

Classification and Health Risk Assessment for Borehole Water Contaminated by Metals in Selected Households in Southwest Nigeria

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Received 17 February 2016; accepted 23 April 2016; published 26 April 2016

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Abstract

Samples of borehole water were randomly collected from twenty households in the Lagos-Ogun axis of southwestern Nigeria. The samples were analyzed for silver, iron, manganese, lead, nickel, magnesium, cadmium, zinc, sodium, potassium, pH, turbidity, dissolved oxygen, electrical conductivity, alkalinity, total hardness, chloride, nitrate and sulphate following standard methods of water analysis. Results obtained were compared with global background values and WHO guidelines for drinking water. The pH values ranged from 4.17 ± 0.26 to 6.07 ± 0.27 while the metal pollution indexes are between 0.01 and 0.11. Cadmium, manganese, iron and nitrate (mg/L) levels were found to be relatively high in most of the water samples. Results obtained were analyzed statistically. Health risk assessment for exposure to cancer and non-cancer indices was evaluated. Kempster and co-workers classification of drinking water quality was applied; nineteen of the twenty household water samples were found to fall short of the ideal water quality suitable for lifetime use.

Keywords

Borehole, Water Quality, Health Risk, Metals, Urbanization

1. Introduction

The unwholesomeness of drinking water resulting from contaminants released from different anthropogenic sources has become a global concern [1]-[4]. Rapid population growth, urbanization and seeming mismanagement

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of resources have hampered the capacity of government owned municipal water providers to meet the needs of the populace [5]-[7], even in cases where community based boreholes are provided lack of maintenance make them go out of operation. In Nigeria, most household in urban and semi-urban areas rely on boreholes or shallow wells for their water supply. This is the situation in the Lagos-Ogun axis, where samples for the present study were collected. The deterioration of water quality can pose a high hazard to human health [8] [9]. To address this concern, water samples are expected to be routinely analyzed and measured against a range of health and non-health based physico-chemical standards. The majority of these standards are based on the World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) guidelines [10].

There are global concerns that the usage of water above permitted limits could result to dire health consequences [6] [11]-[15]. These concerns are manifested in the significantly large number of metals ground water contamination studies across different countries. Representative global studies reviewed are from Nigeria, Malawi, Ghana, Ethiopia, Thailand, Iran, Pakistan, Bangladesh, Turkey, LAO PDR, Hong Kong, India and China [2] [9] [15]-[26].

In many countries of the world, there exist gaps in the provision of potable water. This challenge is even more exacerbated among developing countries like Nigeria with uncontrolled urbanization, population growth coupled with huge infrastructural deficits.

Consumption of unwholesome metal contaminated water has adverse health consequences [2]. This research work was undertaken to evaluate the wholesomeness of water sourced from boreholes in the selected Lagos-Ogun States communities using WHO standards for drinking water as bench mark. The potential health risk occasioned by the exposure of inhabitants to metals contamination through water consumption was evaluated. Classification based on lifetime usage proposed by Kempster *et al.*, 1997 [13] was adopted in this study.

2. Materials and Methods

2.1. Study Area

The sampling locations which are within the Lagos-Ogun State axis of Nigeria are indicated in **Figure 1**. These are predominantly densely populated urban and semi urban settlements. These communities are not covered by government owned municipal water supply network. In addition most of these communities indulge in unhealthy waste management practices like indiscriminate dumping of refuse in available open spaces and street corners and waste burning.

2.2. Sampling and Sample Preparation

Water samples were randomly collected from point of usage in the households fortnightly from July to December, 2013. One hundred groundwater samples were collected for physico-chemical analysis from twenty household boreholes located in the selected communities (Lagos locations are: Erunwen 1 (Yusuf), Erunwen 2 (Mama Tola), Erunwen 3 (Mama Azeezat), Agbele, Kokoro Abu, Eyita 1 (Jembi), Eyita 2 (Okedeyi), Eyita 3 (Ogunlana), Ikosi-Ketu, Oshodi, Ogudu, Akesan 1 (Okuneye), Akesan 2 (Above) and Ilado respectively; the Ogun locations are: Ogijo, Ibafo, Magboro, Ilupeju-Agbara, Lusada 1 (Taiwo) and Lusada 2 (Niyi). 2.5 L of water from each borehole were collected in sterile polypropylene bottles and analyzed for pH, turbidity, dissolved oxygen, electrical conductivity, alkalinity, total hardness, chloride, nitrate and sulphate. Other 2.5 L samples of water from the same borehole were collected, acidified and analyzed for metals, silver (Ag), iron (Fe), manganese (Mn), lead (Pb), nickel (Ni), magnesium (Mg), cadmium (Cd), zinc (Zn), sodium (Na) and potassium (K) (Adeniyi *et al.* 2014; APHA, 1998).

2.3. Analytical Procedure

The pH was determined in situ using Jenway 3505 pH meter; HACH - 2100 N Turbidity meter for turbidity; dissolved oxygen was determined by DO meter; Jenway 470 Conductivity meter for electrical conductivity; alkalinity, total hardness and chloride were determined by titrimetric methods; nitrate and sulphate were detected using HACH DR-3900. Whereas metals were evaluated using atomic absorption spectrophotometry with a Solar Thermo Electron Corporation AA Series Spectrometer. All analyses were carried out in accordance with standard methods for the examination of water and wastewater [27]. The results of the physico-chemical parameters

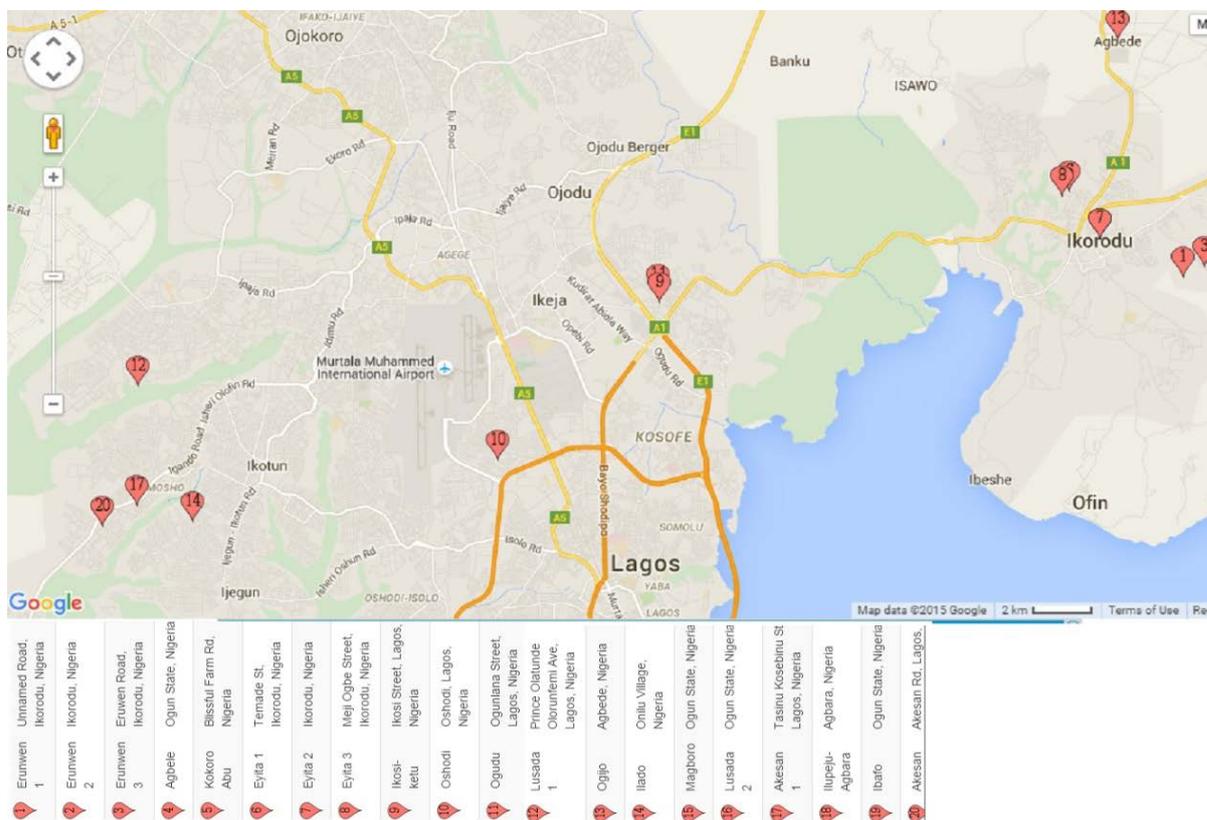


Figure 1. Global positioning system data (1 - 20 are the sampling locations).

and metal pollution index (MPI) are indicated in Table 1 and Table 2. The MPI is derived using the equation proposed by Usero et al., 1997 [28], as shown below:

$$MPI = (Cf_1 \times Cf_2 \cdots Cf_n)^{\frac{1}{n}} \tag{1}$$

where, Cf_n = concentration of the metal n in the sample.

2.4. Quality Assurance

All equipment was calibrated on daily basis using standard solutions. Samples were replicated; blank and previously spiked water samples were analyzed to further assure quality. Stock solutions (Merck) of 1000 mg/L of the different metals were used to prepare the calibration standards. The potential contamination of samples was evaluated by analyzing one acid blank in every batch [5] [29].

2.5. Risk Assessment

To assess potential health risks, interviews were conducted and questionnaires administered to members of the participating households for information about age, source of water supply, water treatment method, waste disposal practices, protection of water sources and health related problems. It was observed that the households involved use the borehole water for cooking, washing and bathing. Similarly, majority of the households also use the water for drinking. Two of the households not drinking theirs have neighbours who rely solely on them as source of drinking water. The health risk indicators, such as average daily dose (ADD) and hazard quotient (HQ) were calculated respectively using equations 2 and 3 [2] [15] [30]-[33] as shown below:

$$ADD = \frac{(CW \times IR \times EF \times ED)}{(BW \times AT)} \tag{2}$$

Table 1. Physico-chemical parameters values in the borehole water samples.

Location	pH	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Electrical conductivity (mS/cm)	Alkalinity (mg/L)	Total hardness (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Sulphate (mg/L)
Erunwen 1	5.28 ± 0.38	1.91 ± 1.70	6.42 ± 0.98	0.13 ± 0.04	18.30 ± 6.91	18.00 ± 15.28	8.50 ± 2.60	6.05 ± 5.30	5.17 ± 4.84
Erunwen 2	5.74 ± 0.16	2.03 ± 3.58	6.00 ± 0.88	0.65 ± 0.90	28.20 ± 4.95	14.67 ± 2.49	5.60 ± 1.46	3.93 ± 2.15	4.67 ± 4.17
Erunwen 3	5.49 ± 0.54	0.64 ± 0.34	5.95 ± 0.76	0.11 ± 0.05	18.60 ± 5.18	19.33 ± 10.27	4.00 ± 2.17	4.58 ± 2.31	3.33 ± 1.89
Agbele	5.23 ± 0.50	0.86 ± 0.37	6.24 ± 0.75	0.15 ± 0.06	24.60 ± 11.19	25.67 ± 28.52	8.20 ± 5.11	4.79 ± 2.73	4.90 ± 2.21
Kokoro Abu	4.23 ± 0.31	0.50 ± 0.41	5.94 ± 1.12	1.49 ± 0.26	15.88 ± 4.92	65.50 ± 17.97	69.60 ± 1.36	50.83 ± 11.46	5.00 ± 3.89
Eyita 1	6.01 ± 0.22	0.59 ± 0.49	6.21 ± 0.66	0.36 ± 0.15	34.40 ± 14.18	48.75 ± 18.61	8.30 ± 1.33	7.99 ± 1.42	2.00 ± 0.71
Eyita 2	5.68 ± 0.69	0.28 ± 0.13	6.28 ± 0.55	0.19 ± 0.07	19.30 ± 9.82	22.50 ± 13.35	8.00 ± 3.78	6.85 ± 1.84	3.33 ± 1.03
Eyita 3	6.07 ± 0.27	0.64 ± 0.62	6.40 ± 0.71	0.28 ± 0.08	34.60 ± 10.80	46.25 ± 34.66	6.50 ± 2.19	5.39 ± 1.39	2.00 ± 0.41
Ikosi Ketu	4.22 ± 0.43	2.20 ± 2.55	5.58 ± 0.67	1.10 ± 0.32	23.00 ± 12.39	58.50 ± 18.45	40.60 ± 3.81	35.86 ± 4.38	2.00 ± 0.41
Oshodi	4.75 ± 0.28	0.41 ± 0.29	5.59 ± 0.47	0.66 ± 0.25	24.30 ± 8.39	30.00 ± 26.84	35.90 ± 11.92	10.53 ± 1.47	2.50 ± 0.71
Ogudu	4.17 ± 0.26	1.05 ± 0.94	5.39 ± 0.94	2.51 ± 0.69	17.80 ± 4.57	95.50 ± 16.35	72.50 ± 47.22	73.18 ± 24.31	12.67 ± 8.72
Akesan 1	5.09 ± 0.29	0.16 ± 0.08	6.87 ± 1.87	0.47 ± 0.09	20.50 ± 7.81	25.00 ± 18.55	12.60 ± 3.34	18.69 ± 15.20	4.50 ± 2.86
Akesan 2	5.59 ± 0.22	0.42 ± 0.42	6.33 ± 1.70	0.34 ± 0.09	27.00 ± 6.00	27.50 ± 5.17	8.50 ± 2.59	8.54 ± 2.52	5.67 ± 2.05
Ilado	5.12 ± 0.41	0.39 ± 0.08	6.86 ± 1.27	0.13 ± 0.09	22.00 ± 8.86	19.00 ± 10.61	7.70 ± 1.69	3.95 ± 2.93	2.17 ± 0.85
Ogijo*	5.70 ± 0.27	1.44 ± 1.92	6.12 ± 0.91	0.16 ± 0.07	25.70 ± 9.56	36.50 ± 23.51	8.20 ± 2.48	4.49 ± 1.51	2.83 ± 0.24
Ibafo*	5.64 ± 0.31	0.26 ± 0.10	6.55 ± 1.30	0.74 ± 0.16	25.00 ± 5.70	57.50 ± 12.44	20.80 ± 2.04	24.43 ± 7.74	2.33 ± 0.94
Magboro*	6.20 ± 0.16	0.28 ± 0.13	6.43 ± 1.63	0.39 ± 0.07	42.00 ± 12.08	35.70 ± 5.45	7.10 ± 4.00	6.76 ± 1.96	1.67 ± 0.47
Ilupeju Agbara*	4.68 ± 0.40	0.23 ± 0.10	6.44 ± 1.43	0.33 ± 0.11	14.50 ± 6.78	14.00 ± 10.61	11.80 ± 3.41	8.93 ± 2.75	3.67 ± 1.25
Lusada 1*	5.23 ± 0.29	0.24 ± 0.08	6.70 ± 1.30	0.16 ± 0.07	21.50 ± 7.52	21.50 ± 10.16	8.40 ± 3.44	4.36 ± 2.86	2.83 ± 1.03
Lusada 2*	5.60 ± 0.31	0.30 ± 0.15	6.94 ± 1.46	0.19 ± 0.07	22.50 ± 8.37	19.00 ± 8.40	7.59 ± 2.59	4.68 ± 3.38	6.17 ± 6.25
WHO, 2011	6.5 - 8.5	-	-	-	-	-	-	50.0	-

Notes: *Ogun samples others are from Lagos State; ND, not detected; WHO (World Health Organization).

Table 2. Mean metal concentrations in the borehole water samples.

Location	mg/L										MPI
	Ag	Fe	Mn	Pb	Ni	Mg	Cd	Zn	Na	K	
Erunwen 1	0.02 ± 0.04	0.03 ± 0.06	0.003 ± 0.002	0.05 ± 0.09	0.007 ± 0.01	0.03 ± 0.04	0.012 ± 0.02	0.001 ± 0.0003	0.06 ± 0.02	0.03 ± 0.04	0.01
Erunwen 2	0.03 ± 0.06	0.05 ± 0.10	0.004 ± 0.003	0.01 ± 0.01	0.008 ± 0.01	0.04 ± 0.05	0.013 ± 0.01	0.014 ± 0.01	0.05 ± 0.05	0.01 ± 0.01	0.02
Erunwen 3	0.04 ± 0.07	0.06 ± 0.12	0.002 ± 0.002	0.01 ± 0.01	0.009 ± 0.01	0.02 ± 0.04	1.121 ± 1.12	0.001 ± 0.001	0.03 ± 0.03	0.01 ± 0.01	0.02
Agbele	0.21 ± 0.32	0.12 ± 0.20	0.002 ± 0.003	0.05 ± 0.08	0.015 ± 0.01	0.01 ± 0.02	ND	0.003 ± 0.004	0.01 ± 0.02	0.01 ± 0.01	0.03
Kokoro Abu	0.06 ± 0.11	0.07 ± 0.11	0.004 ± 0.002	0.01 ± 0.01	0.007 ± 0.01	0.18 ± 0.18	0.002 ± 0.0002	0.002 ± 0.001	0.63 ± 0.46	0.37 ± 0.43	0.03
Eyita 1	0.10 ± 0.20	0.12 ± 0.20	0.003 ± 0.002	ND	0.013 ± 0.01	0.05 ± 0.07	ND	0.001 ± 0.001	0.14 ± 0.10	0.01 ± 0.01	0.04
Eyita 2	0.07 ± 0.13	0.06 ± 0.11	0.002 ± 0.002	0.003 ± 0.01	0.010 ± 0.01	0.04 ± 0.05	0.0001 ± 0.0001	0.002 ± 0.001	0.11 ± 0.12	0.01 ± 0.01	0.01
Eyita 3	0.06 ± 0.12	0.01 ± 0.10	0.001 ± 0.002	0.002 ± 0.002	0.008 ± 0.01	0.07 ± 0.10	ND	0.002 ± 0.001	0.09 ± 0.10	0.01 ± 0.01	0.02
Ikosi Ketu	0.07 ± 0.13	0.06 ± 0.10	0.002 ± 0.003	0.001 ± 0.003	0.007 ± 0.01	0.16 ± 0.14	ND	0.001 ± 0.001	0.50 ± 0.41	0.10 ± 0.11	0.03
Oshodi	0.09 ± 0.18	0.06 ± 0.12	0.001 ± 0.002	0.001 ± 0.01	0.007 ± 0.01	0.04 ± 0.05	0.0004 ± 0.0004	0.001 ± 0.001	0.36 ± 0.30	0.01 ± 0.01	0.01
Ogudu	0.09 ± 0.17	0.05 ± 0.10	0.002 ± 0.002	0.002 ± 0.004	0.006 ± 0.01	0.19 ± 0.16	0.0002 ± 0.0002	0.003 ± 0.003	0.52 ± 0.56	0.96 ± 1.56	0.02
Akesan 1	ND	0.07 ± 0.14	0.14 ± 0.24	0.35 ± 0.70	0.093 ± 0.18	0.04 ± 0.05	0.006 ± 0.01	0.082 ± 0.14	0.71 ± 0.46	0.05 ± 0.09	0.11
Akesan 2	0.01 ± 0.02	0.05 ± 0.08	0.09 ± 0.15	0.23 ± 0.03	0.060 ± 0.11	0.01 ± 0.01	0.0013 ± 0.001	0.001 ± 0.001	0.48 ± 0.20	0.01 ± 0.01	0.02
Ilado	0.01 ± 0.03	0.01 ± 0.01	0.09 ± 0.15	0.01 ± 0.02	0.002 ± 2.07	0.03 ± 0.03	0.0006 ± 0.001	0.024 ± 0.02	0.63 ± 0.78	0.01 ± 0.01	0.02
Ogijo*	0.12 ± 0.23	0.07 ± 0.13	0.002 ± 0.002	0.001 ± 0.001	0.007 ± 0.01	0.04 ± 0.05	0.0001 ± 0.0001	0.002 ± 0.002	0.13 ± 0.16	0.03 ± 0.03	0.01
Ibafo*	0.11 ± 0.19	0.05 ± 0.09	0.004 ± 0.003	0.001 ± 0.002	0.006 ± 0.01	0.13 ± 0.10	0.0001 ± 0.0001	0.001 ± 0.001	0.74 ± 0.80	1.08 ± 1.56	0.02
Magboro*	0.003 ± 0.01	0.02 ± 0.04	0.04 ± 0.07	0.01 ± 0.01	0.029 ± 0.05	0.06 ± 0.06	0.0003 ± 0.0003	0.005 ± 0.01	0.76 ± 0.23	0.10 ± 0.09	0.02
Ilupeju Agbara*	ND	0.05 ± 0.08	0.10 ± 0.13	0.002 ± 0.004	0.037 ± 0.07	0.08 ± 0.09	ND	0.001 ± 0.001	0.59 ± 0.22	0.13 ± 0.02	0.07
Lusada 1*	ND	0.06 ± 0.10	0.11 ± 0.20	0.002 ± 0.003	0.059 ± 0.11	0.04 ± 0.07	ND	0.003 ± 0.003	0.18 ± 0.07	0.003 ± 0.01	0.05
Lusada 2*	ND	0.09 ± 0.15	0.14 ± 0.23	0.01 ± 0.01	0.090 ± 0.18	0.03 ± 0.03	0.0001 ± 0.000	0.001 ± 0.001	0.28 ± 0.12	0.01 ± 0.01	0.03
GBV	-	0.0016 - 24.20	ND - 16.00	ND - 0.70	ND - 0.24	2.00 - 70.00	ND - 0.20	0.015 - 2.499	5.70 - 599.00	1.60 - 15.00	-
WHO	-	-	0.40	0.01	0.07	-	0.03	-	-	-	-

Notes: *Ogun samples others are from Lagos State; ND, not detected; WHO, World Health Organization GBV, Global Background Values.

where, ADD is the average daily dose from ingestion of metal in drinking water (mg/kg/day); CW is the concentration of a particular heavy metal in groundwater (mg/L); IR is the water ingestion rate (L/day); EF is the exposure frequency (day/year); ED is the exposure duration (years); BW is the body weight (Kg); AT is the average time of life expectancy (days). This study used the standard amount of water intake of 2 L/day recommended by the WHO [12]; while EF of 365 days year⁻¹ recommended by the USEPA [33] was used. The life expectancy at birth of Nigerian is 54 years [35], this translates to an (AT) of 19,710 days. The average body weight used is assumed to be 72 Kg for adult and 32.7 Kg for child. Exposure duration was captured from the administered questionnaire.

2.6. Non-Carcinogenic Risk Assessment

The potential non-carcinogenic toxicity was estimated through the non-cancer hazard quotient (non-cancer HQ) shown in Equation (3) [2] [33].

$$\text{Non-cancer HQ} = \frac{\text{ADD}}{\text{Rfd}} \tag{3}$$

where, ADD is the average daily dose from ingestion of metal in drinking water (mg/kg/day); RfD is the oral reference dose (mg/kg/day) of a particular metal. The values (mg/kg/day): Mn, Pb, Ni, Cd, Zn and Ag, 1.4E+01, 3.6E+03, 2E+02, 5E+04, 3E+01 and 5E+03 respectively. The results are presented in Table 3.

2.7. Carcinogenic Risk Assessment for Cadmium

The concentration of Cd in the borehole water was used to assess the probability of cancer developing in individuals over their lifetime [33]-[35]. This was evaluated using Equation (4).

$$\text{CR} = 1 - \exp(-\text{ADD} \times \text{SF}) \tag{4}$$

where, CR is the cancer risk; ADD, is as described earlier; SF is the oral cancer slope factor of Cd (6.3 mg/kg/day). The calculated carcinogenic risk (CR) contribution of cadmium in the sampling locations is presented in Figure 2.

2.8. Classification System

The classification system proposed by Kempster *et al.*, 1997 [13] was used to classify the borehole water examined in this study [36].

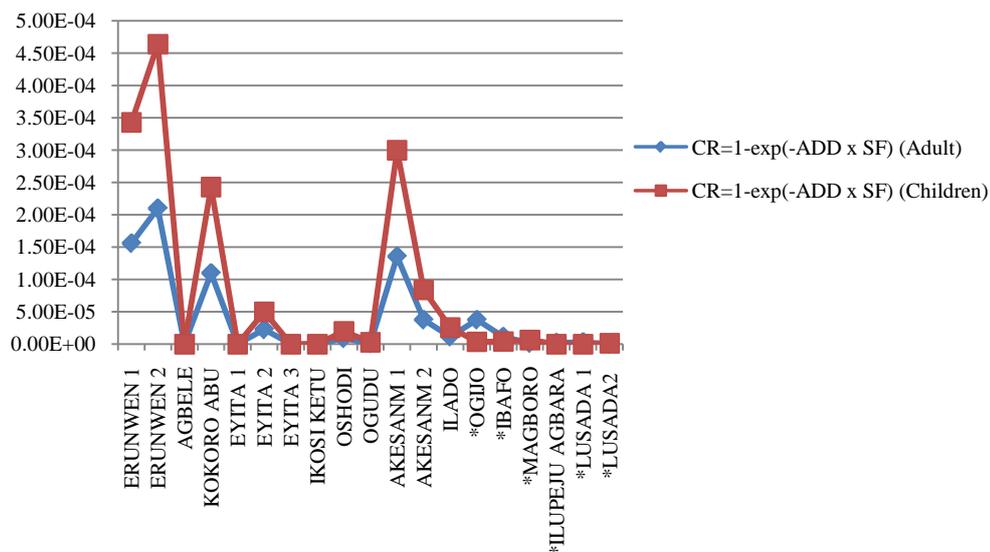


Figure 2. Carcinogenic risk assessment values for cadmium in the water samples. Notes: x-axis, cancer risk quotient; y-axis, sampling locations.

Table 3. Non cancer Health Quotient (HQ) for Lagos and Ogun states locations.

Location	Ag	Fe	Mn	Pb	Ni	Cd	Zn	HI = ΣHQs
Erunwen 1	8.23E-03 (1.81E-02)	2.06E-04 (4.53E-04)	4.41E-05 (9.71E-05)	2.94E-02 (6.47E-02)	7.20E-04 (1.59E-03)	4.94E-02 (1.09E-01)	6.86E-06 (1.51E-05)	8.80E-02 (1.94E-01)
Erunwen 2	1.54E-02 (3.40E-02)	4.29E-04 (9.44E-04)	7.35E-05 (1.62E-04)	7.35E-03 (1.62E-02)	1.03E-03 (2.27E-03)	6.69E-02 (1.47E-01)	1.20E-04 (2.64E-04)	9.13E-02 (2.01E-01)
Erunwen 3	2.88E-02 (6.34E-02)	7.20E-04 (1.59E-03)	5.14E-05 (1.13E-04)	1.03E-02 (2.27E-02)	1.62E-03 (3.57E-03)	8.07E+00 (1.78E+01)	1.20E-05 (2.64E-05)	8.11E+00 (1.79E+01)
Agbele	1.08E-01 (2.38E-01)	1.03E-03 (2.27E-03)	3.67E-05 (8.09E-05)	3.67E-02 (8.09E-02)	1.93E-03 (4.25E-03)	0.00E+00 (0.00E+00)	2.57E-05 (5.66E-05)	1.48E-01 (3.25E-01)
Kokoro Abu	1.05E-01 (2.31E-01)	2.04E-03 (4.49E-03)	2.50E-04 (5.50E-04)	2.50E-02 (5.50E-02)	3.06E-03 (6.74E-03)	3.50E-02 (7.70E-02)	5.83E-05 (1.28E-04)	1.70E-01 (3.75E-01)
Eyita 1	1.34E-01 (2.94E-01)	2.68E-03 (5.89E-03)	1.43E-04 (3.15E-04)	0.00E+00 (0.00E+00)	4.35E-03 (9.57E-03)	0.00E+00 (0.00E+00)	2.23E-05 (4.91E-05)	1.41E-01 (3.10E-01)
Eyita 2	5.04E-02 (1.11E-01)	7.20E-04 (1.59E-03)	5.14E-05 (1.13E-04)	3.09E-03 (6.80E-03)	1.80E-03 (3.96E-03)	7.20E-03 (1.59E-02)	2.40E-05 (5.29E-05)	6.33E-02 (1.39E-01)
Eyita 3	1.85E-02 (4.08E-02)	5.14E-05 (1.13E-04)	1.10E-05 (2.43E-05)	8.82E-04 (1.94E-03)	6.17E-04 (1.36E-03)	0.00E+00 (0.00E+00)	1.03E-05 (2.27E-05)	2.01E-02 (4.42E-02)
Ikosi Ketu	7.20E-02 (1.59E-01)	1.03E-03 (2.27E-03)	7.35E-05 (1.62E-04)	1.47E-03 (3.24E-03)	1.80E-03 (3.96E-03)	0.00E+00 (0.00E+00)	1.71E-05 (3.78E-05)	7.64E-02 (1.68E-01)
Oshodi	6.48E-02 (1.43E-01)	7.20E-04 (1.59E-03)	2.57E-05 (5.66E-05)	1.03E-03 (2.27E-03)	1.26E-03 (2.78E-03)	2.88E-03 (6.34E-03)	1.20E-05 (2.64E-05)	7.07E-02 (1.56E-01)
Ogudu	1.85E-02 (4.08E-02)	1.71E-04 (3.78E-04)	1.47E-05 (3.24E-05)	5.88E-04 (1.29E-03)	3.09E-04 (6.80E-04)	4.12E-04 (9.06E-04)	1.03E-05 (2.27E-05)	2.00E-02 (4.41E-02)
Akesan 1	0.00E+00 (0.00E+00)	8.40E-04 (1.85E-03)	3.60E-03 (7.93E-03)	3.60E-01 (7.93E-01)	1.67E-02 (3.69E-02)	4.32E-02 (9.51E-02)	9.84E-04 (2.17E-03)	4.25E-01 (9.37E-01)
Akesan 2	9.26E-03 (2.04E-02)	7.72E-04 (1.70E-03)	2.98E-03 (6.55E-03)	3.04E-01 (6.70E-01)	1.39E-02 (3.06E-02)	1.20E-02 (2.65E-02)	1.54E-05 (3.40E-05)	3.43E-01 (7.56E-01)
Ilado	6.17E-03 (1.36E-02)	1.03E-04 (2.27E-04)	1.98E-03 (4.37E-03)	8.82E-03 (1.94E-02)	3.09E-04 (6.80E-04)	3.70E-03 (8.15E-03)	2.47E-04 (5.44E-04)	2.13E-02 (4.70E-02)
Ogijo*	6.17E-02 (1.36E-01)	6.00E-04 (1.32E-03)	3.67E-05 (8.09E-05)	7.35E-04 (1.62E-03)	9.00E-04 (1.98E-03)	5.14E-04 (1.13E-03)	1.71E-05 (3.78E-05)	6.45E-02 (1.42E-01)
Ibafo*	6.79E-02 (1.49E-01)	5.14E-04 (1.13E-03)	8.82E-05 (1.94E-04)	8.82E-04 (1.94E-03)	9.26E-04 (2.04E-03)	6.17E-04 (1.36E-03)	1.03E-05 (2.27E-05)	7.09E-02 (1.56E-01)
Magboro*	9.26E-04 (2.04E-03)	1.03E-04 (2.27E-04)	4.41E-04 (9.71E-04)	4.41E-03 (9.71E-03)	2.24E-03 (4.93E-03)	9.26E-04 (2.04E-03)	2.57E-05 (5.66E-05)	9.07E-03 (2.00E-02)
Ilupeju Agbara*	0.00E+00 (0.00E+00)	4.29E-04 (9.44E-04)	1.84E-03 (4.05E-03)	1.47E-03 (3.24E-03)	4.76E-03 (1.05E-02)	0.00E+00 (0.00E+00)	8.57E-06 (1.89E-05)	8.50E-03 (1.87E-02)
Lusada 1*	0.00E+00 (0.00E+00)	3.09E-04 (6.80E-04)	1.21E-03 (2.67E-03)	8.82E-04 (1.94E-03)	4.55E-03 (1.00E-02)	0.00E+00 (0.00E+00)	1.54E-05 (3.40E-05)	6.97E-03 (1.53E-02)
Lusada 2*	0.00E+00 (0.00E+00)	3.09E-04 (6.80E-04)	1.03E-03 (2.27E-03)	2.94E-03 (6.47E-03)	4.63E-03 (1.02E-02)	2.06E-04 (4.53E-04)	3.43E-06 (7.55E-06)	9.12E-03 (2.01E-02)

Notes: The values in parentheses are for the children; E, exponential. Continued on next page. *Ogun State samples.

Class 0: “This is defined as the ideal water quality suitable for lifetime use, with no adverse effects on the user”.

Class I: “Water in this Class is safe for lifetime use, but falls short of the ideal water quality in that there may be instances of adverse health effects, but these are usually mild health effects, almost sub-clinical and difficult to demonstrate. Aesthetic effects may however be apparent”.

Class II: “Water in this Class is defined as that where adverse health effects may become more common particularly with prolonged use over many years, or with lifetime use. This class represents water suitable for short-term or emergency use only, but not necessarily suitable for continuous use over a lifetime”.

Class III: “This water has constituents in concentration range where serious health effects might be anticipated particularly in infants or elderly people with short-term use, and even more so with longer term use. The water in this class is not suitable for use as drinking water without adequate treatment to shift the water into a lower and safer Class”. The classification of water from Lagos-Ogun axis is presented in **Table 4**.

2.9. Statistical Analyses

Pearson’s correlation coefficient and t-test statistical analyses were used at 95% confidence level to evaluate results obtained from the physico-chemical analyses of the water samples from Lagos and Ogun States. The *r* values are indicated in **Table 5** and **Table 6** respectively.

3. Results and Discussion

The pH values ranged from 4.17 to 6.07 and 4.68 to 6.20 in Lagos and Ogun borehole drinking water samples (**Table 1**) respectively and were generally below the permissible limit (6.50 - 8.50) set by World Health Organization [38]. Similarly, they vary from values reported earlier for Chikhwawa, Malawi borehole water (6.90 - 7.70), Lao PDR (3.53 - 7.92), Swat, Northern Pakistan (6.50 - 8.60) respectively [2] [10] [15]. This may be an indication of the unwholesomeness of the water for drinking. The pH of drinking water has no immediate direct effects on human health but acidic water has some indirect health effects by bringing changes in other water quality parameters such as solubility of metals [16]. In sensitive individuals gastrointestinal irritation may also occur [13]. In the present study, the EC (mS/cm) were found to be between 0.11 and 2.51 (**Table 1**), whereas, the Malawi’s and Lao PDR values are respectively, 220.70 - 6574.30 and 20.70 - 2840.0. Nevertheless, turbidity (NTU) of the Lagos-Ogun axis borehole water of 0.23 - 2.20 were found to be generally higher than Chikhwawa, Malawi values (ND - 3.90).

Characteristically, anions also play important roles in the quality of drinking water. The Malawi’s chloride, nitrate and sulphate (mg/L) levels (8.10 - 426.0, ND - 177.60, 4.50 - 294.40 respectively), were generally higher

Table 4. Parameters, values and classification of drinking water quality proposed by Kempster *et al.* 1997.

Constituent	Class 0	Class I	Class II	Class III
Electrical conductivity (mS/cm)	0 - 0.7	0.7 - 1.50	1.50 - 3.70	> 3.70
pH	6.0 - 9.0	5 - 6 or 9 - 9.5	4 - 5 or 9.5 - 10	< 4 or > 10
Nitrate (mg/L)	0 - 6	6 - 10	10 - 20	20
Sulphate (mg/L)	0 - 200	200 - 400	400 - 600	> 600
Chloride (mg/L)	0 - 100	100 - 200	200 - 600	> 600
Iron (mg/L)	0 - 0.1	0.1 - 0.2	0.2 - 2.0	> 2.0
Manganese (mg/L)	0 - 0.05	0.05 - 0.1	0.1 - 1.0	> 1.0
Cadmium (mg/L)	0 - 0.005	0.005 - 0.01	0.01 - 0.02	> 0.02
Zinc (mg/L)	0 - 3.0	3.0 - 5.0	5.0 - 10.0	> 10.0
Magnesium (mg/L)	0 - 30	30 - 70	70 - 100	> 100
Sodium (mg/L)	0 - 100	100 - 200	200 - 400	> 400

Table 5. Pearson correlation coefficient (r) of individual Physico chemical parameters in Lagos and Ogun water samples.

	pH	Turbidity	Dissolved Oxygen	Electrical Conductivity	Total alkalinity	Chloride	Nitrate	Sulphate	Total hardness
pH	1.000 (1.000)	-0.19 (0.22)	0.53 (-0.11)	-0.75 (0.17)	0.66 (0.91)	-0.87 (-0.16)	-0.81 (0.03)	-0.43 (-0.31)	-0.59 (0.57)
Turbidity		1.000 (1.000)	-0.38 (-0.71)	0.19 (-0.37)	0.00 (0.06)	-0.67 (-0.02)	0.12 (-0.29)	0.11 (-0.11)	0.07 (0.19)
Dissolved Oxygen			1.000 (1.000)	-0.68 (-0.05)	0.15 (-0.21)	-0.67 (-0.02)	-0.58 (-0.02)	-0.36 (0.64)	-0.60 (-0.33)
Electrical Conductivity				1.000 (1.000)	-0.34 (0.18)	0.93 (0.88)	0.96 (0.96)	0.72 (-0.42)	0.88 (0.76)
Total Alkalinity					1.000 (1.000)	-0.46 (-0.25)	-0.46 (-0.04)	-0.43 (-0.52)	-0.10 (0.45)
Chloride						1.000 (1.000)	0.94 (0.98)	0.55 (-0.25)	0.85 (0.66)
Nitrate							1.000 (1.000)	0.69 (-0.32)	0.90 (0.76)
Sulphate								1.000 (1.000)	0.53 (-0.57)
Total Hardness									1.000 (1.000)

Note: Values in parentheses are for Ogun samples.

Table 6. Pearson correlation coefficient (r) of individual metals in Lagos and Ogun water samples.

	Ag	Fe	Mn	Pb	Ni	Mg	Cd	Zn	Na	K
Ag	1.000 (1.000)	0.67 (0.11)	-0.55 (-0.84)	-0.39 (-0.58)	-0.36 (-0.76)	0.09 (0.41)	-0.12 (0.02)	-0.41 (-0.30)	-0.44 (0.99)	0.06 (0.99)
Fe		1.000 (1.000)	-0.17 (0.42)	0.07 (-0.06)	0.15 (0.52)	-0.05 (-0.44)	0.01 (-0.55)	-0.03 (-0.68)	-0.06 (-0.56)	-0.15 (-0.50)
Mn			1.000 (1.000)	0.85 (0.39)	0.82 (0.95)	-0.30 (-0.50)	-0.14 (-0.41)	0.80 (-0.17)	0.54 (-0.93)	-0.08 (-0.97)
Pb				1.000 (1.000)	0.99 (0.57)	-0.30 (-0.41)	-0.11 (0.66)	0.75 (0.42)	0.44 (-0.44)	-0.12 (-0.48)
Ni					1.000 (1.000)	-0.27 (0.60)	-0.099 (0.21)	0.76 (0.10)	0.47 (0.86)	-0.13 (0.84)
Mg						1.000 (1.000)	-0.21 (-2.08)	-0.16 (0.28)	0.63 (0.97)	0.78 (0.93)
Cd							1.000 (1.000)	-0.11 (0.68)	0.00 (0.64)	-0.13 (0.53)
Zn								1.000 (1.000)	0.53 (0.64)	-0.07 (0.39)
Na									1.000 (1.000)	0.31 (0.64)
K										1.000 (1.000)

Note: Values in parentheses are for Ogun samples.

than the values reported for this study [36] (**Table 1**). Whereas, chloride and sulphate have no stated WHO guideline values, while for nitrate it is 50 mg/L [37]. Kokoro Abu and Ogudu samples exceeded this guideline value, 50.83 ± 1.46 mg/L (Kokoro Abu) and 73.18 ± 24.31 mg/L (Ogudu) respectively. This is an indication that nitrate contamination is not widespread in the Lagos-Ogun axis groundwater. The primary health problem associated with high intake of NO_3^- in drinking water is methemoglobinemia (blue baby syndrome) (Gupta *et al.* 2000). However, the adult individuals can tolerate high levels of NO_3^- with little or no documented adverse health effects as posited by Bruning-Fann and Kaneene, 1993 [11]. The levels of Na and K in the water samples (**Table 2**) are lower than the reported global background values (mg/L) of 5.70 - 599.00 (Na) and 1.60 - 15.00 (K) respectively. Na and K are essential elements for human nutrition; they maintain the normal osmotic pressure in cells. USEPA limit for Na in drinking water is 20 mg/L. There are scientific evidences linking excessive sodium intake to age-related increases in blood pressure leading to hypertension [38].

The concentrations of Mn, Pb, Ni and Cd were compared with WHO guidelines [37] for drinking water (**Table 2**). All water samples are within the acceptable guideline values of 0.4 mg/L (Mn), 0.003 mg/L (Cd) and 0.07 mg/L (Ni) as recommended by WHO. However, nickel value at Akesan 1 and Lusada 2 (0.09 mg/L) were than the WHO value. The concentration of Pb in Erunwen 1, Akesan 1 and Akesan 2 exceed the permissible limit of 0.01 mg/L by WHO.

The other metals have no WHO guideline values but compares favourably with other reported global background values (mg/L): 0.00094 - 0.067 (Pb), 0.00065 - 0.0156 (Ni), 0.00017 - 0.00023 (Cd), 0.0069 - 0.302 (Zn) for Ubon Ratchathani province of Thailand; 0.12 - 0.72 (Fe), 0.028 - 0.20 (Mn), 0.053 - 0.70 (Pb), 0.032 - 0.24 (Ni), ND - 0.017 (Cd), 0.078 - 2.499 (Zn) for Tigray region, Northern Ethiopia; 0.0016 - 0.347 (Fe), ND - 0.113 (Mn), ND - 0.0088 (Pb), ND - 0.013 (Ni), ND - 0.0015 (Cd), 0.0003 - 0.32 (Zn) for Kermanshah, Iran; 0.002 - 0.57 (Fe), 0.005 - 0.02 (Mn), 0.00 - 0.04 (Pd), 0.00 - 0.002 (Cd), 0.00 - 0.047 (Zn) for Ejisu-Juaben municipality, Ghana; 2.42 - 2.675 (Fe), 0.51 - 0.67 (Mn), 0.11 - 0.29 (Pb), 0.025 - 0.065 (Ni), 0.015 - 0.03 (Cd), 0.35 - 0.59 (Zn) for Eket and Esit Eket, Nigeria; 0.11 - 24.2 (Fe), 0.06 - 16.00 (Mn), 2.00 - 70.00 (Mg), ND - 0.2 (Cd), 5.70 - 599.00 (Na), 1.60 - 15.00 (K) for Bangladesh; 0.0007 - 0.01 (Pb), 0.00013 - 0.00050 (Cd) for Shizuishan city, Northern China. The Pb values (ND - 0.35 mg/L) obtained in this study were higher than most recorded global background values with the exception of the values obtained in Ethiopia, Lao PDR and Swat, Northern Pakistan (0.015 - 0.075 mg/L). The zinc and iron concentrations obtained in this study (0.001 - 0.082 mg/L) and (0.01 - 0.012 mg/L) respectively were below the values reported for Ethiopia, Thailand, Iran, Ghana, India and Bangladesh respectively [9] [17] [21]-[25].

Kempster and co-workers [13] are of the opinion that no undesirable health or aesthetic effects have been shown to be associated with magnesium concentrations in drinking water of < 70 mg/L. However, Grimason *et al.*, 2013 [36] opined that levels > 30 mg/L may impair the lathering of soap, while concentrations ranging from 70 - 100 mg/L may impart a bitter taste to the water and cause diarrhoea in sensitive users including infants [39]. At levels above 100 mg/L the bitter taste and diarrhoea may be exacerbated. Studies have equally suggested that dissolved metals in drinking water such as iron, magnesium and calcium may contribute significantly to the dietary intakes of these metals thus reducing the risk of anaemia, cardiovascular and osteoporosis respectively [40].

The MPI shown in **Table 2** reveal values ranging from 0.01 to 0.11 mg/L. These values are less than the baseline value of 1 mg/L reported earlier [41].

The t-test statistical analysis for the physico-chemical parameters recorded between the Lagos and Ogun States samples indicate non-significant differences ranging from 0.49 to 1.70 (t_{cal}) except for dissolved oxygen which recorded a significant difference of 2.34 (t_{cal}) against a t_{tab} value of 2.10. These values indicate that contamination by metals and the levels of other physico-chemical parameters are not State dependent. Strong positive correlation existed between the metals in most of the sample sites, thus suggesting that the metals are likely to have originated from similar sources (**Table 5** and **Table 6**).

The non-cancer health quotient for the study area for both adult and children is shown in **Table 3**. Whereas, the carcinogenic risk assessment values for Erunwen 3 sampling site are $2.51\text{E}-02$ and $5.75\text{E}-02$ for adult and children respectively, the other values are shown in **Figure 2**.

The non-cancer HQs of all eight metals in Lagos, Ogun for both adult and children were below the recommended HQ threshold of 1, indicating no immediate significant adverse health effects from the groundwater consumption in most of the sampling areas. However, long-term daily consumption of the groundwater in Erunwen 3 could cause chronic negative health effects since the maximum HI values for ingestion were 17.9 and 8.11 for children and adult respectively which are far greater than 1.

Only Cd, among the metals analyzed in this study area is classified as a known human carcinogen by the International Agency for Research on Cancer and the Integrated Risk Information System of United States Environmental Protection Agency [42].

The quanta of potential exposure to carcinogenic risk in the study area are (%): Negligible ($<1E-06$), 50 and 55 respectively for adults and children; Acceptable ($1E-06$ to $1E-04$), 45 and 40, adults and children respectively; Excessive ($>1E-04$), 5 for both adult and children.

Following the scheme proposed by Kempster *et al.* [13] on the classification of drinking water quality (Table 4), Eyita 3 is in Class 0 (ideal and suitable for lifetime use). However, water sourced from Erunwen 1 and 2, Agbele, Eyita 1 and 2, Akesan 2, Ilado, Ogijo and Magboro fall into Class I, *i.e.* water safe for lifetime use but falls short of the ideal water quality in that there may be possible exposure to health hazards. Slightly acidic pH values and relatively high nitrate, Fe, Mn and Cd values are responsible for these water samples falling short of the ideal range of values [36]. Similarly, borehole water samples collected from Oshodi, Akesan 1, Ilupeju-Ag- bara, Lusada 1 and 2 are in Class II, which is water that may result in adverse health effects with prolonged use over many years or with lifetime use. Nonetheless, water samples from five locations *i.e.* Erunwen 3, Kokoro Abu, Ikosi-Ketu, Ogudu and Ibafo are in Class III, water not suitable for use as drinking water without adequate treatment to shift it to lower and safer Class. It should be noted that Ibafo fell into class III because of its relatively high nitrate level of 24.43 ± 7.74 mg/L, whose source appears to be diffuse [43] [44].

4. Conclusion

It is concluded among others, that improper disposal of solid waste and sewage, may have contaminated the ground water in these communities with nitrate and metals such as Ag, Mn, Pb, Ni and Cd. Inter-metal correlation showed a strong correlation between metal pairs. The computation of non-cancer HQs of selected metals in Lagos and Ogun sampling locations for both adult and children were below the recommended HQ threshold of 1. This is an indication that there are no immediate significant adverse health effects arising from the consumption of groundwater in most of the sampling locations. However, water sourced Erunwen 3, Kokoro Abu, Ikosi-Ketu, Ogudu and Ibafo are of Class III, *i.e.* water not suitable for drinking without adequate treatment. The water classification system adopted here is incisive making it imperative for proper water quality monitoring and management in these areas. Emphasis should be on municipal and community based water supply. It is also recommended that mitigation measures be conducted in the areas at risk, with the particular aim of lowering the concentrations of Ag, Mn, Pb, Ni, Mg and Cd to meet WHO drinking water standards. Public health awareness programs should be conducted by relevant government and non-governmental agencies to raise consciousness about the adverse health consequences of consuming metal contaminated water above recommended limits.

Acknowledgements

The authors are grateful to Lagos State Environmental Protection Agency (LASEPA) and Dr. Wale Raimi, University of Dundee, Scotland, for valuable assistance. We are equally grateful to the families whose households were used for this study.

Ethical Statement

The work has not been published before and it's not under consideration anywhere else. Authors approve of the submission to Journal Water Resource and Protection. We affirm that it is an original work and there is no conflict of interest.

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