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Assessment of Dissolved Silica Content of Groundwater from Southwestern Nigeria

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ABSTRACT The groundwater resources from open dug wells in Abeokuta municipality are mostly abstracted from shallow depth of < 10.0 m with a static water level in the range of 0.2 to 5.0 m. Study was carried out to assess dissolved silica (DSi, SiO_2) in these groundwater resources to establish their baseline concentrations. 200 shallow wells were sampled from 47 communities in Abeokuta and parameters namely: Static Water Level (SWL), total depth (TD), pH, total dissolved solids (TDS), electrical conductivity (EC) and DSi were determined. The water pH varied between 6.2 and 8.1 (slightly acidic and slightly alkaline) with appreciable amount of TDS (37.0 - 601.0 mg/l). The groundwater also contains abundant dissolved silica (0.5 – 19.3 mg/l) and EC in the range of 57-1002 µS/cm. Since major source of potable water in the city is groundwater from the open dug wells, it then implies that majority of the residents are exposed to water borne silica on a daily basis. Unlike in the airborne crystalline silica, which has been established to be the cause of silicosis, the health impact of the water borne silica in the municipality is unknown.

INTRODUCTION

Silicon is the most abundant solid element, being second only to oxygen. It makes up more than 25% of the earth's crust (Keller 1957). Silicon rarely occurs in elemental form; virtually all exist as compounds (Krauskopf 1967). The widely known compound of silicon is silicon dioxide (SiO_2) otherwise called silica. Silica is capable of existing as polymorphs viz: - crystalline and amorphous forms. The three most common crystalline forms are quartz, cristoballite and tridymite which are inter-related under different conditions of temperature and pressure (NIOSH 1992). However, the most common of the quartz silica is the alpha-quartz, which is a major component of igneous rocks - granite and pegmatites. They are also found in sedimentary rocks – sandstones, slate and shale (Birkeland 1974). Due to the abundance of silica in the tropical regions, it has become a major chemical constituent of natural water bodies. According to Hem (1985), the primary source of dissolved silica in natural waters is the chemical breakdown of silicate minerals in rock and sediments by chemical weathering process (Jansen et al. 2010). However, the presence of multivalent ions such as Al^{3+}, Ca^{2+}, Mg^{2+}, Fe^{3+} and others affects silica solubility (Hann 1993). Reynolds (1984) observed that silica plays an important role in the ecology of aquatic systems as it is an essential element for diatoms as it comprises 26-69% of cellular dry weight.

Previous studies have shown that exposure to airborne crystalline silica normally results in silicosis (Cherry et al. 1997, 1998). Silicosis is a serious lung disease caused by the accumulation of silica dust in the lungs. The scarring of the lungs causes stiffening and this eventually obstruct breathing and cause shortness of breath. This can lead to permanent heart and lung disease. Silicosis development is directly associated with workplace exposure to silica dust. Workers who are most at risk include those engaged in dust generating activities such as tunneling and digging work, road construction, all forms of demolition activities, mining and pottering (Cocco et al. 2001; Pelucchi et al. 2006). Quartz silica is rampant in activities like mining, quarrying, foundries among others. It is a widely known air pollutant in these industries where it has wrecked many havoc on the health of the workers (NISA 1997).

Based on amount of exposure and length of time, silicosis can be chronic, accelerated or acute. It is capable of rendering the victim more susceptible to infection and diseases like tuberculosis and lung cancer. Also, the carcinogenicity of crystalline silica in both animals and humans has been proved by several authors (IARC 1987, 1997). Silica dust causes irritation of the eyes, nose and throat like most other dusts. However, if excessive amounts of silica dust are breathed into the lungs over a period of time, it can cause damage to the lung tissue. The exposure limit for silica dust (respirable quartz) is 0.1 mg/m^3 (Steenland et al. 2001). However, much thought have not been given to the possible health effects of animals and humans exposed to the dissolved silica in drinking/ potable water. This study therefore was initiated to open up a line of thought on the potential health impact of ingestible dissolved silica that forms a major chemical component of the natural water resources in the tropics.

MATERIALS AND METHODS

The Study Area

Abeokuta, the study area, is the capital of Ogun State which is located on longitude 3^o 262' and 3^o 402' E and latitude 7^o 92† and 7^o 142' N. Abeokuta metropolis enjoys a favourable climatic condition, which is the same as that of the entire state (Areola 1991; Akanni 1992). The geology of the study area is essentially basement complex rocks consisting of pegmatites, older granite and gneisses (Jones and Hockey 1964). These rocks are very rich in silica and other silicate rock forming minerals. The rocks have been quarried in areas of Saje for more than two decades for construction purposes.

Sampling and Analysis

A total of two hundred (200) open dug well water samples from Abeokuta municipality in Ogun state were collected during the rainy season. Water samples were collected between June and September, 2005 from 47 communities in Abeokuta metropolis. Samples were analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS) and dissolved silica (DSi). Total depth (TD) of the wells and static water levels (SWL) were also measured using a meter rule. pH, TDS and electrical conductivity were determined in-situ by probe method (WTWLF 95 meter). Dissolved silica oxide was determined by gravimetric analysis. This method involves heating of the collected groundwater samples between 110 – 120^{o}C to partially dehydrate the silica and render it as insoluble as possible. The residue was extracted with concentrated HCl to remove the salts of iron, aluminium and other metals which might be present. The remaining silica that is not dissolved was filtered off. The filtrate was evaporated to dryness and the residue heated again between 110 – 120^{o}C in order to remove the remaining silicic acid that escaped dehydration. The total filtrates/precipitates were ignited in a platinum crucible at about 1050^{o}C to silicon dioxide (SiO_2) and the latter was weighed and result expressed as mg/l.

To ensure quality control, the following precautions were taken: all reagents were of analytical grade; all the 2L white plastic kegs used for sample collection were pre-washed with detergent water solution, rinsed with tap water and soaked for 48 hours in 2% HNO_3. This was then rinsed thoroughly with distilled-deionized water and was air-dried. Samples for pH, EC and TDS were determined in-situ while samples for dissolved silica were refrigerated prior to analysis.

RESULTS

The results of the analyzed parameters in the groundwater samples were shown in Table 1. The depth of the open dug wells ranged from 0.4 to 9.1 m while the static water levels varied from 0.1 to 6.3 m. The pH values of the water samples ranged from 6.2 to 8.1. Also, the TDS of groundwater varied from 37.0 to 601.0 mg/l while the electrical conductivity varied from 57 to 1002 μS/cm. The values of the dissolved silica in the groundwater were in the range of 0.5 to 19.3 mg/l. More than 65% of the wells are relatively shallow (< 5.0 m deep). This may be as a result of the underlain crystalline basement complex rock. Also, 40.4% of the wells sampled have the SWL below 2.0 m; 48.9% have SWL values close to 5.0 m while 10.6% have SWL of above 5.0 m. This might be an indication that majority of the wells (approximately 60%) are productive.

DISCUSSION

The groundwater pH was slightly acidic in places like Bode Olude, Housing estate, Lafiaji,

Table 1: Range of values of various parameters measured in the well water at different locations

S.No.	*Location*	*Sample No*	*TD(m)*	*SWL(m)*	*EC (µS/cm)*	*TDS (mg/l)*	*pH*	*SiO_2 (mg/l)*
1	Itoko	3	2.3 - 4.7	1.2 - 1.9	418 - 457	90 - 216	7.0 - 7.6	7.5 - 8.5
2	Erube	3	3.1 - 6.9	1.3 - 1.7	295 - 340	154 - 162	7.4 - 7.6	6.2 - 8.0
3	Olumo	2	0.4 - 0.7	0.1 - 0.3	243 - 354	116 - 189	7.3 - 7.5	18.5 - 19.3
4	Ijaye	2	2.5 - 2.9	0.8 - 1.1	290 - 357	134 - 166	6.7 - 7.0	8.7 - 10.5
5	Ago-Ika	2	0.8 - 2.2	0.8 - 0.9	348 - 495	214 - 227	6.4 - 7.3	4.6 - 5.4
6	Adatan	2	1.9 - 3.0	0.3 - 0.8	424 - 575	199 - 269	6.4 - 7.4	1.8 - 2.3
7	Ake	2	1.6 - 3.9	0.7 - 1.2	416 - 460	198 - 205	7.0 - 7.2	2.0 - 4.3
8	Ijemo	2	0.9 - 4.5	0.4 - 1.9	355 - 435	164 - 204	7.3 - 7.7	2.7 - 4.0
9	Idomapa	2	1.4 - 2.2	0.3 - 0.7	334 - 461	177 - 267	7.2 - 7.6	3.6 - 6.3
10	Ikija	2	2.4 - 2.7	0.5 - 0.6	223 - 249	103 - 115	7.1 - 7.4	4.0 - 6.0
11	Kemta	2	0.9 - 2.4	0.5 - 1.2	410 - 424	227 - 242	7.1 - 7.5	4.0 - 4.9
12	Itesi	2	4.2 - 4.5	1.5 - 1.7	111 - 346	192 - 222	7.0 - 7.1	2.3 - 2.6
13	Okejigbo	2	1.9 - 3.9	0.6 - 2.1	306 - 549	143 - 248	6.3 - 7.2	1.9 - 2.3
14	Oke Lantoro	2	3.4 - 4.4	1.0 - 1.4	126 - 148	60 – 74	6.3 - 7.0	0.5 - 1.8
15	Ilugun	2	0.4 - 2.8	0.1 - 0.3	294 - 349	137 - 164	7.1 - 7.4	3.1 - 3.9
16	Itoku	2	1.6 - 3.1	0.2 - 0.7	340 - 686	186 - 312	7.1 - 7.6	1.4 - 1.6
17	Iporo Ake	2	0.9 - 4.8	0.6 - 1.8	71 - 227	37 - 107	7.0 - 7.4	2.4 - 2.6
18	Ijeun	2	2.5 - 2.9	1.8 - 2.3	445 - 690	208 - 341	6.7 - 7.2	8.5 - 9.0
19	Sapon	2	2.4 - 2.7	0.8 - 1.2	377 - 785	206 - 354	7.4 - 7.6	3.1 - 4.7
20	Lantoro	2	5.5 - 6.6	1.3 - 1.4	57 - 175	48 - 176	6.6 - 7.4	3.5 - 4.0
21	Olorunsogo	2	2.9 - 4.3	0.9 - 2.5	109 - 286	59 - 459	7.0 – 7.3	3.2 - 3.5
22	Ikereku	2	2.3 - 5.0	1.4 - 2.5	175 - 572	86 - 356	7.1 - 7.3	12.5 - 16.4
23	Ago Oko	2	2.9 - 3.5	1.2 - 1.9	371 - 623	182 - 358	7.2 - 7.4	5.5 - 6.5
24	Asero	6	2.3 - 4.6	1.8 - 3.7	143 - 568	89 - 341	7.3 - 8.0	9.0 - 13.6
25	Saje	6	1.8 - 4.6	1.6 - 3.7	256 - 420	154 - 252	7.3 - 8.1	6.9 - 8.2
26	Aregba	5	2.7 - 9.1	2.0 - 5.5	231 - 688	139 - 413	7.4 - 7.8	7.5 - 9.0
27	Ikija	4	1.4 - 2.7	0.7 - 1.8	475 - 711	285 - 427	7.3 - 7.6	1.3 - 1.5
28	Ikereku	2	1.8 - 2.1	0.7 - 1.2	588 - 660	83 - 356	7.4 - 7.8	2.4 - 2.6
29	Efon	3	2.1 - 2.9	0.8 - 2.7	450 - 641	270 - 385	6.8 - 7.4	2.5 - 3.0
30	Bode Olude	5	2.3 - 6.4	1.7 - 5.5	173 - 404	104 - 242	6.3 - 6.9	6.0 - 6.4
31	Housing Estate	5	3.7 - 5.5	2.7 - 3.8	106 - 208	64 - 125	6.3 - 6.8	6.5 - 6.8
32	Iberekodo	2	2.6 - 2.7	1.9 - 2.0	588 - 660	353 - 396	7.4 - 7.7	2.4 - 2.6
33	Lafiaji	2	2.7 - 5.4	1.9 - 5.2	359 - 400	215 - 240	6.8 - 6.9	7.9 - 8.2
34	Ita Elega	7	1.8 - 4.5	1.2 - 4.0	377 - 605	226 - 363	6.8 - 7.4	3.9 - 4.5
35	Mokola	3	1.2 - 3.7	0.7 - 1.9	300 - 477	180 - 286	7.1 - 7.4	2.0 - 2.5
36	Adigbe	2	4.3 - 5.4	2.5 - 3.3	393 - 876	236 - 526	6.7 - 7.0	1.0 - 1.7
37	Amolaso	2	2.5 - 5.3	1.0 - 2.1	640 - 850	384 - 510	6.5 - 6.9	3.3 - 3.9
38	Ibara HE	5	3.1 - 4.5	1.4 - 3.8	408 - 809	245 - 485	6.6 - 7.1	3.8 - 4.7
39	Ijeja	5	4.1 - 6.7	2.1 - 5.2	758 - 1002	455 - 601	6.7 - 7.0	1.2 - 2.6
40	Isabo	4	3.2 - 4.7	1.4 - 2.6	290 - 667	174 - 400	6.6 - 7.3	2.1 - 2.5
41	Ita-Eko/Ita Iyalode	3	3.8 - 4.3	1.4 - 2.1	504 - 638	302 - 383	6.7 - 7.1	0.5 - 4.6
42	Kuto	5	2.8 - 5.1	1.3 - 2.4	257 - 594	154 - 356	6.5 - 8.0	2.0 - 3.6
43	NEPA/NUD	7	2.6 - 5.1	1.6 - 3.6	469 - 864	281 - 518	6.7 - 7.2	1.2 - 1.6
44	Oke-Sokori	3	3.9 - 6.4	1.6 - 4.8	592 - 851	355 - 511	7.0 - 7.6	1.2 - 1.7
45	Oke-Ilewo	2	5.1 - 8.1	3.5 - 6.3	162 - 770	97 - 462	6.2 - 6.9	1.3 - 4.7
46	Onikolobo	2	3.1 - 3.8	1.0 - 2.6	362 - 569	217 - 341	6.6 - 7.0	1.4 - 2.6
47	Quarry Rd	2	4.3 - 5.6	3.2 - 3.8	750 - 760	450 - 456	7.1 - 8.0	1.2 - 2.5
	WHO (1971, 1993, 2008)				500 - 1400	500 - 1000	6.5 - 8.5	

Amolasho and Oke-ilewo while others varied from neutral to alkaline. The values were generally within 6.5 to 8.5 of the World Health Organization (WHO) pH standard in drinking water (WHO 2008) for potable water. However, there were few exceptions with the value lower than 6.5, which are still in conformity with the range of 5.5 – 6.5 obtained by Egboka (1986, 1987) for most groundwater samples in Nigeria. The high value of total dissolved solids indicates presence of solutes and also signifies thorough mixing of the dissolved constituents in the groundwater. The electrical conductivity generally is an indication of electrolyte in the dissolved constituents of the groundwater while the high values of the EC (450 – 1002 µS/cm) in some of the

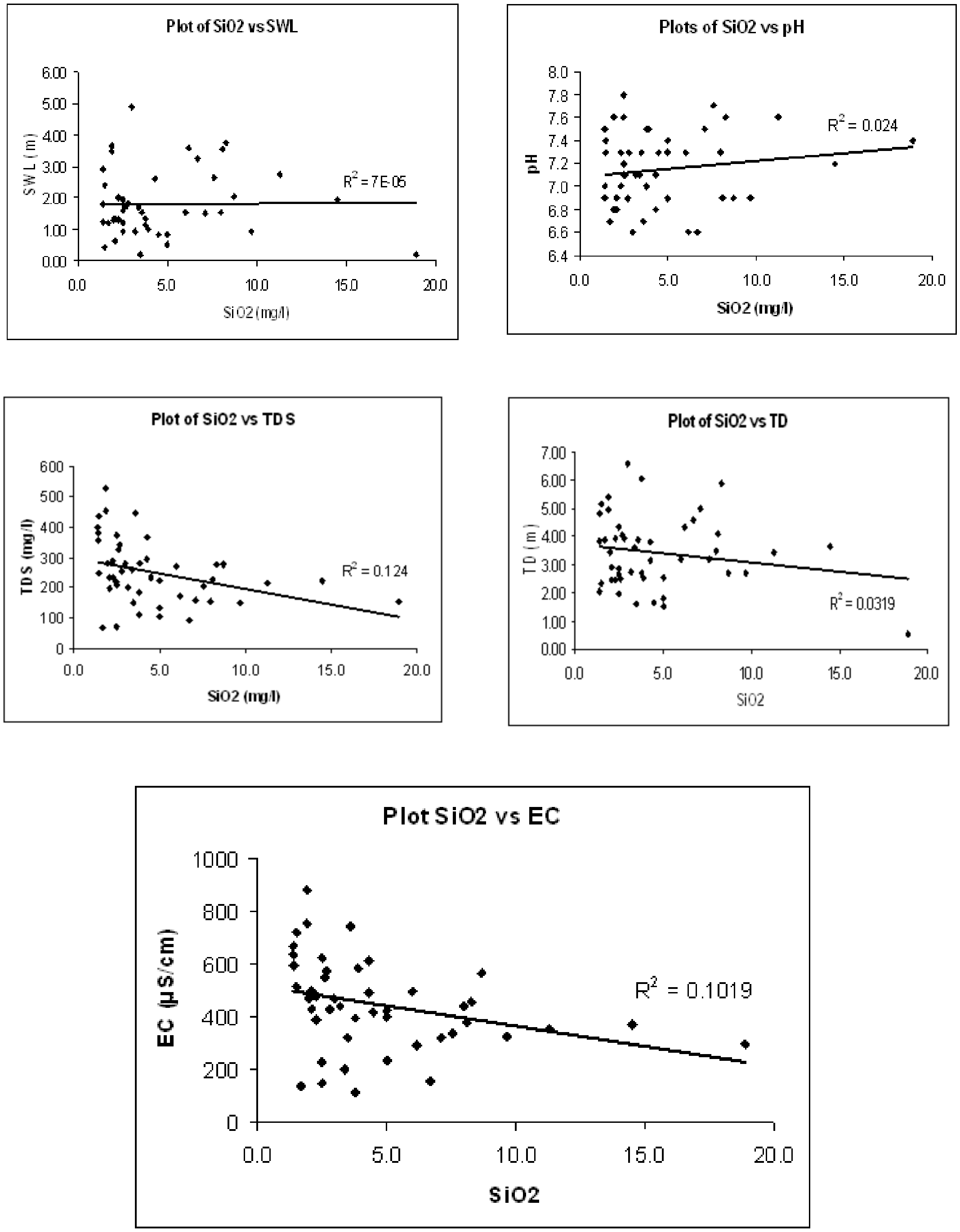

Fig. 1. Bivariate plots of various parameters measured against silica concentration

locations may indicate sewage contamination in these areas (Cole and Ryan 2003). The variation in the level of TDS and EC in the sampled wells might have been occasioned by differential sedimentation along water column in each of the wells (Sobulo 1991; Benaim et al. 1993; Bamgbose et al. 2001). In most of the locations, the values of both the TDS and EC are still within the recommended values of 500 – 1400 mg/l and 500 – 1000 µS/cm respectively (WHO 1971, 1993).

The measured value of silica in the groundwater implies that silica is one of the major chemical components of the water samples from the wells. These high values of dissolved silica with a range of 0.5 – 19.9 mg/l must have been favoured by both the high silica content of the host parent rocks and high degree of weathering that characterizes the tropical regions. Sivasankaran et al. (2004) reported an extremely high DSi which varied between 13 mg/l and 100 mg/l as against the normal 5 mg/l in un-reactive aquifer due to the presence of amorphous silica in the subsurface formations, slightly acidic to neutral nature of water in aquifers and also interaction between formation materials and water. Similarly, a range of DSi of 23.46-28.83 mg/l has been observed in the upstream of Citarum and Kaligarang Rivers in Indonesia by Wakatsuki and Masunaga (2009). As a result of the favourable climatic conditions (high temperature and rainfall) in the tropics the silicate minerals (feldspar and ferromagnesians) are easily weathered thereby releasing more of the crystalline silica (SiO_2) in solution (Stokes et al. 1978). Ma and Takahashi (2002) observed that the concentration of DSi in rivers and streams, or irrigation water is affected by water regulation structures, such as dams, weathering of rock and soil in the watershed. Positive correlations between DSi concentration and rainfall have been reported (Sigleo and Frick 2007; Wakatsuki and Masunaga 2009).

According to NEST (1991), more water is stored underground than is available on the surface. This explains why the groundwater in the study area contains more of silica loads. Since occupational sources of quartz silica in the environment include mining and quarrying; therefore, the high values of DSi in the groundwater of Olumo, Ikereku I and Asero may be as a result of parent rocks and high degree of weathering that characterizes these regions.

The observed low levels of DSi in the wells from Adatan, Ake, Ikereku II and others, which are zone of granite quarry activities is an indication that the source of silica content in groundwater is more of chemical weathering of the host rock rather than human activities (Iler 1979).

As observed by Hem (1970), weathering of silicate minerals will result in high concentration of DSi in groundwater. The DSi content of the groundwater may be partly from weathered profile of the basement complex rocks, which have been found to be rich in mineral concentration (Palacky and Kadekaru 1979). The correlation analysis in Table 2 shows that DSi bears a negative but non-significant association with depth ($r^2 = -0.791$) and TDS ($r^2 = -0.352$), while it bears a significant negative correlation with EC at $p<0.05$ ($r^2 = -0.319$). This shows that concentration of DSi in wells has nothing to do with depth; however, possible external source of silica from airborne silica from the nearby quarry sites might also have contributed to the high load of DSi in some sampled wells. However, a non-significant positive weak correlation was established between DSi and pH ($r^2 = 0.155$), and static water level ($r^2 = 0.009$). The bivariate plots depicted in Figure 1 further confirms the weak associations between DSi load of the wells, SWL, pH, TD, TDS and EC. These parameters have values clustered around the silica concentration < 10 mg/l.

Unlike in the airborne crystalline quartz silica where the occupational safety and health ad-

Table 2: Correlation Analysis of various parameters measured in the well water at different locations

Parameters	*TD*	*SWL*	*EC*	*TDS*	*pH*	*SiO_2*
TD	1					
SWL	0.764**	1				
EC	0.087	.240	1			
TDS	0.280	0.401**	0.906**	1		
pH	-0.321*	-0.265	0.077	-0.033	1	
SiO2	-0.179	0.009	-0.319	-0.352*	0.155	1

** Significant at $p< 0.01$, * Significant at $p< 0.05$

ministration (OSHA) established permissible exposure limits (PEL) of 10 mg/m^3 (NISA 1997); there is no established permissible limit for DSi. It is also an established fact that airborne silica above PEL value of 10 mg/m^3 may result in silicosis (chronic, accelerated or acute). No one is sure of the health impacts of ingestible crystalline quartz silica in natural water. It could be that all the ingested dissolved silica in potable water in the tropics is passed away as waste. Besides, if some are digested in the intestinal parts of animals and human bodies, it probably implies that the dissolved silica may not be in contact with the lungs where they normally cause havoc. Perhaps the level of the dissolved silica is negligible in water to cause any illness (Reen 1970). However, some of the reported cases of shortness of breath, fatigue, loss of appetite, tuberculosis among the patients not exposed to airborne silica may be a symptom of exposure to high concentration of dissolved silica.

CONCLUSION

Groundwater resources from the open dug wells in Abeokuta municipality contain an appreciable level of dissolved silica, which is likely to be sourced from chemical weathering of the host rocks. The health impacts of this silica load on the residents of the community are yet to be ascertained. Furthermore, the absence of recommended permissible level of dissolved silica in potable water makes it difficult to ascertain its health implication.

RECOMMENDATIONS

Though the health implication of dissolved silica in drinking water is yet to be documented, however, silica standard in drinking water should be established by the appropriate environmental agencies in various countries. This will assist in the close monitoring of silica load in the water resources of the tropical regions characterized by intensive weathering.

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