.62	210346.70	5.73	3168.98	39.02	80794.95	169829.35	0.04	0.91
61	8.15	150.88	126667.86	24717.04	0.56	4507.74	0.00	14192.83	64217.34	0.06	0.10
62	8.11	110.09	309367.81	25618.02	6.29	317.15	0.00	8951.93	106556.03	0.05	0.14
63	7.74	168.24	217812.28	29262.34	2.50	939.91	0.00	18089.53	81264.37	0.02	0.09
64	3.54	93.66	86832.36	13113.68	1.62	975.38	0.00	7711.16	66361.52	0.02	0.11
65	1.49	33.29	44143.18	5318.26	9.09	920.01	3.54	1804.21	54282.57	0.03	0.05
66	0.33	15.13	15202.43	1061.41	6.98	1167.62	69.37	1892.68	42215.18	0.03	0.00
67	0.16	28.65	5388.78	3591.17	3.48	5797.44	66.98	4578.36	52804.66	0.06	0.16
68	14.32	29.71	85365.25	21138.38	0.40	15762.72	0.92	3683.68	13131.24	0.14	0.40
69	2.70	38.09	20095.20	13959.59	1.37	12195.45	3828.73	14417.19	81485.41	0.11	0.78
70	2.61	52.15	53665.97	16968.16	6.41	6109.33	0.01	5992.23	67103.66	0.06	0.14
71	4.95	127.85	192195.46	25508.89	2.07	22421.83	35.78	12519.25	61277.49	0.18	0.59
72	1.33	38.71	88465.06	7187.03	2.21	9872.65	71.86	4964.33	94188.46	0.08	0.32
73	1.32	36.22	62796.94	6731.08	14.72	909.03	9.76	3293.09	48150.38	0.03	0.02
74	3.96	37.44	60158.72	16255.03	0.88	5850.54	0.00	2438.85	55706.22	0.05	0.14
75	1.35	40.38	121004.95	10184.75	0.87	6212.32	0.00	4534.44	152858.51	0.10	0.18
76	1.70	61.05	45672.72	20186.90	3.75	7623.49	0.00	2248.90	47355.85	0.07	0.20
77	1.29	49.01	55952.90	10912.87	1.08	8280.94	543.48	14127.66	106791.38	0.09	0.29
78	5.59	153.72	150228.96	55368.31	8.19	3274.32	8.15	14051.04	55871.63	0.04	0.21
79	4.43	165.95	181187.12	36762.94	13.34	3600.70	11.12	40545.78	79804.00	0.09	0.03
80	5.38	167.51	273402.93	29615.06	5.42	1274.63	1.91	29795.99	100478.37	0.06	0.01
81	2.10	87.50	90795.65	16981.98	21.24	3512.14	0.00	9079.05	48654.91	0.04	0.10
82	13.45	421.69	801012.74	92888.59	1.78	735.74	24.78	30286.53	115803.24	0.06	0.04
83	0.42	23.27	34402.72	3964.56	2.74	3243.38	0.00	1362.99	74450.92	0.04	0.09
84	2.53	43.06	23253.81	19146.77	2.36	7474.83	35.71	4592.16	73204.39	0.09	0.19

Table 3. (continued)

Site No.	Li	B	Na	Mg	Al	Si	P	K	Ca	Sc	Ti
85	2.51	34.24	33668.53	4546.55	3.97	4895.85	20.62	1580.55	57310.14	0.05	0.15
86	1.25	26.19	26769.59	2896.25	2.10	3210.40	0.00	964.82	60881.37	0.04	0.11
87	1.45	17.62	11708.78	1744.85	0.62	7190.71	1.92	1458.20	38398.07	0.07	0.19
88	1.70	47.31	62746.01	11660.46	1.65	7881.91	4.31	12296.17	126468.40	0.11	0.15
89	3.05	27.72	36748.54	6484.41	0.69	7399.64	1.71	2233.39	63964.56	0.08	0.17
90	2.47	31.23	60123.50	7295.44	1.81	5458.97	0.08	1825.36	68496.81	0.07	0.16
91	4.90	74.43	158887.37	18194.18	1.00	6649.20	0.00	5014.89	76723.60	0.07	0.12
92	4.37	64.10	141186.75	16695.26	0.96	6875.81	0.00	4400.21	75264.82	0.07	0.14
93	15.84	338.70	889309.34	102439.68	5.28	2098.22	0.00	28029.93	172368.79	0.10	0.01
94	3.21	57.04	119512.27	6994.78	1.85	1980.25	0.00	1956.36	140087.06	0.06	0.08
95	6.85	125.75	364075.33	42679.57	2.45	2174.25	3.66	9056.30	141513.07	0.07	0.20
96	20.09	521.64	1359864.42	159449.99	2.66	1908.11	0.00	58288.54	207553.24	0.13	0.12
97	1.53	21.71	16730.90	2142.42	0.76	20532.61	2.70	1819.50	30890.46	0.16	0.60
98	1.03	29.22	25001.03	11155.87	2.02	19084.81	102.18	1199.82	46548.60	0.16	0.54
99	1.59	24.61	10988.73	8000.69	2.16	12644.30	0.00	1802.61	54619.38	0.09	0.23
100	3.29	19.17	6718.60	749.01	3.07	5553.16	0.00	2109.38	1989.65	0.05	0.21
101	1.79	34.39	16559.07	5052.51	0.04	5071.19	0.00	3460.70	95723.60	0.06	0.15
102	1.23	28.53	38926.89	2693.18	0.11	4706.77	1.81	664.36	102035.41	0.06	0.14
103	0.96	27.99	38931.25	2719.95	0.13	4684.08	0.45	660.54	101797.32	0.06	0.11
104	2.40	31.01	34541.75	8376.74	0.48	7312.60	0.00	1207.84	85402.16	0.05	0.14
105	1.70	28.80	23395.31	7768.28	1.13	8119.62	0.50	1670.90	92130.84	0.09	0.22
106	1.36	27.97	23841.19	6595.10	0.66	8016.28	0.00	734.98	88902.63	0.09	0.23
107	1.76	37.06	9083.11	3441.55	4.30	4131.63	0.42	1927.70	57773.15	0.04	0.14
108	2.20	35.99	38984.65	5908.69	2.14	5152.58	0.00	1812.11	64175.63	0.05	0.08
109	0.07	24.94	5468.08	1587.12	5.12	3487.34	21.66	1141.15	51919.34	0.06	0.08
110	4.14	63.58	105129.36	19939.34	0.57	13923.27	0.00	1628.40	75822.63	0.10	0.43
111	0.58	16.78	6094.88	1239.64	1.52	2548.28	58.07	1462.84	70788.75	0.03	0.04
112	7.05	118.77	33175.88	29857.04	0.39	13633.10	0.00	3475.70	109694.38	0.13	0.24
113	0.47	17.61	5759.30	2224.81	1.70	3279.81	136.21	8966.36	59097.65	0.04	0.13
114	0.59	21.04	9609.36	2771.13	1.57	4685.11	14.54	1253.65	55793.49	0.05	0.15
115	0.41	13.57	8296.86	959.28	2.80	1602.96	23.77	524.53	45010.84	0.01	0.03
116	0.75	19.65	6996.13	5813.72	0.49	6474.86	34.06	666.51	93310.77	0.06	0.11

Source) Analysis by K.C. Shin (Research Institute for Humanity and Nature)
Note) Water quality standard in Japan (μg L^{-1}; MHLW, 2008): B > 800; Na > 200,000; Mg > 300,000; Al > 200; Ca > 300,000.
Water quality guideline (μg L^{-1}; WHO, 2011): B > 2,400; Al > 200.
Quality of drinking water (μg L^{-1}; EWURA, 2014): Nil.

Table 4. Dissolved metal (μg L^{-1}) analyzed by ICP-MS (ICP-MS 7500cx)

Site No.	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb
1	1.41	15.54	0.00	0.00	0.02	0.13	0.00	0.19	0.81	0.60	2.20
2	1.44	4.19	0.00	0.00	0.03	0.39	0.00	0.09	0.46	0.54	2.70
3	0.86	1.25	0.06	0.00	0.01	0.18	0.00	0.00	0.26	0.19	1.08
4	1.97	2.47	0.00	0.00	0.01	0.17	0.00	0.00	0.51	0.60	2.20
5	0.12	0.00	6.18	0.79	0.03	0.12	0.07	0.97	0.60	0.36	4.55
6	0.99	0.00	0.38	0.36	0.01	0.16	0.00	0.00	1.58	0.07	1.21
7	8.87	0.14	0.03	0.58	0.22	0.78	0.43	31.77	4.08	0.61	32.63
8	2.28	0.00	1.59	0.00	0.03	0.55	0.17	0.00	0.35	0.31	10.81
9	6.70	5.70	0.03	0.00	0.04	0.60	0.20	0.00	0.20	0.45	4.55
10	1.77	17.37	0.01	0.00	0.07	0.24	0.00	0.00	0.44	0.64	1.69
11	1.02	28.27	0.03	0.00	0.08	0.83	0.00	0.00	0.31	0.63	2.96
12	1.66	6.80	0.00	0.00	0.02	0.23	0.00	0.00	0.32	0.24	1.19
13	4.66	1.33	0.00	0.00	0.00	1.10	0.00	9.82	1.64	0.37	18.13
14	2.05	0.72	1.26	0.00	0.02	1.82	0.00	21.73	1.52	0.26	55.20
15	3.33	0.00	0.00	0.00	0.00	3.24	0.00	0.47	1.99	0.44	51.96
16	3.80	0.09	0.00	0.00	0.05	0.97	0.00	2.16	3.07	0.83	60.48
17	3.48	0.31	0.00	0.00	0.07	1.08	0.11	0.00	3.21	0.99	72.00
18	3.13	0.00	0.00	0.00	0.04	1.37	0.00	2.60	2.13	0.58	34.14
19	3.12	0.00	0.00	0.00	0.04	1.94	0.00	0.00	7.96	0.14	42.53
20	0.08	0.00	2.27	6.74	0.03	0.22	0.00	0.18	0.13	0.09	3.49
21	0.14	0.04	46.09	7.59	0.08	0.23	0.17	1.65	0.03	0.35	0.50
22	0.69	0.64	1.67	0.03	0.11	0.16	0.16	0.16	0.11	0.72	14.49
23	2.54	1.50	0.00	0.00	0.01	1.28	0.00	0.65	1.24	0.30	12.27
24	4.57	0.00	0.00	0.00	0.01	1.05	0.00	2.80	1.53	0.56	21.75
25	1.29	0.66	0.00	0.00	0.00	1.05	0.00	5.27	0.72	0.31	13.62
26	1.19	1.05	0.00	0.00	0.00	0.38	0.00	1.12	0.60	0.38	7.10
27	0.43	0.00	0.70	0.04	0.05	0.17	0.07	0.00	0.33	0.32	2.76
28	1.06	0.11	0.15	0.06	0.03	0.43	0.35	0.00	0.70	0.92	2.18
29	0.71	0.23	0.16	0.00	0.02	0.23	0.19	0.00	0.45	0.50	2.56
30	0.95	0.28	0.00	0.00	0.02	0.14	0.02	0.00	0.43	1.04	2.39
31	0.15	0.00	0.30	0.18	0.02	0.40	0.00	0.00	2.09	0.00	1.87
32	0.93	0.00	0.08	0.00	0.01	1.19	0.00	0.19	0.42	0.28	1.72
33	0.62	0.27	0.83	0.00	0.03	1.86	0.00	0.65	0.19	0.09	15.07
34	0.78	0.08	0.07	0.00	0.02	0.38	0.20	0.00	0.17	0.34	4.37
35	0.96	0.20	1.30	0.13	0.02	0.15	0.14	0.16	0.20	0.80	4.80
36	0.73	0.49	0.02	0.00	0.01	0.15	0.00	0.00	0.36	0.26	2.66
37	0.39	0.20	0.12	0.05	0.01	0.14	0.00	0.00	0.18	0.33	4.42
38	0.44	0.83	0.01	0.00	0.01	0.13	0.09	0.39	0.05	0.36	1.23
39	1.58	1.35	0.00	0.00	0.01	0.12	0.00	0.00	0.37	0.14	1.30
40	0.01	0.06	66.08	39.91	0.36	0.18	0.31	0.19	1.73	0.05	7.81
41	0.92	0.31	0.14	0.91	0.01	0.14	0.22	0.00	0.51	0.12	1.79
42	1.11	0.73	1.98	1.15	0.02	0.13	0.29	0.01	0.45	0.17	2.45

Table 4. (continued)

Site No.	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb
43	0.79	1.30	0.00	0.00	0.01	0.16	0.04	0.00	0.36	0.50	2.90
44	1.22	1.37	0.00	0.00	0.01	0.00	0.00	0.00	0.34	0.09	2.02
45	0.38	0.42	0.21	0.81	0.00	0.00	0.00	0.38	2.76	0.00	17.67
46	1.46	0.64	0.00	0.00	0.00	0.10	0.02	0.00	0.45	0.00	15.10
47	1.78	0.87	0.11	0.17	0.03	0.10	0.21	0.04	0.67	0.78	2.80
48	0.09	0.06	0.87	0.48	0.06	0.13	0.30	0.04	1.05	0.01	5.41
49	0.79	0.05	2.29	1.52	0.09	4.87	0.51	0.73	1.83	0.04	16.26
50	2.02	0.59	0.00	0.00	0.03	0.38	0.55	0.33	1.85	0.59	44.33
51	1.60	1.34	0.22	0.00	0.00	0.55	0.52	3.80	1.44	0.24	29.12
52	2.57	1.16	0.00	0.00	0.01	0.70	1.13	2.41	2.35	1.03	22.99
53	1.97	2.20	0.00	0.00	0.00	0.05	0.00	10.62	2.55	0.54	29.67
54	0.94	1.60	0.00	0.00	0.00	0.18	0.13	3.38	0.62	0.17	3.31
55	1.20	1.59	0.00	0.00	0.00	0.16	0.04	0.23	0.45	0.26	2.05
56	1.07	1.90	0.00	1.50	0.00	0.00	0.00	0.00	0.74	0.00	11.09
57	1.09	1.89	0.00	0.00	0.00	0.11	0.00	1.65	0.82	0.08	13.73
58	2.22	1.70	0.00	0.00	0.13	0.48	0.50	1.40	1.83	0.19	41.85
59	2.25	1.34	0.56	0.00	0.02	0.47	0.17	7.30	2.10	0.34	33.39
60	2.05	1.33	0.00	0.00	0.06	1.31	0.42	4.61	0.86	0.68	37.78
61	0.78	0.12	0.08	0.00	0.03	0.48	0.33	0.26	1.14	0.09	10.51
62	0.44	0.12	0.15	0.13	0.04	0.20	0.15	0.78	1.76	0.09	4.03
63	0.55	0.74	0.00	0.00	0.05	0.22	0.35	0.76	0.34	0.49	9.25
64	0.65	0.70	0.00	0.12	0.02	0.07	0.00	0.00	0.25	0.20	3.88
65	0.61	0.45	0.00	0.00	0.01	0.03	0.06	0.00	0.22	0.26	0.75
66	0.56	0.30	0.56	1.78	0.03	0.15	0.27	0.66	0.46	0.04	3.15
67	0.06	0.05	65.61	4.54	0.17	0.17	0.24	0.29	5.13	0.05	11.05
68	0.95	0.50	0.26	9.33	0.03	0.15	0.25	0.00	0.73	0.11	3.34
69	0.62	0.10	23.36	6.72	0.53	1.45	1.05	1.96	4.23	0.27	16.69
70	4.51	1.18	0.07	0.03	0.02	0.24	0.43	0.00	1.90	0.97	8.26
71	28.25	0.22	0.00	0.00	0.06	0.49	0.47	0.00	1.18	2.42	5.70
72	0.34	0.02	0.15	0.09	0.06	1.02	0.34	0.42	0.53	0.00	4.54
73	0.63	1.31	0.08	0.15	0.03	0.20	0.35	1.69	0.18	0.32	1.90
74	1.17	1.70	1.24	0.04	0.04	0.34	0.48	0.00	0.92	0.16	3.25
75	1.43	1.04	0.01	0.00	0.12	0.46	0.20	0.29	0.26	1.30	2.29
76	1.40	0.05	1.28	0.35	0.02	0.14	0.33	0.00	1.32	0.34	2.17
77	0.38	0.01	1.24	2.05	0.43	0.66	0.10	1.21	9.98	0.01	22.42
78	6.45	0.57	0.02	0.20	0.05	1.41	1.46	8.62	2.79	0.15	21.38
79	2.96	3.20	0.00	0.00	0.02	1.26	0.69	6.07	1.09	1.00	62.25
80	0.46	0.79	0.00	0.00	0.01	0.57	0.33	8.13	0.42	0.27	30.09
81	1.20	2.44	0.00	0.00	0.05	0.82	0.58	53.45	0.39	0.06	13.02
82	0.85	1.04	0.00	0.00	0.00	0.05	0.00	2.51	0.26	0.13	8.90
83	0.76	0.44	0.04	0.00	0.04	0.24	0.19	0.00	0.29	0.33	1.69
84	2.33	0.55	0.27	0.32	0.02	0.31	0.54	5.06	0.90	0.28	2.44

Table 4. (continued)

Site No.	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb
85	1.28	0.18	0.26	0.19	0.02	0.26	0.49	1.18	1.15	0.94	1.50
86	1.72	0.19	0.08	0.03	0.03	0.20	0.26	0.00	0.62	0.54	1.12
87	0.55	1.60	0.00	0.00	0.05	0.28	0.18	0.00	0.11	0.78	2.29
88	1.07	0.97	0.00	0.00	0.20	0.56	0.46	0.09	0.16	1.63	20.02
89	1.61	1.95	0.00	0.00	0.01	0.21	0.07	0.00	0.50	0.14	2.16
90	0.82	1.11	0.12	0.00	0.02	0.34	0.12	0.00	0.37	0.17	1.73
91	1.09	1.28	0.00	0.02	0.00	0.20	0.00	0.35	0.45	0.26	3.11
92	1.12	1.02	0.00	0.00	0.00	0.24	0.00	0.22	0.46	0.21	2.80
93	0.84	0.91	0.00	0.00	0.00	0.28	0.06	3.54	0.37	0.11	9.83
94	0.39	0.18	0.00	0.00	0.02	0.17	0.10	0.00	0.33	0.24	1.34
95	0.66	0.66	0.00	0.00	0.00	0.16	0.07	1.08	0.58	0.15	4.91
96	0.77	0.97	0.00	0.00	0.05	0.74	0.33	3.02	0.50	0.29	24.00
97	0.40	0.03	141.53	11.93	0.11	0.73	0.57	1.26	0.74	0.02	2.58
98	2.72	0.06	76.89	0.13	0.04	0.40	0.02	0.23	0.39	0.04	1.09
99	0.35	0.03	1.36	0.00	0.01	0.27	0.16	0.00	0.48	0.01	2.14
100	0.08	0.00	107.00	5.41	0.85	0.93	0.94	6.58	0.43	0.02	6.42
101	1.21	1.50	0.09	0.04	0.01	0.13	0.02	0.00	0.19	0.33	1.34
102	1.24	0.90	0.00	0.00	0.04	0.06	0.01	0.00	0.22	0.15	1.01
103	1.17	0.93	0.00	0.00	0.04	0.06	0.02	0.00	0.22	0.15	1.01
104	1.24	0.64	0.05	0.04	0.04	0.28	0.05	0.00	0.22	2.76	1.52
105	2.58	1.12	0.00	0.03	0.02	0.24	0.06	0.00	0.29	5.57	1.01
106	2.12	0.98	0.05	0.01	0.01	1.31	0.00	0.00	0.27	1.31	1.46
107	2.13	0.71	0.45	0.68	0.01	0.38	0.08	0.32	1.19	0.31	3.76
108	1.85	1.80	0.13	0.17	0.01	0.15	0.01	0.00	0.77	0.70	3.50
109	1.10	0.51	2.78	1.16	0.02	0.08	0.11	0.65	1.88	0.08	2.12
110	2.05	1.81	0.04	0.00	0.01	0.27	0.00	0.59	0.25	0.56	1.85
111	0.67	0.14	0.31	0.33	0.02	0.25	0.16	10.76	0.19	0.09	2.45
112	1.10	0.00	0.02	0.00	0.02	0.34	0.01	0.12	0.59	0.59	0.79
113	0.89	0.71	5.09	4.39	0.02	0.21	5.17	135.27	0.26	0.29	23.14
114	0.57	0.01	657.49	1.09	0.25	0.49	0.21	0.63	0.65	0.09	5.92
115	0.71	0.05	0.50	0.13	0.01	0.12	0.10	2.50	0.54	0.29	2.47
116	1.05	0.19	2.93	1.54	0.02	0.11	0.01	1.31	0.38	0.18	2.26

Source) Analysis by K.C. Shin (Research Institute for Humanity and Nature)
Note) Water quality standard in Japan (μg L^{-1}; MHLW, 2008): Se > 10.
Water quality guideline (μg L^{-1}; WHO, 2011: Se > 40.
Quality of drinking water (μg L^{-1}; EWURA, 2014): Se > 50.

Table 5. Dissolved metal (μg L^{-1}) analyzed by ICP-MS (ICP-MS 7500cx)

Site No.	Sr	Mo	Ag	Cd	Sn	Sb	Cs	Ba	W	Pb	U
1	252.40	0.08	0.01	0.00	0.00	0.03	0.00	114.93	0.00	0.00	0.80
2	444.16	0.04	0.00	0.00	0.00	0.03	0.00	213.12	0.00	0.00	1.73
3	164.57	0.03	0.00	0.00	0.00	0.01	0.01	32.81	0.00	0.00	0.89
4	392.13	0.13	0.00	0.00	0.00	0.02	0.00	147.11	0.00	0.00	1.25
5	257.57	0.30	0.00	0.00	0.00	0.03	0.03	232.28	0.00	0.00	0.44
6	356.46	0.31	0.00	0.00	0.00	0.01	0.00	120.00	0.00	0.00	1.96
7	453.56	4.94	0.00	0.01	0.00	0.68	0.02	157.00	0.00	0.00	9.69
8	297.67	0.39	0.00	0.00	0.00	0.12	0.01	255.39	0.00	0.00	0.53
9	688.41	0.21	0.00	0.00	0.01	0.04	0.01	213.62	0.00	0.00	3.41
10	141.54	0.09	0.00	0.00	0.00	0.02	0.00	57.76	0.00	0.00	4.58
11	261.64	0.01	0.01	0.00	0.00	0.02	0.00	129.40	0.00	0.00	3.05
12	173.57	0.27	0.00	0.00	0.00	0.02	0.00	62.62	0.00	0.00	4.81
13	3301.95	1.12	0.02	0.00	0.00	0.03	0.08	3.46	0.00	0.00	0.73
14	2800.24	2.93	0.03	0.00	0.00	0.07	0.11	9.13	0.00	0.00	1.40
15	3003.50	3.19	0.00	0.00	0.02	0.08	0.06	5.69	0.00	0.00	1.07
16	1463.37	3.13	0.01	0.00	0.01	0.27	0.18	2.22	0.00	0.00	0.74
17	1716.94	4.40	0.02	0.00	0.00	0.43	0.16	2.84	0.00	0.00	1.05
18	3052.11	1.36	0.00	0.00	0.01	0.06	0.06	4.26	0.00	0.00	2.63
19	2443.43	2.38	0.02	0.00	0.00	0.76	0.15	3.94	0.00	0.00	2.30
20	229.36	0.03	0.01	0.00	0.00	0.03	0.01	166.27	0.00	0.00	0.00
21	40.70	0.00	0.00	0.03	0.00	0.01	0.00	74.70	0.00	0.28	0.00
22	279.46	0.11	0.00	0.00	0.00	0.03	0.11	433.04	0.00	0.00	0.04
23	2302.69	1.06	0.01	0.00	0.00	0.07	0.02	14.70	0.00	0.00	0.76
24	2767.68	0.94	0.00	0.00	0.00	0.73	0.02	11.75	0.00	0.00	1.77
25	1502.85	1.05	0.03	0.00	0.00	0.03	0.05	93.29	0.00	0.00	1.53
26	952.00	0.48	0.01	0.00	0.00	0.02	0.00	84.13	0.00	0.00	1.18
27	255.71	0.17	0.00	0.00	0.00	0.04	0.00	104.57	0.00	0.00	1.58
28	209.48	0.16	0.00	0.00	0.01	0.04	0.00	52.29	0.09	0.00	0.90
29	403.09	0.12	0.00	0.00	0.01	0.03	0.00	85.31	0.02	0.00	2.19
30	316.56	0.05	0.00	0.00	0.00	0.04	0.00	75.56	0.00	0.00	1.95
31	248.63	0.55	0.00	0.00	0.01	0.08	0.00	74.34	0.02	0.00	0.51
32	1135.12	0.15	0.00	0.00	0.01	0.13	0.00	213.14	0.00	0.00	3.06
33	1460.56	0.51	0.01	0.00	0.01	0.07	0.07	99.44	0.00	0.00	1.08
34	309.74	0.19	0.00	0.00	0.01	0.06	0.00	72.14	0.03	0.00	2.31
35	93.28	0.13	0.00	0.00	0.00	0.03	0.02	133.68	0.00	0.00	0.11
36	253.90	0.43	0.00	0.00	0.00	0.03	0.00	47.94	0.00	0.00	0.83
37	238.11	0.23	0.00	0.00	0.00	0.03	0.00	55.30	0.00	0.00	1.40
38	89.16	0.03	0.00	0.00	0.01	0.02	0.00	100.59	0.00	0.00	0.03
39	422.69	0.23	0.00	0.00	0.00	0.02	0.00	27.54	0.00	0.00	0.88
40	165.60	0.08	0.00	0.00	0.01	0.03	0.10	0.22	0.11	0.00	0.20
41	335.56	0.22	0.00	0.00	0.01	0.05	0.02	25.70	0.11	0.00	1.04
42	427.73	0.29	0.00	0.00	0.01	0.04	0.02	21.28	0.11	0.00	0.86

Table 5. (continued)

Site No.	Sr	Mo	Ag	Cd	Sn	Sb	Cs	Ba	W	Pb	U
43	393.96	0.15	0.01	0.00	0.00	0.03	0.04	291.83	0.16	0.00	0.62
44	569.72	0.15	0.01	0.00	0.00	0.02	0.06	25.29	0.12	0.00	1.00
45	796.50	0.57	0.03	0.00	0.05	0.03	0.27	19.03	0.53	0.00	0.55
46	979.20	0.73	0.04	0.00	0.03	0.21	0.22	22.61	0.43	0.00	1.28
47	192.30	0.10	0.01	0.00	0.00	0.06	0.03	22.54	0.06	0.00	1.20
48	211.33	0.06	0.00	0.00	0.01	0.02	0.03	35.00	0.05	0.00	0.38
49	148.26	0.17	0.00	0.00	0.01	0.08	0.13	6.42	0.05	0.00	0.28
50	2281.37	2.11	0.01	0.00	0.02	0.07	0.13	5.06	0.16	0.00	1.37
51	2110.44	1.14	0.03	0.00	0.02	0.17	0.25	7.25	0.33	0.00	1.04
52	2430.08	1.85	0.07	0.00	0.05	0.08	0.25	10.77	0.16	0.00	2.62
53	2706.63	2.24	0.05	0.00	0.04	0.12	0.34	21.70	0.37	0.00	1.85
54	485.41	0.19	0.00	0.00	0.01	0.03	0.05	26.66	0.09	0.00	0.87
55	383.42	0.15	0.00	0.00	0.00	0.03	0.03	21.28	0.05	0.00	0.88
56	1035.43	0.25	0.01	0.00	0.01	0.03	0.19	34.34	0.15	0.00	1.11
57	1217.16	0.35	0.04	0.00	0.03	0.02	0.24	36.26	0.17	0.00	1.12
58	1125.06	2.68	0.01	0.00	0.04	0.47	0.15	4.15	0.08	0.00	1.06
59	1774.94	2.37	0.04	0.00	0.02	0.24	0.18	9.62	0.09	0.00	0.87
60	2406.64	2.01	0.03	0.00	0.09	0.12	0.39	7.28	0.21	0.00	1.17
61	1723.39	2.17	0.00	0.00	0.01	0.12	0.04	6.53	0.03	0.00	3.43
62	438.61	0.44	0.01	0.00	0.01	0.12	0.08	2.69	0.07	0.00	3.09
63	379.07	0.66	0.00	0.00	0.01	0.07	0.03	2.24	0.04	0.00	0.97
64	285.33	0.14	0.01	0.00	0.00	0.01	0.03	2.06	0.02	0.00	0.60
65	167.89	0.04	0.00	0.00	0.00	0.01	0.01	1.26	0.00	0.00	0.32
66	68.66	0.08	0.00	0.00	0.01	0.04	0.05	2.61	0.03	0.00	0.24
67	103.28	0.42	0.00	0.00	0.01	0.02	0.03	21.96	0.02	0.00	0.02
68	450.61	0.70	0.00	0.00	0.01	0.02	0.02	44.26	0.02	0.00	2.30
69	277.26	0.47	0.00	0.00	0.05	0.04	0.06	20.30	0.05	0.00	0.28
70	1269.25	1.00	0.00	0.00	0.01	0.13	0.02	23.04	0.03	0.00	0.61
71	178.28	1.57	0.00	0.00	0.01	0.22	0.04	135.90	0.45	0.00	2.35
72	205.03	0.07	0.01	0.00	0.02	0.11	0.02	121.79	0.04	0.00	0.34
73	236.26	0.12	0.00	0.00	0.02	0.02	0.02	3.00	0.01	0.00	0.34
74	323.62	2.55	0.00	0.00	0.00	0.10	0.01	28.90	0.00	0.00	2.48
75	208.37	0.45	0.01	0.00	0.01	0.05	0.03	92.34	0.01	0.00	3.23
76	765.15	0.45	0.00	0.00	0.01	0.07	0.02	26.26	0.01	0.00	1.29
77	407.27	0.03	0.00	0.00	0.01	0.08	0.03	23.20	0.00	0.00	0.03
78	3899.13	1.14	0.01	0.00	0.04	0.11	0.08	2.81	0.06	0.00	0.38
79	5644.25	2.83	0.01	0.00	0.03	0.46	0.37	6.97	0.07	0.00	0.66
80	1628.68	0.67	0.00	0.00	0.02	0.13	0.17	4.86	0.00	0.00	0.71
81	2711.03	0.57	0.00	0.00	0.01	0.06	0.07	2.76	0.18	0.00	0.64
82	1233.46	0.47	0.03	0.00	0.02	0.02	0.11	4.44	0.07	0.00	1.20
83	150.46	0.15	0.00	0.00	0.00	0.04	0.01	16.13	0.00	0.00	0.80
84	481.44	2.56	0.00	0.00	0.01	0.06	0.01	24.39	0.01	0.00	1.95

Table 5. (continued)

Site No.	Sr	Mo	Ag	Cd	Sn	Sb	Cs	Ba	W	Pb	U
85	125.59	1.19	0.00	0.00	0.01	0.06	0.01	17.71	0.01	0.00	1.93
86	85.74	0.20	0.00	0.00	0.01	0.03	0.01	18.48	0.01	0.00	0.78
87	363.17	0.13	0.00	0.00	0.01	0.04	0.01	87.69	0.06	0.00	1.32
88	724.67	0.16	0.00	0.00	0.02	0.03	0.02	133.28	0.04	0.00	1.64
89	388.23	0.30	0.00	0.00	0.00	0.05	0.01	50.72	0.00	0.00	0.96
90	357.06	0.23	0.00	0.00	0.00	0.02	0.02	37.60	0.00	0.00	1.04
91	413.88	0.39	0.00	0.00	0.01	0.04	0.03	57.03	0.00	0.00	1.16
92	415.34	0.34	0.00	0.00	0.00	0.02	0.02	57.39	0.00	0.00	1.09
93	1261.84	0.40	0.03	0.00	0.03	0.05	0.18	8.09	0.00	0.00	0.89
94	387.60	0.10	0.01	0.00	0.01	0.04	0.04	1.90	0.00	0.00	1.03
95	1194.81	0.31	0.01	0.00	0.01	0.05	0.06	10.96	0.00	0.00	1.25
96	1530.13	1.26	0.02	0.01	0.03	0.06	0.18	18.42	0.00	0.00	1.04
97	141.84	0.02	0.00	0.00	0.00	0.02	0.02	116.31	0.00	0.00	0.13
98	383.20	0.25	0.00	0.00	0.00	0.02	0.02	56.78	0.00	0.00	0.22
99	305.43	0.15	0.00	0.00	0.01	0.02	0.02	166.51	0.00	0.00	0.49
100	21.77	0.00	0.00	0.01	0.01	0.02	0.07	60.78	0.00	0.00	0.01
101	220.40	0.03	0.00	0.00	0.01	0.03	0.00	137.48	0.00	0.00	1.97
102	173.61	0.00	0.00	0.00	0.00	0.04	0.01	83.58	0.00	0.00	2.34
103	175.21	0.01	0.00	0.00	0.00	0.04	0.00	83.18	0.00	0.00	2.33
104	334.34	0.16	0.00	0.00	0.00	0.04	0.01	88.20	0.00	0.00	2.63
105	355.03	0.34	0.01	0.00	0.01	0.07	0.01	53.59	0.00	0.00	3.75
106	301.56	0.27	0.00	0.00	0.00	0.06	0.03	41.24	0.00	0.00	4.00
107	114.82	0.08	0.00	0.00	0.01	0.03	0.01	43.28	0.00	0.00	0.45
108	275.43	0.11	0.00	0.00	0.00	0.02	0.01	50.43	0.00	0.00	0.66
109	73.48	0.06	0.00	0.00	0.01	0.03	0.01	20.04	0.00	0.00	1.06
110	757.83	0.52	0.01	0.00	0.00	0.02	0.02	78.19	0.00	0.00	3.15
111	214.89	0.04	0.00	0.00	0.00	0.01	0.02	14.30	0.00	0.00	0.54
112	4591.30	3.24	0.01	0.00	0.00	0.02	0.01	56.22	0.00	0.00	5.90
113	331.28	0.07	0.01	0.00	0.00	0.03	0.02	39.54	0.00	0.02	0.61
114	181.38	0.23	0.00	0.00	0.00	0.02	0.02	36.92	0.00	0.00	0.51
115	128.38	0.11	0.00	0.00	0.00	0.27	0.01	45.07	0.00	0.00	0.43
116	174.43	0.12	0.00	0.00	0.00	0.03	0.02	31.31	0.00	0.00	0.81
116	0.18	2.26	174.40	0.01	0.00	0.12	0.00	0.00	0.00	0.03	0.02

Source) Analysis by K.C. Shin (Research Institute for Humanity and Nature).
Note) Water quality standard in Japan (μg L^{-1}; MHLW, 2008): Cd > 3; Sb > 15.
Water quality guideline (μg L^{-1}; WHO, 2005): Cd > 3; Sb > 20; Ba > 700.
Quality of drinking water (μg L^{-1}; EWURA, 2014): Cd > 50; Ba > 1,000.

Table 6. Comparison of the levels of some heavy metals by the districts in Unguja Island, Zanzibar

District (n = sites)		Dissolved metal (μg L^{-1}) analyzed by ICP-MS (ICP-MS 7500cx)				
		Cr	Co	Cu	Cd	Pb
North A (n = 25)	Average	3.609 ± 6.861	0.038 ± 0.043	0.045 ± 0.097	0.005 ± 0.097	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	28.268	0.220	0.432	0.013	0.000
North B (n = 23)	Average	0.518 ± 0.596	0.023 ± 0.026	0.073 ± 0.095	0.002 ± 0.007	0.013 ± 0.059
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	1.814	0.106	0.347	0.034	0.278
Central (n = 29)	Average	0.862 ± 0.692	0.041 ± 0.080	0.405 ± 0.967	0.001 ± 0.011	0.008 ± 0.004
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	2.203	0.251	5.172	0.004	0.022
West (n = 14)	Average	0.769 ± 0.630	0.098 ± 0.223	0.219 ± 0.217	0.001 ± 0.002	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	1.947	0.851	0.942	0.006	0.000
South (n = 25)	Average	0.754 ± 0.779	0.079 ± 0.128	0.396 ± 0.321	0.001 ± 0.001	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	3.197	0.531	1.456	0.006	0.000
Water quality standard in Japan (MHLW, 2008)		—	> 1000	—	> 10	—
Water quality guideline (WHO, 2011)		> 50	—	> 2000	—	> 10
Quality of drinking water (EWURA, 2014)		> 50	—	> 3000	> 50	> 100

Source) Analysis by Sheikh

metal contamination referring to the value of Drinking water quality standard in Japan (MHLW, 2008), Water quality guideline (WHO, 2011) and Quality of drinking water supplies (EWURA, 2014) respectively attached under the Table 3 through Table 5.

Table 6 shows the comparison of the levels of some heavy metals among the districts in Zanzibar. The concentrations of the heavy metals were highest in the groundwater from North A, especially the concentrations of Cr, which was significantly higher in North A than in the other districts. This study could not identify any specific reason for the result. Possibility of the heavy metal contamination by ever expanding human activities can not be denied, since the levels in the sites with similar soil type and geological component stay much lower.

II. Levels of Nitrate (NO_3^-) in Groundwater

The average value of the nitrate (NO_3^-) level of groundwater from 116 open-wells was 36.1 ± 58.85 mg L^{-1} with the range between nil and 319.6 mg L^{-1} as previously shown in Table 2. Number of the sites that the nitrate level of groundwater exceeded Water quality standard in Japan (>10 mg L^{-1}) and WHO water quality guideline (>50 mg L^{-1}) was 57 and 28, respectively. In the comparison among the districts, the average levels of nitrate for North A, North B, Central, South and West districts were 68.4 ± 75.89 mg L^{-1}, 18.2 ± 21 mg L^{-1}, 17.2 ± 27.98 mg L^{-1}, 45.3 ± 71.9 mg L^{-1} and 28.9 ± 57.82 mg L^{-1}, respectively. The nitrate contamination is more serious in North A District, which exceeded the level of maximum permissible limit of 50 mg L^{-1} for drinking water quality, which considered not safe for drinking purposes (WHO, 2011), followed by South, West, North A and West District, all of which were higher than that of Water quality standard in Japan. Open-wells are prone to contamination from the surface, however, the result implies the followings: (1) a great possibility of groundwater contamination through the inflow of surface water, including sewage from households, as Hansson (2010) mentioned, and seepage water from soil profile and, thus, (2) a necessity of raising-up the height of well-wall to prevent inflow of contaminants through surface water, lining of the inner-wall to reduce seepage from soil, locating a toilet away and controlling fertilization surrounding cultivated field.

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Photo 1. Open-well (Site No. 108, Upenja Ward, North B District on 14/Feb./2015).

Photo 2. Open-well (Site No. 105, Kuyasini Ngaba Ward, North A District on 14/Feb./2015).

Photo 3. Open-well (Site No. 112, Cheju-Chuchumile Ward, Central District on 15/Feb./2015).

Photo 4. Inside of Open-well (Site No. 114, Mseweni Ward, Central District on 15/Feb./2015).

Photo 5. Open-well (Site No. 116, Ubago Ward, Central District on 15/Feb./2015).

Photo 6. Sealed-well (Not sampled, Chutama Ward, North A District on 14/Feb./2015).