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Radiological and related Chemical Health Impact Assessments of Uranium in Pipe Borne Water from some Waterworks in Lagos Metropolis, Nigeria

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Abstract: The common purifying technique of water for public (human) consumption in Nigeria is by chlorination which only eliminates the microbial contaminants, but the radioactive contaminants remain unaffected. There had been no serious radiological and related chemical health impact assessments of pipe borne water in the country. Water samples were collected from five waterworks across Lagos Metropolis and a single crystal NaI (Tl) detector was used to determine the activity concentration of ^{238}U radionuclide in the water. The radiological health impact assessment determined includes annual effective dose rates and risk of incurring cancer. Using activity concentrations obtained and the relation from United State Environmental Protection Agency (USEPA), the chemical health impact such as life average daily dose (LADD) and hazard quotient (HQ) due to ingestion of ^{238}U in water were determined and data were analyzed using descriptive statistics. The mean ^{238}U activity concentrations were 15.3±4.1 Bql^{-1}, 14.6±5.2 Bql^{-1}, 9.7±2.0 Bql^{-1}, 11.0±2.9 Bql^{-1} and 11.3±1.8 Bql^{-1} for Agege, Shomolu, Iju, Saka and Amuwo respectively. The least mean effective dose, 0.3±0.1 mSvy^{-1} was obtained in Iju while the highest, 0.5±0.2 mSvy^{-1} was obtained in Agege and Shomolu. The least mass concentration of 174.2±35.7μgl^{-1} was obtained in Iju and the highest of 274.9±73.3 μgl^{-1} was obtained in Agege. The highest mean cancer mortality and morbidity risks, (0.6±0.2) x10^{-3} and (0.9±0.2) x10^{-3} respectively were obtained in Agege. The activity concentrations of radionuclide in the water were low hence the morbidity and mortality risks in the study were low when compared to the world average value of 1.0x10^{-3}. The result showed high radioactivity and chemical levels therefore caution and control should be taken to avoid any health crisis later in future.

Keywords: uranium impact assessment, pipe born water, water works, Lagos metropolis, Nigeria

1. INTRODUCTION

Water covers about 70 percent of the earth with a total of about 1,386 million cubic kilometers [1]. Only 3 percent of the world's water supply is fresh or portable, and 77 percent of the freshwater is frozen. Out of the 23 percent that is not frozen, only 0.5 percent is available for the use of plants, animals and peoples on the earth [2]. As shown in Table 1, the percentage of freshwater in the total global water distribution is about 0.77%. Water sustains life and its scarcity can mar the health status of people of any nation. It is the most essential needs to all forms of lives and a pre-requisite for human health and preservation of the environment.

The uranium-238 and thorium-232 as well as the non-series potassium-40 are natural radionuclides found in water either because of natural processes (dissolution of radionuclides in water) or technological processes (mining and processing of mineral sands) [3]. The most common radioactive elements uranium-238 and thorium-232 decay slowly and produce other radioactive elements (daughter elements). As contaminants in water, radionuclides are colorless, odorless, and tasteless, and typically cannot be detected by human senses, unlike many other contaminants that may exhibit undesirable color, odor, or taste. Natural radioactivity in drinking water and its effect on human health have recently become a major environmental concern. The World Health Organization (WHO) and its Member States have always advocated that all people deserve the right to have adequate supply of clean and safe drinking water [4].

Although the Nigerian Government has set up many agencies and put in place various policies on provision of clean drinking water, but lack of political will has been the only obstacle hindering their implementation. Majority of the Nigerian populace depends on ground and surface waters that may have been contaminated from several sources including waste materials from oil facilities and waste chemical products from industries [5]. The pipe born waters (clean and safe drinking waters) are only available to rich people in the cities and urban centers, the poor people in slum areas depend mainly on ground waters from shallow or deep wells that are rarely treated for drinking. Of course, the chlorination processes used for purifying waters in various waterworks do not remove radioactive contaminants in the waters supply to the public for consumption.

Lagos, the acclaimed megacity with an estimated population of about twenty-one (21) million persons is surrounded by the lagoon which covers about 81.3% of its land mass area [6,7]. The raw water from the lagoon is highly polluted, so the waterworks collect waters from Ogun and Owo Rivers for treatment before supply to the public for consumption [7]. With a view to solve the scarcity of portable and drinkable water in Lagos, the government established Lagos Water Corporation (LSWC) and constructed many water works and plants. Figure 1 shows some of the areas where the water works are sited. The oldest water treatment plant constructed in 1910 is in Iju on the Ogun River; the plant treats about 45 million gallons per day for drinking [7]. Another water treatment plant built in the 1970s at Ishashi collects waters from Owo River and treats a few million gallons per day for public consumption. The biggest water treatment plant was commissioned in 1991, the waters are also collected from Owo River and about 70 million gallons are treated per day for public drinking. To further strengthen the supply of water in the megacity, additional seven mini-waterworks drawing waters from local sources with a combined capacity of 18 million gallons per day has recently been commissioned. The Lagos State Water Corporation reported that the waters produced and supplied from these plants are sufficient, safe and clean for the general populace in the megacity to drink [7]. The sources from where the waters are collected and chlorinated before supply to the populace may have been contaminated by several wastes including radioactive and chemical from many industries across the metropolis. In addition, the purported safe and clean water is subject of radiological health detriments to the consumers as water washes natural radioactive substances in the earth crust and retains them as contaminants even after the chlorination processes at the water works [8].

It is therefore necessary to measure the radioactivity and determine the radiological and associated health impact of the pipe born water consumed by the inhabitants of the Lagos megacity in Nigeria

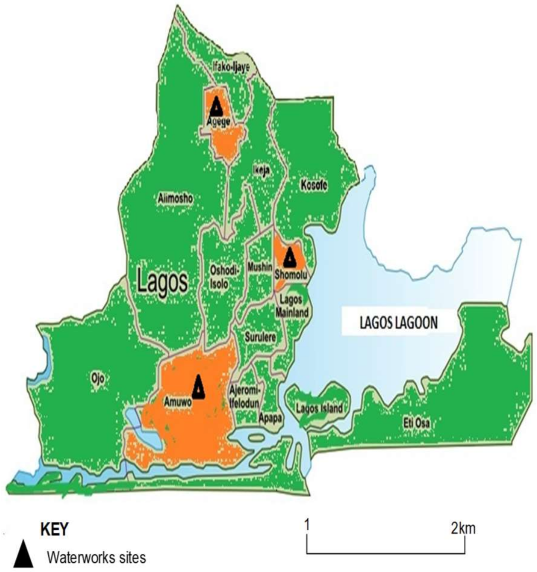

Fig. 1. Map of Lagos showing some areas where water works are sited.

Table 1: Global water distribution [2]

Water source	Water volume x 10^3 (km^3)	Freshwater (%)	Total water (%)
Ocean, seas, & Bays	1,338,000	-	96.5
Ice caps, glaciers, snow	24,064	68.7	1.74
Groundwater	23,400	-	1.69
Fresh	10,621	30.36	0.77
Saline	12,955.4	-	0.99
Soil moisture	16.5	-	0.001
Ground ice and permafrost	300	0.86	0.022
Lakes	176.4	-	0.013
Atmosphere	12.9	0.04	0.001
Swamp water	11.47	0.03	0.0008
Rivers	2.12	0.006	0.0002
Biological water	1.12	0.003	0.0001

2. MATERIALS AND METHODS

2.1 Sample collection and preparation

Ten water samples were collected from each of the five waterworks that treat and supply drinking water for the study area. The waterworks are situated in Agege, Shomolu, Iju, Saka and Amuwo. Water samples were randomly collected at ten different points from the reserviour in each water works. Each water sample was collected into plastic bottle, rinsed with 0.1M of diluted hydrochloric acid (HCl) to avoid absorption of radionuclides into the walls of the bottle. 200ml each of the water samples was filled into Marinelli plastic container after being rinsed with diluted Sulphuric acid (H_2SO_4) and dried to avoid contamination of the water [9]. The plastic containers were there after firmly sealed for four weeks to ensure a state of secular equilibrium between ^{226}Ra and ^{228}Ra and their respective gaseous progenies prior to gamma spectroscopy.

2.2 Radioactivity measurments

The samples were analysed using single crystal 51mm x 51mm NaI (Tl) detector, manufactured by Scintitech Instrument, USA, coupled through Hamamatsa (R1306NSV3068) photomultiplier tube to a Multichannel Analyser, MCA (2100R:01) manufactured by Price gamma Technology, USA. It does not require any internal PC interface slot or special memory reservations. The MCA 2100R includes Quantum MCA software for qualitative analysis. The MCA 2100R performs an automatic adjustment of the detector bias and amplifier gain. Each

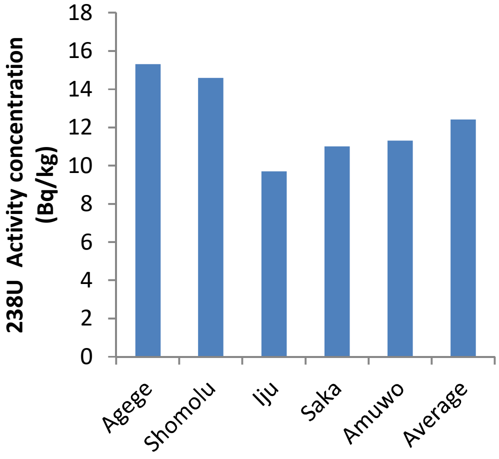

Fig. 2. Bar chart of average activity concentrations of ^{238}Uin water samples from Lagos

sample was placed on top of the detector housed well shielded and counted for a period of 36000 seconds for activity concentration. Equation (1) shows the usual relationship between activity concentration and the count rate under the photo peak from a given NaI (Tl) detector [10].

$$C = \frac{C_n}{\varepsilon_p I_\gamma V} \tag{1}$$

where C is the activity concentration of the radionuclide in the sample (Bql^{-1}); C_n is the count rate under the photo peak, ε_p is the detector efficiency at the specific γ-ray energy, I_γ is the absolute transition probability of the specific gamma ray and V is the volume of the water sample.

3. RESULTS AND DISCUSSION

3.1 Specific Activity concentrations

The activity concentration of ^{238}U in pipe born water samples collected from five waterworks in Lagos were presented in Table 2 and the bars chart of average activity concentrations of ^{238}U in water samples are shown in Figure 2. The least ^{238}U activity concentration value of 6.4 Bql^{-1} was recorded in Iju and Saka and the highest value was obtained in Shomolu. The average ^{238}U activity concentration of the five water works was 12.4 Bgl^{-1}.

3.2 Specific Activity concentrations

USEPA [11] and Amakom and Jibiri [12] related elemental concentration to activity concentration of radionuclides as:

$$M = 0.67 \times 27 \times A \tag{2}$$

where M is the elemental concentration (µgl^{-1}) and A is the activity concentration (Bql^{-1}).

Using Equation 2, the elemental concentrations in pipe born water samples collected from five waterworks in Lagos were calculated and presented in Table 2. As shown in the table, the elemental concentrations in the water from the study area ranged from 114.3 µgl^{-1} (Iju and Saka) to 472.5 µgl^{-1} (Shomolu). The average uranium elemental concentration of 222.7±71.4 µgl^{-1}in the drinking water in the study area was higher than 127.20 µgl^{-1}and 179.63 µgl^{-1}reported for respective well water and bore hole in Odeda Ogun State.

Table 1: Activity concentration, effective dose, mortality and morbidity risks in water samples from the study area.

Water works		Activity concentration (Bql^{-1})	Effective dose (mSvy^{-1})	Mortality risk (x 10^{-3})	Morbidity risk (x 10^{-3})
Agege	Range	9.0 – 21.3	0.3 – 0.7	0.3 – 0.8	0.5 – 1.2
	Mean $\pm\delta$	15.3 ± 4.1	0.5 ± 0.1	0.6 ± 0.2	0.9 ± 0.2
Shomolu	Range	9.4 – 26.3	0.3 – 0.9	0.4 – 1.0	0.5 – 1.5
	Mean $\pm\delta$	14.6 ± 5.2	0.5 ± 0.2	0.6 ± 0.2	0.8 ± 0.3
Iju	Range	6.4 – 12.0	0.2 – 0.4	0.2 – 0.5	0.4 – 0.7
	Mean $\pm\delta$	9.7 ± 2.0	0.3 ± 0.1	0.4 ± 0.1	0.6 ± 0.1
Saka	Range	6.4 – 17.0	0.2 – 0.6	0.3 – 0.6	0.4 – 1.0
	Mean $\pm\delta$	11.0 ± 2.9	0.4 ± 0.1	0.4 ± 0.1	0.6 ± 0.2
Amuwo	Range	8.8 – 14.7	0.3 – 0.5	0.3 – 0.6	0.5 – 0.8
	Mean $\pm\delta$	11.3 ± 1.8	0.4 ± 0.1	0.4 ± 0.1	0.7 ± 0.1
Average $\pm\delta$		12.4 ± 4.0	0.4 ± 0.1	0.5 ± 0.1	0.7 ± 0.2

Table 1: Activity concentration, effective dose, mortality and morbidity risks in water samples from the study area.

Water works		Effective dose (mSvy^{-1})	Mortality risk (x 10^{-3})	Morbidity risk (x 10^{-3})
Agege	Range	161.5 – 382.5	4.4 – 10.5	7.4 – 17.5
	Mean ± δ	274.9 ± 73.3	7.5 ± 2.0	12.6 ± 3.3
Shomolu	Range	168.3 – 472.5	4.6 – 12.9	7.7 – 21.6
	Mean ± δ	262.9 ± 94.1	7.2 ± 2.6	12.0 ± 4.3
Iju	Range	114.3 – 216.5	3.1 – 5.9	5.2 – 9.9
	Mean ± δ	174.2 ± 35.7	4.8 ± 1.0	8.0 ± 1.6
Saka	Range	114.3 – 306.5	3.1 – 8.4	5.2 – 14.0
	Mean ± δ	197.6 ± 51.5	5.4 ± 1.4	9.0 ± 2.4
Amuwo	Range	158.4 – 264.6	4.3 – 7.2	7.2 – 12.1
	Mean ± δ	203 ± 32.5	5.6 ± 0.9	9.3 ± 1.5
Average ± δ		222.7 ± 71.4	6.1 ± 2.0	10.2 ± 3.3

The World Health Organisation [13] recommended uranium elemental concentration value of 15.0µgl^{-1}; United States Environmental Protection Agency [11] recommended 30µgl^{-1} and Health Canada [14] recommended 20 µgl^{-1}for drinking water. These recommended values are lower than the average value obtained in the study.

3.3 Radiological impact assessments

Effective dose rates

The effective dose rate is obtained when the activity concentration (Bql^{-1}) of the radionuclide in the water is multiplied by water consumption rates and dose conversion factor (Sv Bq^{-1}) for the radionuclide. According to NHMRC and NRMMC [15], the effective dose due to intake of individual radionuclide in water is given by:

$$D_E = D_L \times W_C \times U \quad (3)$$

where D_L and W_C denote dose limit intake of water and annual water consumption rate and U is the activity concentration of ^{238}U. The value of dose limits intake for^{238}U is 4.5 x 10^{-5}mSv Bq^{-1} for adult members of the public (adult) [16, 17]. In the study, the dose calculation assumed that the annual water consumption rate for an adult is 730litres [18]. The effective dose equivalent due to consumption of pipe borne water from the study area is presented in Table 2. The annual effective dose ranges from equivalent were 0.5±0.1mSv, 0.5±0.2mSv, 0.3±0.1mSv, 0.4±0.1mSv and 0.4±0.1mSv for Agege, Shomolu, Iju, Saka and Amuwo respectively and the mean effective dose equivalent for water from the five waterworks was 0.4±0.1mSvy^{-1}.This value was observed to be four to five times higher than the world average value of 0.1 mSv [19 – 21].

Excess life time cancer risks

Cancer is a dreadful and common disease that can result from excessive exposure of human to ionizing radiation. However, a life time cancer risk (ELCR) is defined in this work as probable estimate of the risk to member of a population incurring cancer because of ingestion of radionuclides [22]. The life time cancer risks associated with intake of radionuclides in the water was determined using the cancer risk coefficients for ingestion of radioactive elements and per-capital ingestion of the radionuclides [22, 23]:

$$R = f \times A \times C \times T \quad (4)$$

where f is the cancer risk coefficient of the radionuclide, A is the activity concentration of ^{238}U radionuclide, C is the water consumption rate and T is the average life expectancy. The average life expectancy at birth in Nigeria is 45.5 years [18] and the annual recommended adult water consumption rate is 730litres [20]. The cancer mortality risk coefficient, *f* is 1.13x10^{-9} Bq^{-1}for ^{238}U and the cancer morbidity risk coefficient, *f* is 1.73x10^{-9} Bq^{-1} for ^{238}U [22, 23]. Using Equation (4), the cancer risks were evaluated and the results were presented in Table 2. The value for mortality risk ranges from 0.3x10^{-3} at Iju while the highest value of 1.0x10^{-3} was obtained at Shomolu and the average mortality risk value of all the water works was 0.5±0.1x10^{-3}.

Iju exhibited the least mean morbidity risk value of (0.6±0.1) x 10^{-3} each while Shomolu exhibited the highest mean morbidity risk value of (0.9±0.2) x10^{-3} and the average morbidity of all the water works was (0.7±0.2) x10^{-3}. The respective cancer mortality and morbidity risks in the study indicated that 5 and 7 out of every 10,000 people are liable to incur cancer in the study area. Both the mortality and morbidity risks in the study are higher than the reported values for well and borehole waters from Odeda in Ogun State [12]. The excess life time cancer risk (ELCR) of 1.80×10^{-7}reported by Ye-Shin et al., [24] was about 2000 and 3000 times lower than the mortality and morbidity risks respectively in the study. However, the world average value of 1.0×10^{-3} as reported by Ye-shin et al., [24] for either mortality or morbidity is higher than the values obtained in the study.

3.4 Chemical Impact assessment

Life time average daily dose

The life time average daily dose (LADD) of uranium element through the intake of water from the study area was determined using [24]

$$LADD = \frac{EPC \times IR \times EF \times ED}{AT \times BW} \qquad (5)$$

where LADD is the lifetime average daily dose (μg.kg^{-1}day^{-1}); EPC is the exposure point concentration (μgl^{-1}); IR is the ingestion water rate (lday^{-1}); EF is the exposure frequency(days.yr^{-1}); ED is the total exposure time (yr); AT is the average time (days) and BW is the body weight (kg). Ye-shin et al., [24] considered IR as 2 liters per day, EF as 350 days, ED as 45.5 y, AT = 45.5 × 365 (16,607.5) and BW = 70 kg (for an adult) and these values were used to determine the life time average daily dose in the present study.

Using Equation (5), the life average daily dose (LADD) was determined and the results are presented in Table 3. It is observed from the table that Iju has the least mean LADD value of 4.8±1.0 μgkg^{-1}day^{-1}and Agege has the highest mean value of 7.5±2.0 μgkg^{-1}day^{-1}. The average LADD value over the entire water works was 6.1±2.0 μg.kg^{-1}day^{-1}and this was about ten times higher than the recommended reference dose (RD) of 0.6 μgkg^{-1}day^{-1} as reported by Gilman et al., [25].

Hazard quotient

Gilman et al., [25] reported 0.6 μg.kg^{-1}day^{-1}as the lifetime average daily dose of uranium due to intake of portable water. This is regarded as a reference dose (RD) or standard criteria set by different organizations for intake of uranium in water and thereby determined the hazard quotient using [19].

$$HQ = \frac{LADD}{RD} \qquad (6)$$

where HQ is hazard quotient, LADD is the lifetime average daily dose and RD is the reference dose. The least hazard quotient of 5.2 was obtained from Iju and Saka while the highest value of 17.5 was obtained in Shomolu. The average hazard quotient of 10.2±3.3 over the entire five water woks was over 10^3orders of magnitude higher than 0.005 reported for ground water in Korea [24].

5. Conclusion and recommendation

The radiological and chemical assessments of uranium in pipe born water from water works in Lagos have been carried out. The activity concentrations of ^{238}U were correlated to the elemental concentrations of uranium in the water samples.

The study showed that radioactivity levels in the water differ from one location to the other and this is attributed to the heterogeneity of radionuclides deposited influenced by the type of vegetation and precipitation by organic metabolism [8]. The uranium elemental concentrations obtained in the study were higher than the respective 30.0 μgl^{-1}, 15.0 μgl^{-1} and 20.0 μgl^{-1} for USEPA, WHO and Health Canada recommended limits. The annual effective dose and life time average daily dose obtained in the study were also higher than WHO recommended values of 0.1mSvy^{-1} and 0.6 μgkg^{-1}day^{-1}respectively. The radiological excess life time cancer risk (ELCR) obtained in the study was low when compared to the world average value of 1.0×10^{-3}.

The elevated radioactivity and chemical levels in the water samples from the study area is attributed to channeling of effluents and radioactive wastes into rivers that the water works would collect, chlorinate and supply for public consumption. Therefore caution and control should be taken with a view to avoid any radiological and chemical health challenges in the future.

However when raw water contains high concentrations of radionuclides, the water treatment plant should combine coagulation, sedimentation and sand filtration processes to remove substantial part of the suspended radionuclides present in the waters. Also lime-soda ash softening plants can be employed to remove practically all the suspended radionuclides in the raw water.

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