

Determination of Annual Effective Dose Equivalent, Annual Gonadal Dose Equivalent and Excess Lifetime Cancer Risk from Sachet Water around Kaduna

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Abstract

A survey of the gross alpha and beta radionuclide activity of source of water from ground water Kaduna state has been carried out. Ten water samples were collected from the residential in the community and were analyzed using the protean instrument corporation (PIC) MPC 2000DP, single channel proportional counters. The count results show that the mean alpha activities in the residential shows the value of gross alpha concentration (Bq/L) obtained from lowest to highest for VEHEZSA is 0.0003 ± 0.0001 to TODAY 0.0155 ± 0.059 . While the value of gross beta concentration (Bq/L) for from lowest to highest were obtained to be in the region of 0.0148 ± 0.0033 to SAFA "A 2.2233 ± 0.44848 Three radiological parameters, which are AEDE, AGDE and ELCR were all determined. Where the excess lifetime cancer risk is the probability of developing cancer over a lifetime at a given exposure level. We are assuming 70years as the average duration of life for human, the summation of the results gotten are; $AEDE_{(\alpha \text{ and } \beta)} 8.3804/0.1738\text{mSv/y}$, $AGDE_{(\alpha \text{ and } \beta)} 0.0368/23.8242\text{mSv/y}$ and $ELCR_{(\alpha \text{ and } \beta)} 0.0132 / 0.0167$ respectively. The overall results show that the alpha and beta activities in the SACHET WATER are far below the practical screening levels of radioactivity in drinking water of 100 Bq L^{-1} for alpha and 100 Bq L^{-1} for beta recommended by ICRP and WHO and therefore may not pose any serious detrimental health side-effects to the public users of water in that environment.

Keywords: proportional counters, gross α , and β , $AEDE_{(\alpha \text{ and } \beta)}$, $AGDE_{(\alpha \text{ and } \beta)}$, $ELCR_{(\alpha \text{ and } \beta)}$

Introduction

Atoms are the smallest particles of mass with distinctive chemical properties. An atom consists of a nucleus surrounded by electrons. The nucleus consists of positively charged proton and uncharged neutrons. The diameter of an atom is of the order 10^{-10} meter(m) and the diameter of a nucleus is of the order 10^{-15} metre(m).In addition, protons and neutrons have a mass of $1.67 \times 10^{-27}\text{kg}$, while the mass of the negative charged electrons is 9.11×10^{-31} kg, the elementary charge is 1.602×10^{-19} coulombs(c).(IAEA,2003).

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The presence of radionuclide in water poses a number of health hazards, especially when these radionuclides are deposited in the human body through drinking. Dissolved radionuclides in water emit particles (alpha and beta) and photons (gamma) which gradually serve as exposure pathway to living tissues. Human and animal studies show that radiation exposure at low to moderate doses may increase the long time incidence of cancer. The World Health Organization guidelines for drinking water quality recommended the determination of gross alpha and gross beta activity concentrations in drinking water as the first step of the radiological aspect of the drinking water quality (World Health Organization, 2004). Generally, radiation exposure due to gross alpha is of greater concern than that due to gross beta for natural radioactivity (Gazineu et al., 2005). Irradiation of the human body from external sources is mainly by gamma radiation from radionuclides of the ^{235}U , ^{238}U and ^{232}Th decay series and from ^{40}K . These radionuclides may be present in the body and irradiate various organs with alpha and beta particles as well as gamma rays (IAEA; 2005)

The International Basic Safety Standards (BSS) for protection against ionizing radiation and the safety of radiation sources (IAEA, 1996) specify the basic requirements for the protection of health and the environment from ionizing radiation. These are based on the latest recommendations of the International Commission on Radiological Protection [ICRP, 2007] on the regulation of Practices and Interventions. The BSS is applied to both natural and artificial sources of radiation in the environment and the consequences on living and non-living species. The mining activities is capable of enhancing the NORMS. A single channel proportional counters was used to determine the activity concentration of gross alpha and beta, Annual effective dose equivalent (AEDE), the annual gonadal dose equivalent (AGDE) and the excess lifetime cancers risk (ELCR) were also determined.

Materials and Methods

The following laboratory apparatus were used for this analysis of gross alpha, gross beta: Laboratory beakers, petri-dishes, Hot plate, infra-radiator lamp, Experimental (Digital) weighing balance, planchets, cotton wool GPS map, 2litres of container keg (10pieces), fume cup board. Acetone, vinyl acetate and Nitric acid.

Sampling Method

Random sampling method was used for this study. Ten (10) water samples were collected from underground water sources (1) Zanfara Road Housing Estate Barnawa(2) Mallam Madori (3) Bye Pass Housing Estate Bungalow(4)Crescent road Housing Estate(5) Lemu Road(6) Cass Bye Pass(7) Panteka Housing Estate(8) Bypass Housing Estate Block Offflats(9) CesBarnawa (10)Enugu Road.

All samples were collected in Kaduna metropolis area.

Methodology

The following procedures were carefully carried out during the collection and preparation of the samples:

Samples of water were collected directly into 2 liter plastic kegs (polyethylene containers) after washing the containers properly and rinsed with the water sample to be collected. About 10ml of concentrated hydrochloric acid (HNO_3) was added at the point of collection. The addition of concentrated HNO_3 help preserve the radionuclides present in the water samples and it also prevent the absorption of the water with the inner wall of the containers among others. The addition of HNO_3 assists in reducing the pH of the water samples below 2 (ICRP,2017). Surface water from borehole and pond within the area were collected and

treated with the reagent. Care was taken to avoid fetching from the stagnant areas. Lake water samples (if there is any) should not be taken near the shoreline (W.H.O., 2012). Normally for bore-holes; electric pumps are used to pump water to the reservoir which is connected to different pipes and taps within the community. The tap boreholes were first turned on at full capacity for three (3) minutes to purge the plumbing system of any water which might have been there for some time. The flow rate was reduced to attain steady turbulence and radon loss while collecting the water into the kegs.

The water samples were transferred to CERT, ABU Zaria in clean condition where they were prepared and analyzed for gross alpha (α) and gross beta (β) activities. Ten (10) water samples were collected from underground water sources. These samples were kept in a plastic container and covered properly. The samples were analyzed at the Centre for Energy Research and Training (CERT), ABU Zaria, Kaduna state as stated above.

10ml of concentrated nitric acid were added to the water sample immediately after collection so as to: Reduce the pH, minimize precipitation and Prevent the absorption on the wall of the container.

Procedure

The beakers, crucibles (petri-dishes), planchets and spatula were washed properly, rinsed with clean water and sterilized using acetone. Then the apparatus were kept and dried inside the oven. A little quantity of the water sample was used to rinse the beaker twice so as to ensure that there is no cross contamination before evaporation. About 500ml of the water sample was measured into the beaker and set on the hot plate with steady temperature below boiling point to allow gradual evaporation and to avoid excessive loss of the residue. This process continues until when the volume of the water sample reduced to a very little quantity (about 50ml), then it will be transferred into the petri-dish and evaporated to dryness under infra-radiator lamp. This process is known as surface drying. Having taking the initial weight (i.e empty dish), the weight of the residue together with petri-dish was measured using digital analytical weighing balance. The weight of the total residue obtained from the total volume evaporated was then calculated by using the relation below.

$$W_r = W_{(d+s)} - W_d \quad (2.1)$$

Where: $W_{(d+s)}$ is the weight of the dish with sample's residue,

W_d is the weight of empty dish

W_r is the weight of the total residue.

0.0770g of the residue is transferred in the sterilized planchet and the exact volume that produced this required weight (0.0770g) is calculated by the use of the expression that follows.

$$0.0770g \times V_{tr} = W_{tr} \times V. \quad (2.2)$$

Where: V_{tr} is the volume that generated total residue,

W_{tr} is the weight of the total residue obtained

V is the volume that yielded the required residue.

For samples with residue obtained greater than or equal to 0.0770g, the sample efficiency is said to be 100%. But for the samples with residue less than 0.0770g, its sample efficiency can be obtained using the expression below;

$$\text{Sample eff.} = \frac{\text{weight of residue}}{0.0770g} \times 100\%. \quad (2.3)$$

Sample Analysis

The international standards organization procedure (ISO 9696 and ISO 9697: 2014E) for the measurement of gross alpha (α) and gross beta (β) activities in water was employed in this

analysis. This method provided a screening technique to measure the gross alpha (α) and gross beta (β) radioactivity in water samples. To analyze drinking-water for gross alpha (α) and gross beta (β) activities (excluding radon), the most common approach is to evaporate a known volume of the sample to dryness and measure the activity of the residue. As alpha (α) radiation is easily absorbed within a thin layer of solid material, the reliability and sensitivity of the method for alpha (α) determination may be reduced in samples with high total dissolved solids (TDS) content.

Samples analysis was done using a proportional counter system; a portable non filled gas MPC2000B-DP single channel gross alpha and gross beta radiation detector. The equipment was mainly designed purposely for gross alpha (α) and gross beta (β) counting. Each sample was placed on the detector and counted for 2700 seconds (45 minutes).

Results

The Three Radiological Parameters

There are 3 radiological risk parameters. These include the annual effective dose equivalent (AEDE), the annual gonadal dose equivalent (AGDE) and the excess lifetime cancers risk (ELCR).

The Annual Effective Dose Equivalent Is Given By the Relative

$$AEDE = A (\alpha, \beta) \times Wc \times F.D \text{ ----- } 1$$

Where A (α, β) = activity concentrations of gross alpha and gross beta in Bq/L

WC= water consumed by a person in a year (For an adult it is approximately 2litre a day, which is approximately to 730L in a year)

F.D (α, β) = activity to dose conversion factor for gross alpha and gross beta radiations

It is assumed that the major contribution to AEDE due to ingestion of water from gross alpha radiation is radium - 226 and the major contribution to gross beta are pb - 210 and radium - 228. Activity dose conversion factor F.D for radium 226 is $2.8 \times 10^{-4} \text{ mSvy}^{-1}$ for gross alpha radiation. For radium 228 and pb - 210, dose conversion factor F.D = $6.7 \times 10^{-4} \text{ mSvy}^{-1}$ for beta radiation.

The AEDE for gross alpha and gross beta radiation of sample ID files with alpha activities 0.0041Bq/L and beta activities 0.3554 Bq/L is given using equation 1 and are calculated as follows

AEDE α for Satchet samples

$$AEDE\alpha = A (\alpha) \times WC \times F.D$$

$$0.0041\text{Bq/L} \times 730 \times 2.8 \times 10^{-4} \text{ mSvy}^{-1} \text{ (assuming WC = 730L per year)}$$

$$= 8.3804 \times 10^{-4} \text{ mSv/y}^{-1}$$

AEDE β (Beta) for Pond samples

$$AEDE\beta = A (\beta) \times WC \times F.D$$

$$0.3554 \times 730 \times 6.7 \times 10^{-4} \text{ mSv/y}$$

$$= 0.1738 \text{ mSvy}^{-1}$$

Table 1 shows the tabulated result of AEDE for gross alpha & gross beta radiation of all samples

S/N	Sample ID	Alpha Concentration (Bq/L)	AEDE α (mSvy ⁻¹)	Beta Concentration (Bq/L)	AEDE β (mSvy ⁻¹)
1.	FISL	0.0041±0.0037	8.3804 x 10 ⁻⁴	0.3554±0.1503	0.1736
2.	TODAY	0.0155±0.0059	1.20596 x 10 ⁻³	1.0208±0.2029	0.4993
3.	KADPOLY	BDL	0	15929±0.3443	0.7791381106
4.	FORMULA	BDL	0	0.9887±0.2116	0.4836
5.	ADAMS	0.0055±0.0023	1.1242 x 10 ⁻³	1.5347±0.1761	0.7506
6.	AMFAT	BDL	0	1.4917±0.2402	0.7296
7.	DEEZ	0.0013±0.002	2.657 x 10 ⁻⁴	0.0305±0.0048	0.0149
8.	SAFA-A	0.0013±0.0000	2.044 x 10 ⁻⁴	2.2233±0.4484	1.0874
9.	VEHESZA	0.0003±0.0001	6.132 x 10 ⁻⁵	0.0148±0.0033	7.2387X10-3
10.	AURORA	0.0054±0.0003	1.10376 x 10 ⁻³	04897±0.1093	0.2395

Table 1: Calculated AEDE α and AEDE β (mSvy⁻¹) for both gross alpha and gross beta activity radiation

Annual Gonadal Dose Equivalent (AGDE)

Annual gonadal dose equivalent measures the dose of gross alpha and gross beta received by the gonadal surface cells as a result of exposure to radiation. The computation of AGDE for gross α or gross β is given by the formula:

$$AGDE = \frac{AEDE}{R.W.F \times T.W.F} \text{ ----- 2}$$

Where R.W.F = Radiation weighing factor

T.W.F = Tissue weighing factor

R.W.F = 2 for α - activity

1 for β - activity

T.W.F = 0.20 (for both α and β activity)

The sum of AGDE for gross alpha and gross beta radiation is given as AGDE_T (α , β)

$$= \sum_i(\alpha, \beta) \frac{AEDE}{R.W.F \times T.W.F} \text{ ----- 3}$$

$$\text{Therefore; } AGDE_{T\alpha} = \sum_{i(\alpha, \beta)} \frac{8.3804 \times 10^{-4}}{2 \times 0.20}$$

$$2.0951 \times 10^{-3} \text{ Sv} \cdot \text{y}^{-1}$$

$$AGDE_{\beta} = \frac{0.1736}{1 \times 0.2}$$

$$= 0.868 \text{ Sv} \cdot \text{y}^{-1}$$

AGDE for all the samples are tabulated in table 4.3 below

Table 2 The AGDE for all samples

S/N	Sample ID	AEDE α (mSvy $^{-1}$)	AEDE β (mSvy $^{-1}$)	AGDE α (mSvy $^{-1}$)	AGDE β (mSvy $^{-1}$)
1.	FISL	8.3804×10^{-4}	0.1736	2.0951×10^{-4}	0.8680
2.	TODAY	1.20596×10^{-3}	0.4993	3.015×10^{-3}	2.4965
3.	KADPOLY	0	0.7791	0	3.8955
4.	FORMULA	0	0.4836	0	2.418
5.	ADAMS	1.1242×10^{-3}	0.7506	2.81×10^{-3}	3.753
6.	AMFAT	0	0.7296	0	3.648
7.	DEEZ	2.657×10^{-4}	0.0149	6.643×10^{-4}	0.0745
8.	SAFA·A	2.044×10^{-4}	1.0874	5.11×10^{-4}	5.437
9.	VEHESZA	6.132×10^{-5}	7.2387X10-3	1.533×10^{-4}	00362
10.	AURORA	1.10376×10^{-3}	0.2395	2.7595×10^{-2}	1.1975
Total				0.0368	23.8242mSvy$^{-1}$

Table 2: The sum of AGDE for gross alpha for all samples is 0.0368mSvy $^{-1}$ and for gross beta is 23.8242mSvy $^{-1}$ respectively.

Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk is the probability of developing cancer over a lifetime at a given exposure level. We are assuming 70years as the average duration of life for humans. The excess lifetime cancer risk is calculated for gross alpha or gross beta, using the formula;

$$ELCR_{(\alpha, \beta)} = AEDE \times DL \times RF \text{ ----- 4}$$

$$ELCR_T (\alpha, \beta) = \sum_{i(\alpha, \beta)} AEDE \times DL \times RF \text{ ----- 5}$$

Where;DL = Average duration of life (estimated at 70years)

RF = Risk factor (Sv $^{-1}$) which is fatal risk per sivert

For stochastic effect ICRP used RF = 0.5/sv equivalent to 5×10^{-5} /mSv for the public

The ELCR α for the first sample ID FISL is computed using (7) as follows

ELCR α for Pond samples

$$ELCR(\alpha) = AEDE_{\alpha} \times DL \times RF$$

$$= 8.3804 \times 10^{-4} \times 70 \times 5 \times 10^{-5}$$

$$= 2.933 \times 10^{-6} \text{ mSv}$$

Table 3: Showing result of Excess Lifetime Cancer Risk (ELCR)

S/N	Sample ID	AEDE α (mSvy $^{-1}$)	AEDE β (mSvy $^{-1}$)	ELCR α	ELCR β
1.	FISL	8.3804×10^{-4}	0.1736	2.933×10^{-6}	6.076×10^{-4}
2.	TODAY	1.20596×10^{-3}	0.4993	4.221×10^{-6}	1.7476×10^{-3}
3.	KADPOLY	0	0.7791	0	2.7269×10^{-3}
4.	FORMULA	0	0.4836	0	1.6926×10^{-3}
5.	ADAMS	1.1242×10^{-3}	0.7506	3.9347×10^{-3}	2.6271×10^{-3}
6.	AMFAT	0	0.7296	0	2.5536×10^{-3}
7.	DEEZ	2.657×10^{-4}	0.0149	9.3002×10^{-5}	5.215×10^{-5}
8.	SAFA·A	2.044×10^{-4}	1.0874	7.154×10^{-3}	3.8059×10^{-3}
9.	VEHESZA	6.132×10^{-5}	7.2387X10-3	2.1462×10^{-7}	2.5335×10^{-5}
10.	AURORA	1.10376×10^{-3}	0.2395	3.8633×10^{-6}	8.3825×10^{-4}

Total	0.280742	1.77×10^{-3}
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The total excess lifetime cancer risk for gross α is 0.0132 and for gross β is 0.0167

Discussion

The instrument used for this research work is a non gaseous ionization detector device use to measure particles of ionizing radiation. The key feature is it ability to measure the energy of incident radiation, by producing a detector output pulse that is proportional to the radiation energy absorbed by the detector due to an ionizing event, hence the detectors name. it is widely used where energy levels of incident radiation must be known , such as in the discrimination between alpha and beta particles or accurate measurement of X - ray radiation dose. The MPC 2000 is protein instrument corporations latest addition to an extensive hire of gross alpha/beta counting system. The MCP 2000 has modern control and interface options, a significantly reduced footprint and a non - gas flow detector option. Annual Efficiency Dose Equivalent of alpha to be 4.8034×10^{-3} , and beta to be 4.7648 mSv/y, an Annual Gonadal Dose Equivalent of alpha to be 0.0368, and beta to be 23.8242mSv/y and Excess Lifetime Cancer Risk of alpha to be 0.0132, and beta to be 0.0167 respectively.

These are good values for this type of counter. A low background activity was also observant with a 0.33cpm for alpha and 0.22cpm for beta. This is quite representative of the environment. Similarly, the results obtained from all the counting modes are reproducible and are hence reliable. The gross alpha and beta activity concentrations in the water samples were found to be in the range 0.0003 ± 0.0001 Bq/L to 0.155 ± 0.0059 with a control of 0.06476 ± 0.01159 for alpha concentration and 1.10376 ± 8.3804 to 0.05781 ± 0.01542 with a control of 0.28508 ± 0.02058 Bq/L for beta concentration respectively. This shows that the concentrated values of beta are much higher than their corresponding values of alpha and ICRP accepted values of 0.5Bq/L for alpha and 1Bq/L for beta shows elevated values.

Conclusion

The determination of gross alpha and gross beta radionuclide activities from water sample in sachet water from Kaduna metropolis has been studied. The gross alpha and beta activity concentration (Bq/L⁻¹), the Annual Effective Dose Equivalent (AEDE), Annual Gonadal Dose Equivalent (ADGE) and Excess Lifetime Cancer Risk (ELCR) in the water samples from sachet water differ in quantity from sample to sample. This is explained by the heterogeneity of radionuclide deposits, water transportation, precipitation by organic metabolism and effluent discharge. The overall low value gross alpha and gross beta of radionuclide activities observed may be due to the present mining activities in the community and the low level of soil formation that constitute the geology of the area.

The measured gross alpha and gross beta concentration (Bq/L⁻¹), AEDEs, AGDEs and ELCRs activities are higher than those reported in other parts of the country. The mean and average values of gross alpha and gross beta concentrations (Bq/L⁻¹) were also determined. The sum of AEDE, AGDE and ELCR of both gross alpha and gross beta of all samples were calculated. However, the values obtained are far below the WHO and ICRP recommended maximum permissible limit and may not pose any serious health side-effects to the public users as their source of drinking water.

The results of the values obtained are far below the 100 Bq L⁻¹ for gross alpha and 100 Bq L⁻¹ for gross beta WHO and ICRP recommended practical screening levels of radioactivity in drinking water.

Since, the results obtained are below the international standard recommended permissible limits for drinking waters, a regular programme of environmental audit and monitoring is hereby recommended to checkmate the activities and there is also the need to carry out other certain parameters such as sodium iodide thallium (NaI(Tl)), neutron activation analysis (NAA) and plants elemental analysis using the community soil samples.

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