

## 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 ( $\text{NO}_3^-$ ) 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:  $1.359 \pm 3.419 \mu\text{g L}^{-1}$  for Cr;  $0.052 \pm 0.109 \mu\text{g L}^{-1}$  for Co;  $0.238 \pm 0.533 \mu\text{g L}^{-1}$  for Cu;  $0.001 \pm 0.004 \mu\text{g L}^{-1}$  for Cd; and  $0.003 \pm 0.026 \mu\text{g L}^{-1}$  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 ( $\text{NO}_3^-$ ) was  $36.1 \pm 58.85 \text{ mg L}^{-1}$ . 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 as 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).

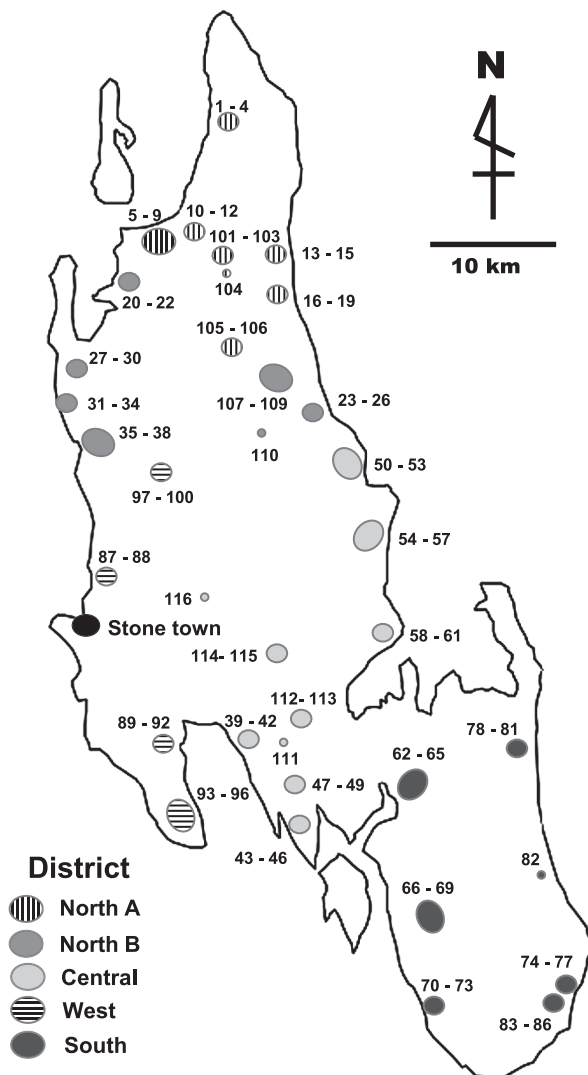
## II. Sampling and Analyses

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  $\mu\text{m}$ ) 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 DISCUSSION

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:  $1.359 \pm 3.419 \mu\text{g L}^{-1}$  (ranged from not detected-ND to  $28.267 \mu\text{g L}^{-1}$ ) for Cr;  $0.052 \pm 0.109 \mu\text{g L}^{-1}$  (ND to  $0.851 \mu\text{g L}^{-1}$ ) for Co;  $0.238 \pm 0.533 \mu\text{g L}^{-1}$  (ND to  $5.172 \mu\text{g L}^{-1}$ ) for Cu,  $0.001 \pm 0.004 \mu\text{g L}^{-1}$  (ND to  $0.034 \mu\text{g L}^{-1}$ ) for Cd; and  $0.003 \pm 0.026 \mu\text{g L}^{-1}$  (ND to  $0.278 \mu\text{g L}^{-1}$ ) 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. ( $\mu\text{S cm}^{-1}$ ) | pH ( $\text{H}_2\text{O}$ ) |
|----------|---------------------------------------|----------------------|-------------------------|-----------------|------------------|--------------------------------|-----------------------------|
| 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        | North A (Kaskazini A)/Kivunge         | -5.87672             | 39.26881                | 17.5            | 27.1             | 1,200                          | 7.6                         |
| 10       |                                       | -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)/Mwanda          | -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       | North B (Kaskazini B)/Makoba          | -6.00293             | 39.38089                | 7.8             | 26.9             | 4,400                          | 7.8                         |
| 27       |                                       | -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       | North B (Kaskazini B)/Mangapwani      | -5.95027             | 39.19494                | 17.7            | 28.2             | 790                            | 7.4                         |
| 31       |                                       | -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       | North B (Kaskazini B)/Kiombamvua      | -5.99014             | 39.19540                | 17.7            | 27.5             | 710                            | 7.4                         |
| 35       |                                       | -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       | Central (Kati)/Bungi                  | -6.02604             | 39.20876                | 5.0             | 27.5             | 240                            | 7.4                         |
| 39       |                                       | -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. ( $\mu\text{S cm}^{-1}$ ) | pH ( $\text{H}_2\text{O}$ ) |
|----------|-------------------------------------|----------------------|-------------------------|-----------------|------------------|--------------------------------|-----------------------------|
| 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. ( $\mu\text{S cm}^{-1}$ ) | pH ( $\text{H}_2\text{O}$ ) |
|----------|--------------------------------------|----------------------|-------------------------|-----------------|------------------|--------------------------------|-----------------------------|
| 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)/Upinja         | -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<sup>-1</sup>) 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 <sub>2</sub> | Br    | NO <sub>3</sub> | SO <sub>4</sub> | PO <sub>4</sub> | 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 <sub>2</sub> | Br   | NO <sub>3</sub> | SO <sub>4</sub> | PO <sub>4</sub> | 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<sup>-1</sup>; MHLW, 2008): F > 0.8; Cl > 200; NO<sub>3</sub> > 10.

Water quality guideline (mg L<sup>-1</sup>; WHO, 2011): F > 1.5; Cl > 5; NO<sub>2</sub> > 3; Br > 0.01; NO<sub>3</sub> > 50.

Quality of drinking water (mg L<sup>-1</sup>; EWURA, 2014): F > 4.0; Cl > 800; NO<sub>3</sub> > 75.0; SO<sub>4</sub> > 600; Mg > 100; Ca > 300.

**Table 3.** Dissolved metal ( $\mu\text{g L}^{-1}$ ) 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 ( $\mu\text{g L}^{-1}$ ; MHLW, 2008): B > 800; Na > 200,000; Mg > 300,000; Al > 200; Ca > 300,000.

Water quality guideline ( $\mu\text{g L}^{-1}$ ; WHO, 2011): B > 2,400; Al > 200.

Quality of drinking water ( $\mu\text{g L}^{-1}$ ; EWURA, 2014): Nil.

**Table 4.** Dissolved metal ( $\mu\text{g L}^{-1}$ ) 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 ( $\mu\text{g L}^{-1}$ ; MHLW, 2008): Se > 10.

Water quality guideline ( $\mu\text{g L}^{-1}$ ; WHO, 2011): Se > 40.

Quality of drinking water ( $\mu\text{g L}^{-1}$ ; EWURA, 2014): Se > 50.

**Table 5.** Dissolved metal ( $\mu\text{g L}^{-1}$ ) 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 ( $\mu\text{g L}^{-1}$ ; MHLW, 2008): Cd > 3; Sb > 15.

Water quality guideline ( $\mu\text{g L}^{-1}$ ; WHO, 2005): Cd > 3; Sb > 20; Ba > 700.

Quality of drinking water ( $\mu\text{g L}^{-1}$ ; 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<br>(n = sites)                      | Dissolved metal ( $\mu\text{g L}^{-1}$ ) analyzed by ICP-MS (ICP-MS 7500cx) |                   |                   |                   |                   |                   |
|----------------------------------------------|-----------------------------------------------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                                              |                                                                             | Cr                | Co                | Cu                | Cd                | Pb                |
| North A<br>(n = 25)                          | Average                                                                     | $3.609 \pm 6.861$ | $0.038 \pm 0.043$ | $0.045 \pm 0.097$ | $0.005 \pm 0.097$ | 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<br>(n = 23)                          | Average                                                                     | $0.518 \pm 0.596$ | $0.023 \pm 0.026$ | $0.073 \pm 0.095$ | $0.002 \pm 0.007$ | $0.013 \pm 0.059$ |
|                                              | Minimum                                                                     | 0.000             | 0.000             | 0.000             | 0.000             | 0.000             |
|                                              | Maximum                                                                     | 1.814             | 0.106             | 0.347             | 0.034             | 0.278             |
| Central<br>(n = 29)                          | Average                                                                     | $0.862 \pm 0.692$ | $0.041 \pm 0.080$ | $0.405 \pm 0.967$ | $0.001 \pm 0.011$ | $0.008 \pm 0.004$ |
|                                              | Minimum                                                                     | 0.000             | 0.000             | 0.000             | 0.000             | 0.000             |
|                                              | Maximum                                                                     | 2.203             | 0.251             | 5.172             | 0.004             | 0.022             |
| West<br>(n = 14)                             | Average                                                                     | $0.769 \pm 0.630$ | $0.098 \pm 0.223$ | $0.219 \pm 0.217$ | $0.001 \pm 0.002$ | 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<br>(n = 25)                            | Average                                                                     | $0.754 \pm 0.779$ | $0.079 \pm 0.128$ | $0.396 \pm 0.321$ | $0.001 \pm 0.001$ | 0.000             |
|                                              | Minimum                                                                     | 0.000             | 0.000             | 0.000             | 0.000             | 0.000             |
|                                              | Maximum                                                                     | 3.197             | 0.531             | 1.456             | 0.006             | 0.000             |
| <hr/>                                        |                                                                             |                   |                   |                   |                   |                   |
| 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 ( $\text{NO}_3^-$ ) in Groundwater

The average value of the nitrate ( $\text{NO}_3^-$ ) level of groundwater from 116 open-wells was  $36.1 \pm 58.85 \text{ mg L}^{-1}$  with the range between nil and  $319.6 \text{ mg L}^{-1}$  as previously shown in Table 2. Number of the sites that the nitrate level of groundwater exceeded Water quality standard in Japan ( $>10 \text{ mg L}^{-1}$ ) and WHO water quality guideline ( $>50 \text{ mg L}^{-1}$ ) 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  $68.4 \pm 75.89 \text{ mg L}^{-1}$ ,  $18.2 \pm 21 \text{ mg L}^{-1}$ ,  $17.2 \pm 27.98 \text{ mg L}^{-1}$ ,  $45.3 \pm 71.9 \text{ mg L}^{-1}$  and  $28.9 \pm 57.82 \text{ mg L}^{-1}$ , respectively. The nitrate contamination is more serious in North A District, which exceeded the level of maximum permissible limit of  $50 \text{ mg L}^{-1}$  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).