ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

MEASUREMENT OF GROSS ALPHA (α) AND BETA (β) RADIOACTIVITY IN BORE HOLES AND WELL WATER IN JOS CITY CENTER

Pahalson C. A. D[1], Habila N[1], Joshua G. D[1]

[1] Dept of Science, School of Science and Technology, Plateau State Polytechnic Barkin Ladi, Nigeria

Abstract: **A study of the - radioactivity in drinking water from boreholes and well water from Jos city center Plateau State, Nigeria were selected using a stratified random sampling has been carried out. Forty (40) water samples were analyzed by MPC 2000 DP (Monitor Proportional Counter) detector. The result shows that the range of alpha activity range from 0.740 ± 0.03Bq/l – 0.051 ± 0.04 Bq/l, with a geometric mean of 0.27245 ± 0.01855 Bq/l for Boreholes water samples and 0.90 ± 0.013Bq/l – 0.0212 ± 0.011Bq/l with a geometric mean of 0.316005 ± 0.01935Bq/l for well water. While the range of beta activity varied between 5.0352 ± 0.02 Bq/l – 0.081 ± 0.02 Bq/l, with a geometric mean of 1.28614 ± 0.0186 Bq/l and 2.09 ± 0.03Bq/l – 0.036 ± 0.01 Bq/l, with a geometric mean of 0.52165 ± 0.0184Bq/l for Boreholes water and well water samples respectively. The study results reveal that; the groundwater in the study area, most of the data points, and all average measurement outcomes turned out to be inside the allowed values given by organizations like WHO, USEPA, and UNSCEAR even though some of the individual parameters showed slightly over the world average desired values. The annual effective doses of alpha radionuclide ranged from 0.002mSv to 0.151mSv with a mean value of 0.055 mSv and beta radionuclide ranges from 0.017mSv to 0.620 mSv with a mean value of 0.260 mSv for boreholes water. The annual effective doses of alpha radionuclide ranged from 0.004mSv to 0.164mSv with a mean value 0.067mSv and beta radionuclide ranges from 0.010 mSv to 0.427 mSv with a mean value of 0.107 for the well water. Thus, the values obtained when compared with their corresponding world permissible values were found to be below the standard limits. The results from models that have been detected and put in the evaluation refer that the water of Jos city center is safe to drink.**

Keywords: **Determination, Gross Alpha, Gross Beta, Radioactivity, Geometric mean, Borehole water, Well water.**

I. INTRODUCTION

Clean and plentiful water provides the foundation for prosperous communities in an environment [1]. Water is one of the most important natural resources and demand for it is on the increase. Skillful management of water bodies is therefore required if they are to be used for diverse purposes. Even though much of the water supplies for domestic, crop irrigation, transport recreation, sport, commercial fisheries, industrial supply, and power generation, etc., [2] come from surface streams, borehole's, lakes, and wells, a large part of the world still depends on groundwater on wells and springs [3]. We rely on clean water to survive, yet right now we are heading towards a water crisis. Dirty water is the world's biggest health risk and continues to threaten both quality of life and public health in developing countries like Nigeria. The United Nations considers fundamental human rights and an essential step toward improving living standards throughout the world. Water-poor communities are typically poor economies, and their residents are trapped in a cycle of poverty. Exposure to ionizing radiation can lead to several cancers and can cause death in extremely high doses of radiation can [4].

ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

In Nigeria and other countries, most rural and many suburban areas depend on hand-dug wells for their water supply. The presence of radionuclides such as alpha and beta particles in drinking water presents several health hazards, especially when these radionuclides are deposited in the human body, through drinking water. However, human activities such as mining, milling, manufacture of fertilizers, drilling, transportation, processing and burning of fossil fuels, etc., have raised naturally occurring radioactive material concentrations in the environment and contaminated surface and sub-surface groundwater when found in high concentrations [5]. Comprising about 70% of the earth's surface, water is undoubtedly the most precious natural resource that exists on our planet earth. Without the seemingly invaluable compound comprising of hydrogen and oxygen, life on earth will be non-existent: it is essential for everything on earth to grow and prosper. 95% of all fresh water on earth is groundwater [6]. Groundwater is found in natural rock formations. These formations, called aquifers, are a vital natural source with many uses. Generally, sources of water supply in Nigeria are from upland surface water or groundwater from boreholes and hand-dug wells. The earth's crust contains naturally occurring radioactive materials (terrestrial radioactivity), which increase with depth and of most concern are the uranium series, thorium series, and their progeny (radon and thoron) [7], [8]. As a result of this, drinking water from deep wells and boreholes is likely to contain a higher concentration of radioactive elements than surface water. Groundwater pollution is much more difficult to abate than surface water pollution because groundwater can move great distances through unseen aquifers [9]. It is therefore important to determine the amount of radioactivity in drinking water for every area where people live, to guard against its health hazards.

In Nigeria, monitoring of radioactivity content of drinking water in terms of alpha, beta, and gamma at the various waterworks has not been instituted as a routine practice; due to ignorance and lack of capacity in terms of techniques, facilities, and human resources. It is however well known that radioactivity could contribute to the deleterious health effects amongst people living in Nigeria and Jos in particular. Measurement of radioactivity from mining waste on the plateau of Jos has indicated high levels of activity and the regulatory authority; Nigeria Nuclear Regulatory Agency (NNRA), recently organized a workshop on the challenges of mine waste management. This work is a major contribution to the determination of the possible health effects of radioactivity in this region and helps in efforts to eliminate them. In developed countries, radioactivity measurement is always part of their water quality determination. However, in Nigeria, this is not the case, as not much work has been done in this area. To the best of our knowledge, not much work has been done on this subject on the Jos plateau, even though, some few studies have been conducted elsewhere in the country [10] - [12]. This study aims to evaluate gross alpha and beta radioactivity of groundwater in Jos-city center Plateau State, North-Central Nigeria as a useful guide for the improvement of the health and wellbeing of the citizens.

II. LITERATURE REVIEW

Water pollution occurs when a body of water is adversely affected due to the addition of a large number of substances (materials) to the water. When it is unfit for its intended use, water is considered polluted [6]. Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support human use (like serving as drinking water) or undergoes a marked shift in its ability to support its constituent biotic communities [9]. Two types of water pollutants exist; point source and non-point source. A point source of pollution occurs when harmful substances are emitted directly into a body of water; e.g. Oil spill best illustrates the point source of water pollution. Non-point source pollution delivers pollutants indirectly through environmental changes; e.g. When fertilizer from a field is carried into a stream by rain, in the form of run-off which in turn affects aquatic life. Other forms of water pollution exist in the form of radioactive contaminants and heat. There are two sources of radioactive contaminants in drinking water. The first is the naturally occurring radionuclides that are contained in the soil and rocks that water moves through. The second source of radioactive contaminants comes from man-made sources The problems associated with water pollution can disrupt life on our planet to a great extent. This work is concerned with examining the pollution of underground water by radioactive elements present in the soil. Gross alpha particle activity is a measure of the total amount of radioactivity in a water sample attributed to the radioactive element [13]. Activity in water is expressed in units of Pico-Curies per liter, where 1pCi/l is equal to 2.2 radioactive disintegrations per minute per liter of water [13]. The biological effects resulting from exposure to ionizing radiation are classified into stochastic and deterministic (non-stochastic) effects. Most biological effects fall into the deterministic effect category [14]. Several radioactive components may be released into the environment, and hence into drinking water supplies, from human activities and man-made sources. Monitoring for radioactive materials is therefore of primary importance for humans, organisms, and for environmental protection, but

ISSN 2350-1030
International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

rapid and accurate methods for the assay of radioactivity are essential [15]. When outdoors, humans are exposed to natural terrestrial radiation that originates predominantly from the upper 30 cm of the soil [16]. Humans are also exposed to contamination of the food chain which occurs as a result of direct deposition of radionuclides on plant leaves, root uptake from contaminated soil, sediment, or water [17], and direct ingestion of contaminated water [18]. Recently, a great interest arose towards the natural radioactivity concentration in drinking water around the world due to the great danger it presents. Some work has been done on the measurement of radioactivity in water in Nigeria [19] - [28], [10], [29], [30], [18], [31] - [34]. This present study assesses the specific Gross Alpha and Beta activities and examines some of the radiation hazard indices of these naturally occurring radionuclides (226 Ra, 232nd, and 40K) in groundwater samples from the Jos-city center. The values reported in this study constitute a baseline for radioactivity in the study area as no such study has been carried out before. The worldwide per capita effective dose from diagnostic medical examination 2000 was 0.4 mSv/yr (typical range is 0.04-1.0 mSv/yr depending on the level of health care) [35]. Uranium level in drinking water is reported by many authors to range from 2.5-105Bq/m^3 (Slovenia), 20-600Bq/m^3 (France), 12-25kBq/m^3 (USSR), and 250-2000kBq/m^3 (Finland) [36]. WHO guidelines assume an intake of total radioactive materials from the consumption of 2 liters of water per day. Consequently, the recommended reference level of committed effective dose is 0.1mSv/yr from consumption of drinking water during a year for any individual, independent of age [36]. The maximum acceptable equivalent dose from man-made radionuclides was set at 0.04mSv/yr [37].

III. MATERIALS AND METHODS

3.1 Description of Study Area

This will be carried out in the Jos city center; covering an area of 42 square kilometers, with an average altitude of 1280 meters above sea level, with its highest point at 2010 meters. It is located at $9^0\ 56'00''$ (9.93^0) N, $8^0\ 53'00''$ (8.88^0) E. The city has an average population density of about 500 people per square kilometer as shown in Figure 1.

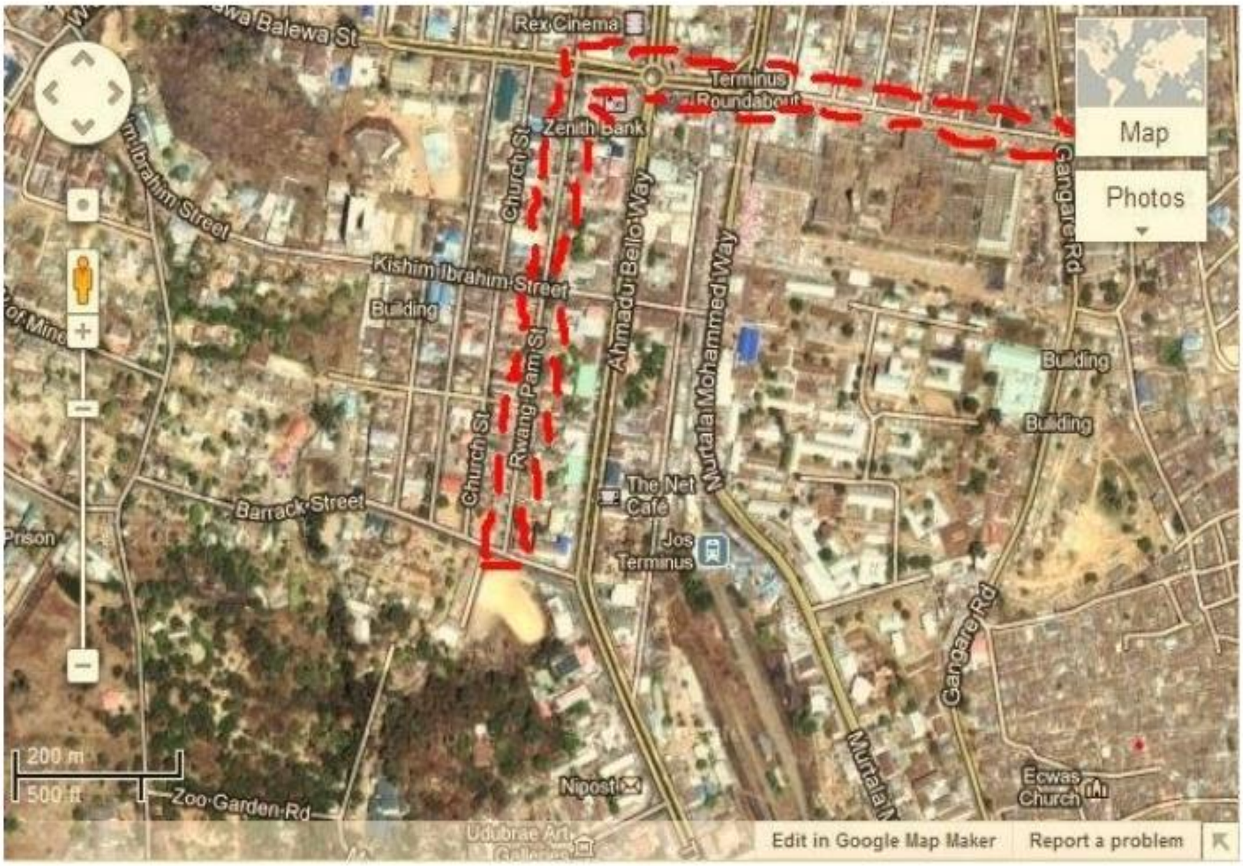

Fig. 1: Map of the-Study Area

3.2 Materials

The equipment used for the gross alpha and beta radioactivity measurement in groundwater samples included: MPC 2000 DP (Monitor Proportional Counter), Electric hot plates, Beakers (Pyrex), 2L plastic containers, drying oven, drying lamp, graduated cylinders, measuring cylinders of capacity 1000cm^3, Porcelain dish of capacity 50ml, Stainless steel Counting Planchette (3 cm), Analytical balance, Gloves, Plastic containers, Masking tape, Blur forceps and Concentrated trioxo nitrate(v) acid (nitric acid).

3.3 Sampling and Samples Preparation

3.3.1 Sample selection

Twenty water samples each were collected from different locations using the stratified random sampling technique [38]. This technique was more important than others in this work because it ensured that all sources were adequately represented in the sampled population. The area under survey is the Jos city center and environs. It is mapped and divided into grids. Each area was square kilometers. Two compounds were selected within the grid by a simple random process. The samples were prepared and analyzed at the Center for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria.

3.3.2 Sample procedure

The raw data collection (field) was carried out in March/April and it lasted for about two weeks. The month of March was chosen because it represents the peak of the dry season in the study area. This is the time when water quality determination is critical. Groundwater (Boreholes and well) samples were collected from the Jos city Center. Twenty (20) of each groundwater sample from borehole and well water was collected in two-liter capacity, sterilized plastic bottles. With about 1% air space left for thermal expansion. Containers were rinsed twice with the samples being collected to reduce contamination by the original content of the sample container. All the samples were prepared by evaporation, at low temperatures. They were evaporated slowly at 70 °C to near dryness (approximately 2-3 ml). Then each sample was transferred quantitatively to an aluminum planchette and dried until precipitation occurred. Each sample precipitation on the planet was directly applied to counting systems. The results were obtained by measurements of the radioactivity level of all water samples were analyzed [39] at the Center for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria. The international standards organization, procedure [40] for the measurement of gross alpha and gross beta activity in water was employed in this analysis. This method provides a screening technique to measure the gross alpha and beta radioactivity in water samples. The water samples collected were preserved by the ISO standard (20 ml of 50% V/V of HNO_3 per liter of water). The purpose of this was to minimize the loss of radioactive material from the solution due to absorption by the walls of the container and to avoid the growth of micro-organisms. The samples were air-tight and were taken to the laboratory and held for about one month to reach secular equilibrium before radiometric analysis [41]. Certain volume (100 ml) VA of each of the samples was filtered in the filtration unit with a suction pump using a cellulose membrane filter of 47 mm in diameter with an effective pore size of 0.45µm. The filtrate was transferred to a porcelain evaporating dish of mass XB in grams and evaporated to dryness in a hot plate. The mass of the evaporating dish and the dried residue XC was obtained. The difference between the former and the later weighing gave the mass of the residue $XC - XB$ (g). For each sample, the total dissolved solid TDS was calculated in mg/l using the formula [40].

$$TDS = \frac{XC - XB}{VA} \times 10^{6} \qquad (1)$$

The value of the TDS for each sample was used to calculate the volume of sample V_P which when evaporated will give a mass of residue corresponding to 0.1A mg, where A is the area of the planchette.

$$V_P = \frac{0.1A}{TDS} \times 10^{6} \qquad (2)$$

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

The calculated volume V_p of each sample was measured and evaporated into a beaker to about 50 ml volume using a Binatone regulated temperature hot plate and then transferred to a clean dry petri dish. Few drops of acetone sample were added to act as a binder to prevent the precipitation of the source of the radionuclides in the sample. The planchette and residue were weighed and the difference between the weight of the empty planchette and the weight of the planchette and residue is about 0.077g according to the ISO (manufacturer) standard that approximately 0.1A mg of the residue should be transferred to the planchette. Efficiency in sample preparation was obtained from the relationship:

$$\frac{\text{Weight of residue tranferred to planchet}}{0.077\text{A}} \times 100\ \% \qquad (3)$$

3.4 Background measurement

Counting

The gross alpha counting equipment used in this work was a Eurysis System Low Background multiple channel (eight) alpha and beta detector. The equipment is a gas flow proportional counter with a 450µg/cm^3 thick window of a diameter of 60mm. It allows simultaneous counting on eight 300mm or 55mm diameter samples. Alpha (α) and beta (β) activity measurement on compound sources can be selective, sequential, or simultaneous. The procedure involves entering the present time, the number of cycles, and the operational voltage. Also, the sampling efficiency, background measurements, and plateau tests were carried out using standard methods [40]. The principles of the counting system are depicted in Figure 2.

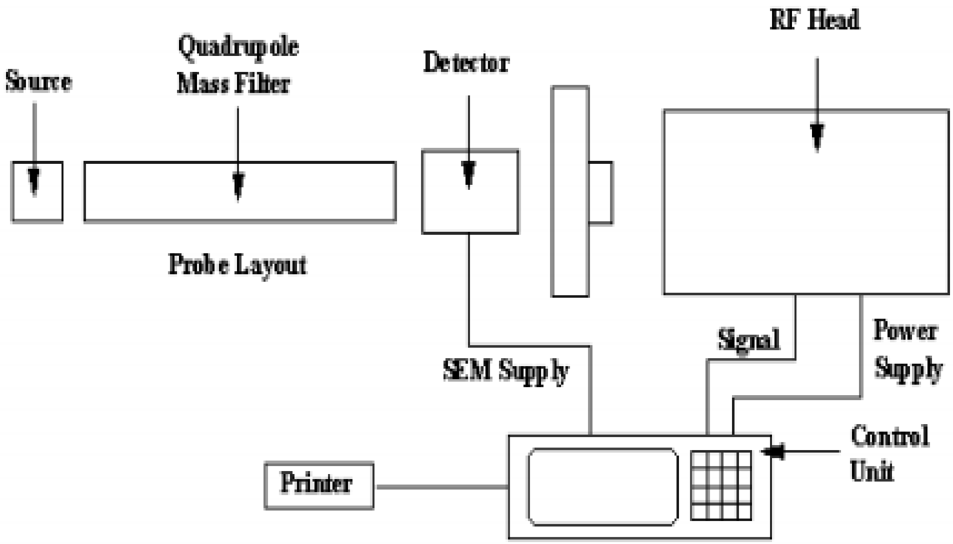

Fig. 2: Block diagram of the proportional gas counter [42]

$$\text{Sample Efficiency} = \frac{\text{Weight Sample}}{\text{Mass residue } (0 - 077)} \qquad (4)$$

Gross alpha counting

For gross alpha counting, selective measurement was adopted. The high voltage of 1650V was used, and samples were counted for 5 cycles of 2700 sec per cycle. The alpha count rates, as well as alpha radioactivity concentration per liter for each groundwater sample, were calculated using Equations 5 and 6 [40].

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

$$\text{Count Rate } (\alpha) = \frac{\text{Raw } (\alpha) \text{ Count x } 60}{\text{Count Time}} \qquad (5)$$

$$\text{Alpha (pCi/L)} = \frac{\text{A x } 1000}{2.22 \text{ x C x V}} \qquad (6)$$

where: A = net alpha count rate (gross alpha count rate minus the background count rate) at the alpha voltage plateau C = alpha efficiency factor, read from the graph of efficiency versus mg of water solids 2 per cm of planchette area, (cpm/dpm) V = volume of sample aliquot, (ml) 2.22 = conversion factor from dpm/pCi

Gross Beta Counting

The counting equipment used for this study is the portable single-channel gas-free proportional counter (MPC2000B-DP) detector. The results were displayed as raw counts and count rate (cpm). The raw counts (cpm) were repeated three times each for all the twenty samples and the mean values were used in calculating the gross beta activity. The high voltage for gross beta counting was set at 1700 volts and samples were counted for three cycles of 3600 secs per cycle in beta only mode. The counting system incorporates interference from high-energy cosmic radiation into the measuring environment and was calibrated following the ISO calibration standard procedure [40]. We obtained the gross beta sample count rate and the beta radioactivity concentration per liter for each groundwater sample were calculated using the following equation (7 and 8)

$$\text{Count rate } (\beta) = \frac{\text{Raw } (\beta) \text{ count x } 60}{\text{Count Time}} \qquad (7)$$

$$\text{Beta (pCi/L)} = \frac{(\text{B - AE}) \text{ x } 1000}{2.22 \text{ xD x V}} \qquad (8)$$

where: A = net alpha count rate (gross alpha count rate minus the background count rate) at the alpha voltage plateau, B = net beta count rate (gross count rate minus the background count rate at the beta voltage plateau) D = beta efficiency factor, read from the graph of efficiency versus mg of water solids per cm of planchette area, (cpm/dpm), E = alpha amplification factor, read from the graph of the ratio of alpha counted at the beta voltage/alpha counted at the alpha voltage vs sample density thickness, V = volume of sample aliquot, (ml), 2.22 = conversion factor from dpm/pCi

3.5 Radiation Dose Estimation in Water Samples

The radionuclide, when ingested, may reach the intestines where it can be absorbed into the body fluids thereby tending to reach all the delicate internal organs. Due to the effects of radionuclide on our body, it is necessary to quantify the effective dose of alpha and beta due to intake of groundwater to ascertain the contributed doses by the major alpha and beta emitters. The annual effective dose equivalents from the consumption of drinking water over one year were evaluated by [43] as

$$E_{DW} = A_W \text{ x } I_{DW} \text{ x } I_{GW} \qquad (9)$$

Where E_{DW} is the annual effective dose equivalent from consumption of drinking water (mSv/yr), A_W is the activity concentration of radionuclides in the ingested water (Bq/L), I_{DW} is the consumption rate of water (L/year). According to [43], the dose was estimated by considering a consumption rate is 730 L/year for adults. The dose conversion factors I_{GW} (mSv/Bq) for adults is $2.8 \text{x} 10^{-4}$, [35] [4].

ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

IV. RESULTS AND DISCUSSION

The results obtained are presented in Table 1 and Table 2, showing the locations of Boreholes and well water that were studied.

Table 1: Laboratory Results for the Gross Alpha and Gross Beta Measurements for Boreholes water

S/N	Sample ID	α (Bq/L)	β (Bq/L)
1	B01	0.060 ± 0.02	0.85 ± 0.01
2	B02	0.37 ± 0.01	0.91 ± 0.02
3	B03	0.53 ± 0.03	1.0176 ± 0.03
4	B04	0.130 ± 0.01	2.0470 ± 0.02
5	B05	0.41 ± 0.02	0.109 ± 0.01
6	B06	0.50 ± 0.03	3.0330 ± 0.01
7	B07	0.230 ± 0.01	5.0352 ± 0.02
8	B08	0.34 ± 0.01	4.85 ± 0.03
9	B09	0.085 ± 0.02	0.967 ± 0.02
10	B10	0.35 ± 0.03	1.376 ± 0.02
11	B11	0.66 ± 0.01	0.483 ± 0.011
12	B12	0.260 ± 0.01	0.433 ± 0.01
13	B13	0.165 ± 0.01	0.337 ± 0.02
14	B14	0.075 ± 0.02	0.480 ± 0.03
15	B15	0.74 ± 0.03	0.560 ± 0.011
16	B16	0.051 ± 0.04	2.061 ± 0.03
17	B17	0.07 ± 0.011	0.081 ± 0.02
18	B18	0.33 ± 0.01	0.285 ± 0.02
19	B19	0.042 ± 0.02	0.396 ± 0.01
20	B20	0.051 ± 0.021	0.412 ± 0.02

Note: α = Alpha, β = Beta, Bq/l; Becquerel per liter, Bn = Boreholes, where n = 1, 2, ….

Table 2: Laboratory Results for the Gross Alpha and Gross Beta Measurements for well water

S/N	Sample ID	α (Bq/L)	β (Bq/L)
1	W01	0.0212 ± 0.011	0.235 ± 0.02
2	W02	0.0309 ± 0.03	0.046 ± 0.02
3	W03	0.40 ± 0.02	0.180 ± 0.02
4	W04	0.040 ± 0.02	0.325 ± 0.02
5	W05	0.141 ± 0.031	0.171 ± 0.03
6	W06	0.216 ± 0.012	0.76 ± 0.011
7	W07	0.43 ± 0.02	0.45 ± 0.002
8	W08	0.251 ± 0.03	0.38 ± 0.022
9	W09	0.120 ± 0.02	1.103 ± 0.02
10	W10	0.35 ± 0.01	0.062 ± 0.02
11	W11	0.56 ± 0.02	1.011 ± 0.03
12	W12	0.9 ± 0.013	0.32 ± 0.04
13	W13	0.614 ± 0.02	2.091 ± 0.03
14	W14	0.102 ± 0.02	0.82 ± 0.013
15	W15	0.80 ± 0.02	0.44 ± 0.02
16	W16	0.39 ± 0.01	0.20 ± 0.02

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

17	W17	0.23 ± 0.02	0.036 ± 0.01
18	W18	0.26 ± 0.03	0.27 ± 0.01
19	W19	0.426 ± 0.02	1.0130 ± 0.03
20	W20	0.245 ± 0.010	0.52 ± 0.002

Note: α = Alpha, β = Beta, Bq/l; Becquerel per liter, Wn = well water, where n = 1, 2, ….

The distribution of the alpha activity and beta activity concentrations for the boreholes water and well water is represented as a bar chart in Figures 3 - 6 respectively.

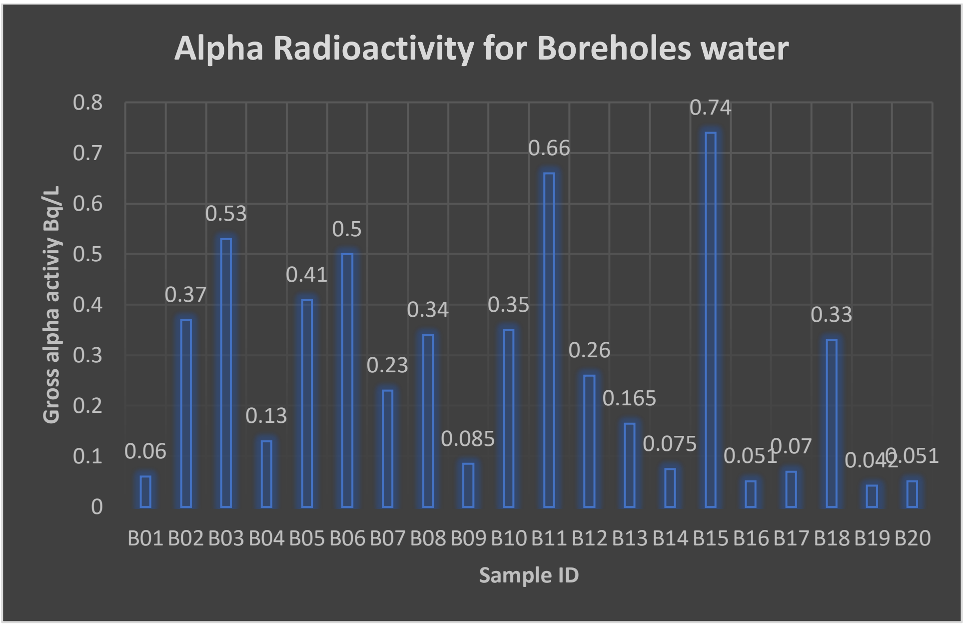

Fig. 3. Bar Chart of the Distribution pattern of Alpha Activity in Boreholes water from the Jos city center.

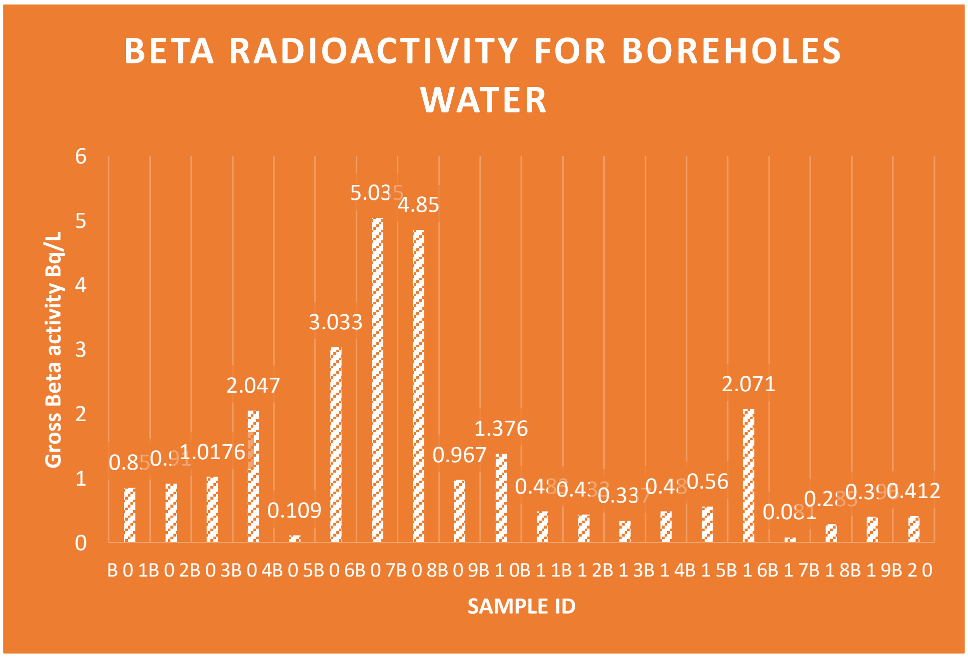

Fig. 4. Bar Chart of the Distribution pattern of Beta Activity in Boreholes water from the Jos city center.

ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

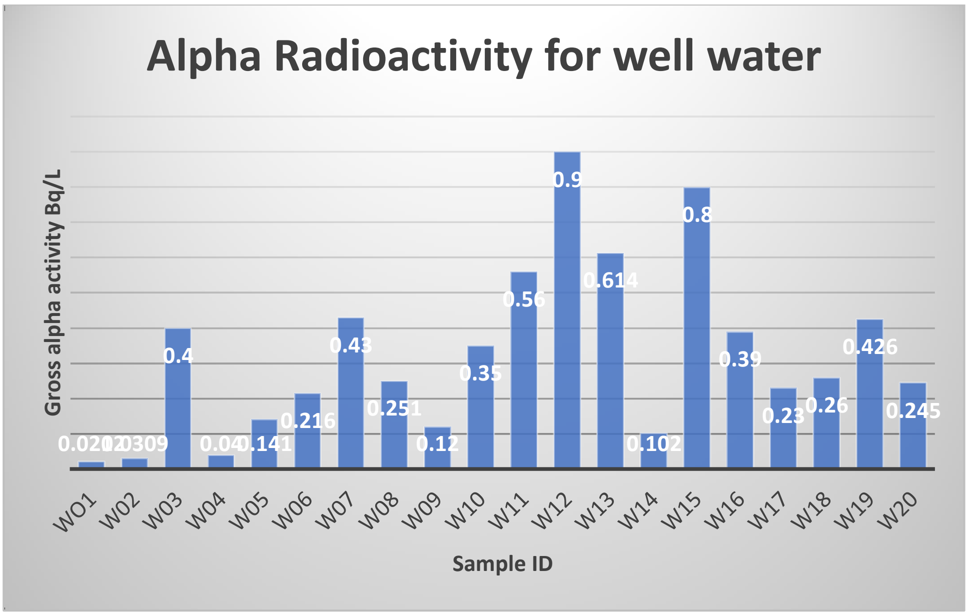

Fig. 5. Bar Chart of the Distribution pattern of Alpha Activity in well water from the Jos city center.

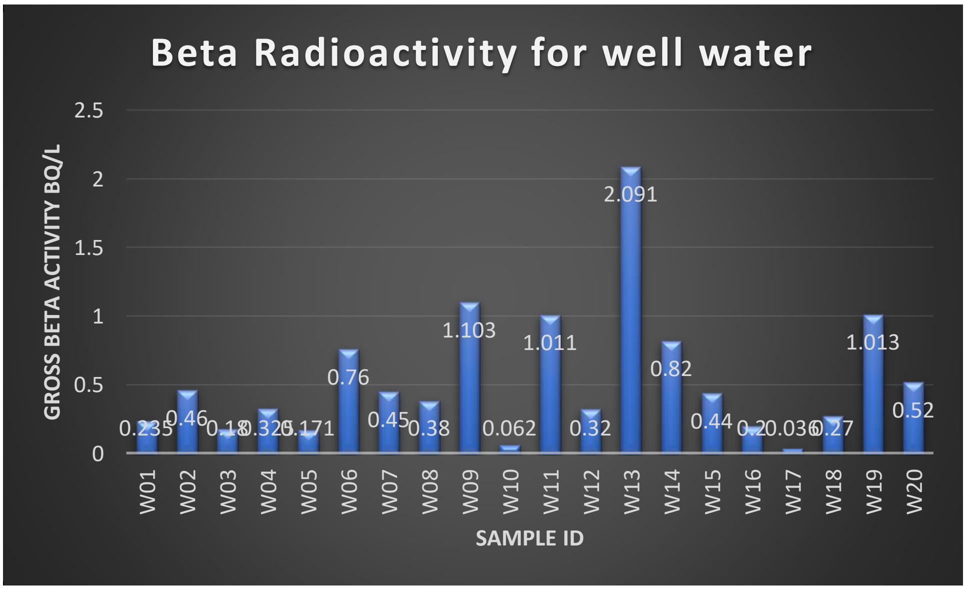

Fig. 6. Bar Chart of the Distribution pattern of Beta Activity in well water from the Jos city center.

The higher value of Gross beta activity could be as a result of the geological formation of the area whose land is highly invaded with phosphorus, a by-product of phosphate that has potassium40 which is a beta and gamma emitter whose source is fertilizer used by farmers. Thus the regular program of environmental audit and monitoring is hereby recommended. However, a comparison to the world standard values of the values obtained from the laboratory results for the gross alpha and beta activities are given in Table 3 to Table 6 respectively.

Table 3: Comparison of Measured Gross Alpha Activity in Jos city center with WHO, USEPA, and UNSCEAR Standards and with Results Obtained from Boreholes water

S/N	Sample ID	α (Bq/L)	WHO	USEPA	UNSCEAR	Remarks
1	B01	0.060 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
2	B02	0.37 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA, and UNSCEAR standard
3	B03	0.53 ± 0.03	0.5	0.55	0.5	more than WHO, Less than USEPA, and more than UNSCEAR standard

ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

4	B04	0.130 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
5	B05	0.41 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
6	B06	0.50 ± 0.03	0.5	0.55	0.5	Equal to WHO, UNSCEAR and less than USEPA standard
7	B07	0.230 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
8	B08	0.34 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
9	B09	0.085 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
10	B10	0.035 ± 0.03	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
11	B11	0.361 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
12	B12	0.260 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
13	B13	0.165 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
14	B14	0.075 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
15	B15	0.74 ± 0.03	0.5	0.55	0.5	Greater than WHO, USEPA and UNSCEAR standard
16	B16	0.051 ± 0.04	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
17	B17	0.07 ± 0.011	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
18	B18	0.0113 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
19	B19	0.042 ± 0.02	0.5	0.5	0.5	Less than WHO, USEPA and UNSCEAR standard
20	B20	0.051 ± 0.021	0.5	0.55	0.5	Less than WHO, USEPA, and UNSCEAR standard

Note: α = Alpha, Bq/l; Becquerel per liter, Bn = Boreholes, where n = 1, 2, ….

Table 4: Comparison of Measured Gross Beta Activity in Jos city center with WHO, USEPA, and UNSCEAR Standards and with Results Obtained from Boreholes water

S/N	Sample ID	β (Bq/L)	WHO	USEPA	UNSCEAR	Remarks
1	B01	0.85 ± 0.01	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
2	B02	0.91 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
3	B03	1.0176 ± 0.03	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
4	B04	2.0470 ± 0.02	1.0	1.85	0.5	Greater than WHO, USEPA and UNSCEAR standard
5	B05	0.0109 ± 0.01	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
6	B06	3.0330 ± 0.01	1.0	1.85	0.5	Greater than WHO, USEPA and UNSCEAR standard
7	B07	0.0352 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
8	B08	4.85 ± 0.03	1.0	1.85	0.5	Greater than WHO, USEPA and UNSCEAR standard
9	B09	0.967 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and greater than UNSCEAR standard
10	B10	1.376 ± 0.02	1.0	1.85	0.5	Less than USEPA and greater than WHO, UNSCEAR standard
11	B11	0.483 ± 0.011	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
12	B12	0.433 ± 0.01	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
13	B13	0.337 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
14	B14	0.482 ± 0.03	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
15	B15	0.513 ± 0.011	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
16	B16	2.061 ± 0.03	1.0	1.85	0.5	Greater than WHO, USEPA and UNSCEAR standard
17	B17	0.087 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
18	B18	0.287 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
19	B19	0.396 ± 0.01	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
20	B20	0.0412 ± 0.02	1.0	01.85	0.5	Less than WHO, USEPA, and UNSCEAR standard

Note: β = Beta, Bq/l; Becquerel per liter, Bn = Boreholes, and, where n = 1, 2, ….

ISSN 2350-1030
International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

Table 5: Comparison of Measured Gross Alpha Activity in Jos city center with WHO, USEPA, and UNSCEAR Standards and with Results Obtained from well water

S/N	Sample ID	α (Bq/L)	WHO	USEPA	UNSCEAR	Remarks
1	W01	0.0212 ± 0.011	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
2	W02	0.0309 ± 0.03	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
3	W03	0.40 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
4	W04	0.040 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
5	W05	0.141 ± 0.031	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
26	W06	0.216 ± 0.012	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
7	W07	0.43 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
8	W08	0.251 ± 0.03	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
9	W09	0.120 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
10	W10	0.015 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
11	W11	0.016 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
12	W12	0.09 ± 0.013	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
13	W13	0.014 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
14	W14	0.102 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
15	W15	0.80 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
16	W16	0.39 ± 0.01	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
17	W17	0.23 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
18	W18	0.26 ± 0.03	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
19	W19	0.426 ± 0.02	0.5	0.55	0.5	Less than WHO, USEPA and UNSCEAR standard
20	W20	0.245 ± 0.010	0.5	0.55	0.5	Less than WHO, USEPA, and UNSCEAR standard

Note: α = Alpha, Bq/l; Becquerel per liter, and Wn = well water, where n = 1, 2, ….

Table 6: Comparison of Measured Gross Beta Activity in Jos city center with WHO, USEPA, and UNSCEAR Standards and with Results Obtained from well water

S/N	Sample ID	β (Bq/L)	WHO	USEPA	UNSCEAR	Remarks
1	W01	0.235 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
2	W02	0.46 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
3	W03	0.180 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
4	W04	0.325 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
5	W05	0.171 ± 0.03	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
6	W06	0.76 ± 0.011	1.0	1.85	0.5	Less than WHO, USEPA and greater than UNSCEAR standard
7	W07	0.45 ± 0.002	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
8	W08	0.38 ± 0.022	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
9	W09	1.103 ± 0.02	1.0	1.85	0.5	Less than USEPA and greater than WHO, UNSCEAR standard
10	W10	0.062 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
11	W11	1.011 ± 0.03	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
12	W12	0.32 ± 0.04	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
13	W13	$2..09 \pm 0.03$	1.0	1.85	0.5	Greater than WHO, USEPA and UNSCEAR standard
14	W14	0.82 ± 0.013	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
15	W35	0.44 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
16	W16	0.20 ± 0.02	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
17	W17	0.036 ± 0.01	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
18	W18	0.27 ± 0.01	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
19	W19	1.0130 ± 0.03	1.0	1.85	0.5	Less than WHO, USEPA and UNSCEAR standard
20	W20	0.52 ± 0.002	1.0	1.85	0.5	Less than WHO, USEPA, and UNSCEAR standard

Note: β = Beta, Bq/l; Becquerel per liter, Wn = well water, where n = 1, 2, ….

ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

The average annual effective dose due to drinking the water that contains specific activities of radionuclides emitters of alpha and beta particles was determined by computing the mean individual annual committed effective doses as shown in Table 7 and Table 8

Table 7: Concentration of radionuclide and the hazard indices in Boreholes water

S/N	Samples ID	Effective equivalent dose to α radionuclides (mSv)	Effective equivalent dose to β radionuclides(mSv)	Total effective equivalent dose(mSv)
1	B01	0.002	0.174	0.176
2	B02	0.076	0.186	0.262
3	B03	0.110	0.21	0.32
4	B04	0.027	0.418	0.445
5	B05	0.084	0.022	0.106
6	B06	0.102	0.620	0.722
7	B07	0.047	1.029	1.076
8	B08	0.069	0.991	1.060
9	B09	0.017	0.198	0.215
10	B10	0.072	0.281	0.358
11	B11	0.135	0.098	0.233
12	B12	0.053	0.089	0.142
13	B13	0.034	0.069	0.103
14	B14	0.015	0.098	0.113
15	B15	0.151	0.114	0.265
16	B16	0.010	0.423	0.433
17	B17	0.014	0.017	0.031
18	B18	0.067	0.058	0.125
19	B19	0.009	0.081	0.090
20	B20	0.010	0.044	0.054
	Average	**0.055**	**0.260**	**0.316**

Table 8: Concentration of radionuclide and the hazard indices in well water

S/N	Samples ID	Effective equivalent dose to α radionuclides(mSv)	Effective equivalent dose to β radionuclides(mSv	Total effective equivalent dose(mSv)
1	W01	0.004	0.048	0.052
2	W02	0.006	0.010	0.016
3	W03	0.082	0.037	0.119
4	W04	0.008	0.066	0.074
5	W05	0.029	0.035	0.064
6	W06	0.044	0.155	0.199
7	W07	0.088	0.092	0.18
8	W08	0.051	0.078	0.129
9	W09	0.025	0.225	0.28
10	W10	0.072	0.013	0.085
11	W11	0.114	0.207	0.321
12	W12	0.184	0.065	0.249
13	W13	0.126	0.427	0.553
14	W14	0.021	0.168	0.189
15	W15	0.164	0.090	0.254
16	W16	0.080	0.041	0.121
17	W17	0.047	0.007	0.054
18	W18	0.053	0.055	0.100
19	W19	0.087	0.207	0.294
20	W20	0.050	0.106	0.156
	Average	**0.067**	**0.107**	**0.174**

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

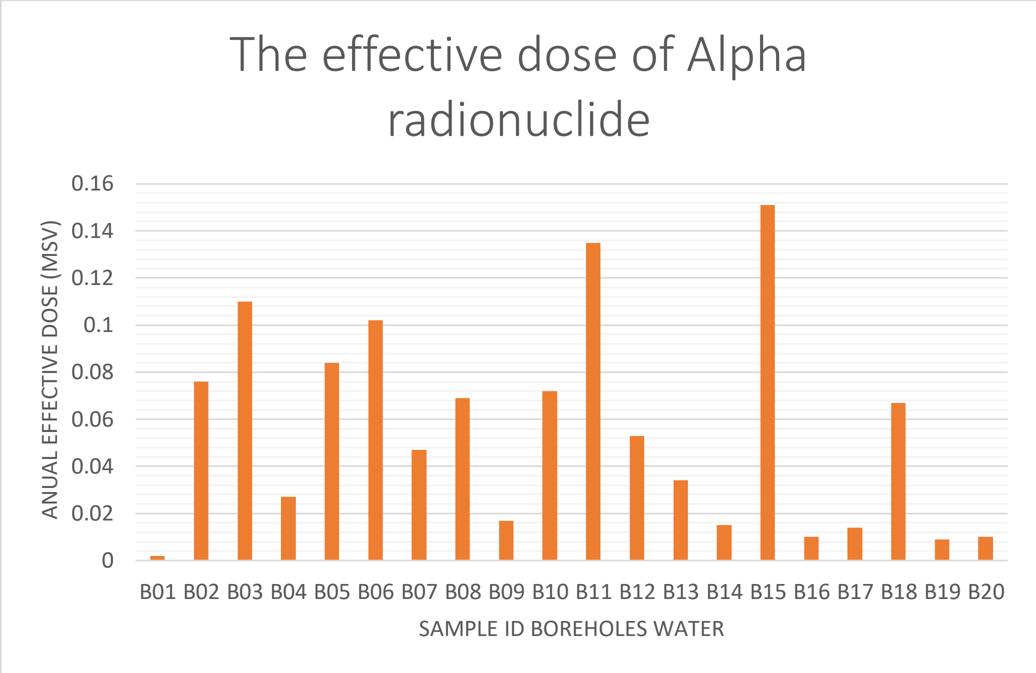

Fig. 7. The relationship between the annual effective dose Alpha and sample ID Boreholes water

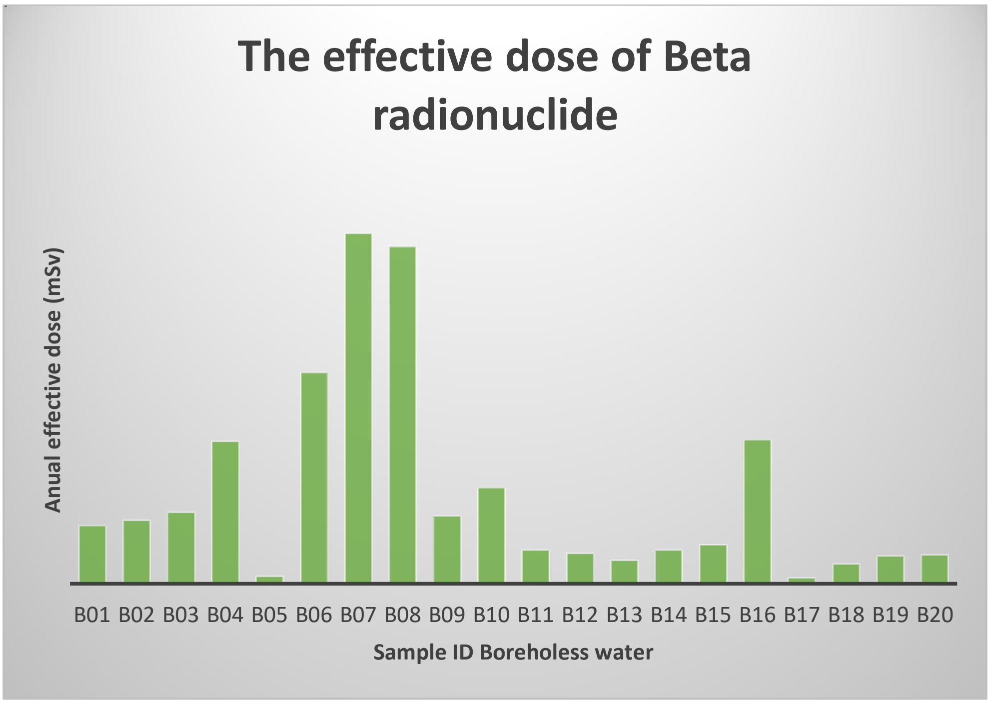

Fig. 8. The relationship between the annual effective dose Beta and sample ID Boreholes water

ISSN 2350-1030

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

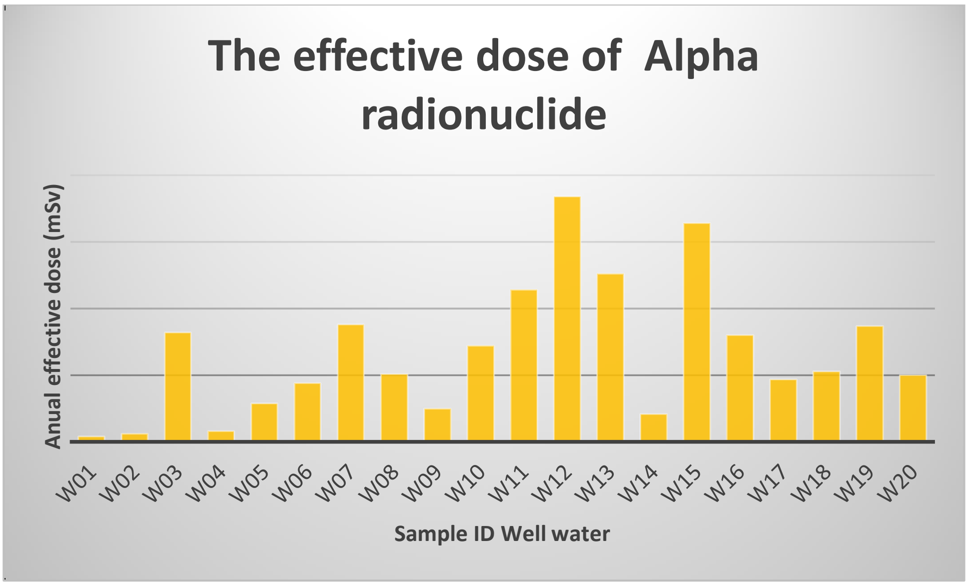

Fig. 9. The relationship between the annual effective dose Alpha and sample ID Well water

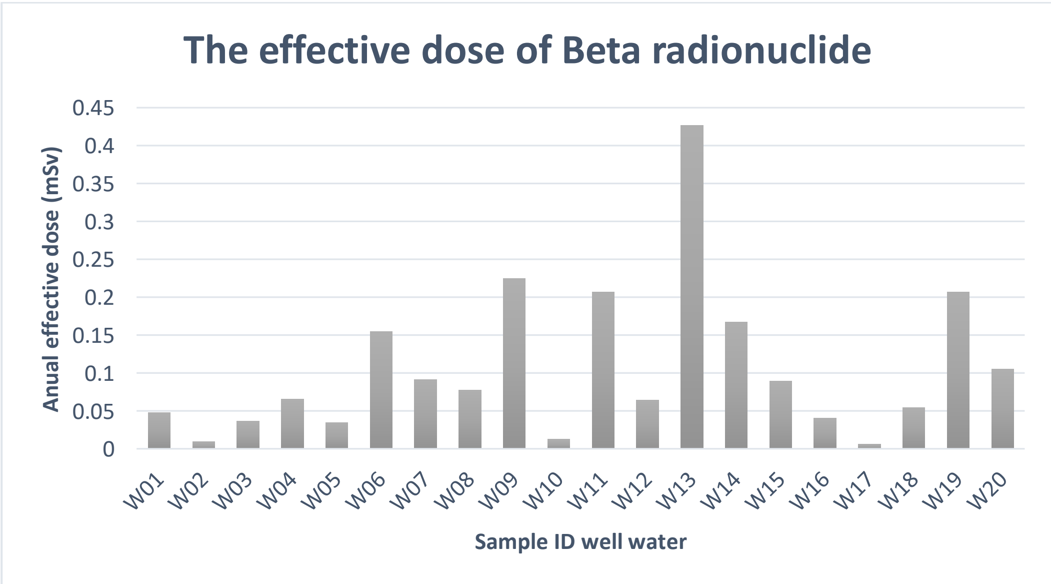

Fig. 10. The relationship between the annual effective dose Beta and sample ID Well water

The evaluation of radiation hazard indices of groundwater in Jos city center has been conducted. The effective doses attributed to gross alpha and beta activities are shown in Tables 7-8 with the range of 0.002–0.151 mSv and 0.017–0.620 mSv, for boreholes water and 0.004–0.164 mSv and 0.010–0.427 mSv for hand-dug well water respectively. The values obtained when compared with the various world permissible values were found to be below the standards for such environment and drink water from this area will pose no significant health threat to human lives and the environment is said to radiologically hazard safe.

V. CONCLUSION

In the presents study, widely used the MPC 2000 DP (Monitor Proportional Counter) detector was employed for the gross alpha and beta radioactivity measurement in groundwater samples (Boreholes and Well water). Thus, twenty (20) of each groundwater sample (Boreholes and well water) were analyzed to give us more meaningful data from a human health perspective. Various published articles and reports were scanned to get the precise world widely accepted information. For the presents data, the focus was on the gross alpha and beta activity. Therefore, average measurements of all the twenty (20) of each sample from Boreholes and well water showed slightly above the world average activities as shown in

International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)
Vol. 8, Issue 1, pp: (1-17), Month: April 2021 – September 2021, Available at: www.paperpublications.org

Tables 3- 6 respectively. The radiological impact of these samples, distinct units of activities were calculated to compare with the world's standards. Based on the calculations, it can be observed that the values are below the worldwide accepted per capita effective dose of 410 μ Sv/yr of one-year intake of drinkable water.

ACKNOWLEDGMENTS

The authors are grateful to the Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria, Kaduna State where all the laboratory works of this manuscript were performed.

REFERENCES

[1] Daburum, N.H. (2015). Gross Alpha And Beta Radioactivity Concentrations In Jos South And Mangu LGA, Plateau State-Nigeria, Unpublished M.Sc Thesis, University of Jos.84pp

[2] Vodela JK, Renden JA, Lenz SD, Mchel Henny WH, Kemppaninen BW. Drinking water contaminants. Poultry Science. 1997; 76:1474 –1497

[3] Ayoade, J.O. (1988). Tropical Hydrology and Water Resources. L.T.D London, Macmillan Publishing, pp. 53 – 57.

[4] USEPA (2010). United State Environmental Protection Agency. Prescribed procedures for the measurement of radioactivity in drinking water. Environmental monitoring support laboratory. EPA.

[5] Agbalagba, E. O and Avwiri, G. O. (2012). "Determination of Gross α and β Activity Concentration and Estimation of Adults and Infants Dose Intake in Surface and Ground Water of Ten Oil Fields Environment in Western Niger Delta of Nigeria." *International Journal of Environmental Engineering Research,* Vol. 1, Issue 1, pp. 30-40, 2012.

[6] Brassard, P.G. (1996). Wetland and Water Pollution. *Boston College of Environment. Off. Law Review.* Vol.23.number4 pp885-919.

[7] Saidu A., Baba-Kutigi A.N. and Buda S. (2012). Determination of Gross Alpha Radioactivity in Underground Water in Usmanu Danfodiyo University Permanent Site, Sokoto. International Journal of Science and Advanced Technology, 1, 1-4.

[8] Kozinski, et al (1995). Natural Radioactivity in and Inorganic chemistry of Ground Water in the Kirkwood-Cohansey Aquifer System, Southern New Jersey. U.S Geological Survey Water Investigation Reports 92-4144

[9] Daniel. (2006). Investing in Tomorrow's Liquid Gold. (USEPA)

[10] Onoja, R.A. (2004). Survey of Gross Alpha and Beta Radioactivity in Wells from Zaria. M.Sc. Thesis A.B.U. Zaria.

[11] Solomon, A.O. (2005). Natural Radiation Hazard Mapping and Distribution of Dose Equivalents within Jos-Bukuru (Naraguta) and Environs, Sheet 168, North Central Nigeria. *African Journal of Natural Science.* Vol.8. pp119-121.

[12] Tajudeen, H.V. (2006). Survey of Radioactivity in Wells and Boreholes from Gwammaja Area of Kano City. M.Sc. Thesis, A. B. U. Zaria.

[13] U.S. Environmental Protection Agency (USEPA) (1976). National Primary Drinking Water Regulations. Agency Report EPA-570/9-76-003.

[14] Cember, H. (1996). Introduction to Health Physics. 3rd edition. McGraw Hill Inc, Toronto. Pp220-237

[15] El-Bahi, S.M., 2004. Assessment of radioactivity and radon exhalation rate in Egyptian cement. Health Phys. 86, 517-522.

[16] Chikasawa, K., Ishii, T., Ugiyama, H., 2001. Terrestrial gamma radiation in Kochi prefecture, Japan. J. Radiol. Prot. 25, 305-312

[17] Arogunjo, A.M., I.P. Farai, and I.A. Fuwape (2004). Impact of oil and gas industry on the natural radioactivity distribution in the delta region of Nigeria. *Nig. J. Phys.*, 16: 131-136.

[18] Avwiry, G.O. and Agbalagba, E.O. (2007). Survey of Gross Alpha and Beta Radionuclide Activity in Okpare-Creek Delta State Nigerian *Journal of Applied Sciences* 7 (22): 3542-3546

[19] Alam, M. N.; Chowdhury, M. I.; Kamal, M.; Ghose, S.; Islam, M. N.; Anwaruddin, M., (1999). Radiological assessment of drinking water of Chittagong region of Bangladesh. Radiation Protection Dosimetry. Vol. 82, No. 3, Pp. 207-214.

[20] Onoja, R. A.; Akpa, T. C.; Mallam, S. P.; Ibeanu, I. G., (2007). Survey of Gross Alpha and Beta Radioactivity in Well Water from Zaria and its Environs, Nigeria. *Journal of Physics* Vol. 19 (1): Pp. 39-48

[21] Fatima, I.; Zaidi, J. H.; Arif, M.; Tahir, S. N., (2007). Measurement of natural radioactivity in bottled drinking water in Pakistan and consequent dose estimates. Radiation Protection Dosimetry, Vol. 123(2), Pp. 234-40. DOI: 10.1093/rpd/ncl093.

[22] Ajayi, T. R.; Torto, N.; Tchokossa, P.; Akinlua, A., (2009). Natural Radioactivity and Trace Metals in Crude oils: Implication for Health. Environ Geochem Health, Vol. 31, Pp. 61-69.

[23] Bomben, A. M.; Equillor, H. E.; Oliveira, A. A., (1996). Natural Radionuclides in drinking water in Argentina. Radiation Protection Dosimetry, Vol. 67 (221).

[24] Isinkaye, M. O.; Shitta, M. B. O., (2010). Natural Radionuclide Content and Radiological Assessment of clay soil collected from different sites in Ekiti State, Southwestern Nigeria. Radiation Protection Dosimetry, Vol. 139 (4), Pp. 590-596.

[25] Zaini, H.; Masitah, A.; Zaharudin, A., (2011). Discriminator setting cocktail preparation for analysis of alpha and beta emitters in aqueous solution using a liquid scintillation counter. The Malaysian Journal of Analytical Sciences, Vol. 15(1), Pp. 27-36. *International Journal of Scientific & Engineering Research* Volume 8, Issue 6, June-2017 ISSN 2229-5518 2160 IJSER

[26] Urkiye, A.; Orhan, G.; Aysegul, K.; Sezai, Y.; Gokay, K.; Ozan, G., (2009). Measurements of radium levels in bottled natural spring Water of Marmara region (Turkey). Rom. Journal of Phys., Vol. 57, Number: 7–8, Pp. 1204–1210, Bucharest 2012

[27] Garba, M. L.; Arabi, A. S.; Adeyemo, D. J., (2013). Assessment of Gross Alpha and Beta Radioactivity in Groundwater by Liquid Scintillation. *J. Appl. Environ. Biol. Sci.*, 3(7), Pp. 1-5.

[28] Ahmed, S. A.; John, S. M.; Chifu, E. N., (2014). An Assessment of Gross Beta Radioactivity Concentration in underground Water in Nassarawa town of Nasarawa State, Nigeria. *International Journal of Latest Research in Science and Technology*, Vol. 3, Issue 5, Pp. 71-74

[29] Avwiri, G.O., Owate, I.O., Enyinna, P.I. (2005). Radionuclide concentration survey of soil, sediment, and water in Aba River. Scientia Africana 2, 67-72.

[30] Avwiri G.O, Osimobi J.C, Ononugbo C.P. (2016). Gross alpha and gross beta activity concentrations and committed effective dose due to intake of water in solid mineral producing areas of Enugu State, Nigeria. *Int. J. Phys.*

[31] Batt A.L., Furlong E.T., Mash H.E., Glassmeyer S.T. and Kolpin D.W. (2017). The importance of quality control in validating concentrations of contaminants of emerging concern in source and treated drinking water samples. Science of the Total Environment, 579, 1618-1628

[32] Shygonskyj Valerij and Shygonska Natalia (2016). Assessment of drinking water quality as a factor affecting human health in Zhytomyr Region. Kontakt, 18(2), 120-126.

[33] Vasile M., Loots H., Jacobs K., Verheyen L., Sneyers L., Verrezen F. and Bruggeman M. (2016). Determination of 210Pb, 210Po, 226Ra, 228Ra, and uranium isotopes in drinking water to comply with the requirements of the EU ‘Drinking Water Directive’. Applied Radiation and Isotopes, 109, 465-469.

[34] Shaban Harb, Abd El-Hadi El-Kamel, Abd El-Bast Abbady, Imran Issa Saleh, Abdallah Ibrahim Abd ElMageed.(2012). Specific activities of natural rocks and soils at quaternary intraplate volcanism north of Sana'a, Yemen, journal of medical physics, Vo.37, No.1,

[35] WHO (2006). Guidance for Drinking Water Quality. 3rd Edition. Chapter 9 (Radiological Aspect). pp197-209.

[36] Othman, I. And Yassine, T. (1995). Natural Radioactivity in the Syrian Environment. Science Total Environ. pp170, 119-124.

[37] Milly, P. And Cothan, C.R. (1990). Scientific Background for Development of Regulations for Radionuclides in Drinking Water. In (Onoja, 2004) Survey of Gross Alpha and Beta Activity in Well Water from Zaria.

[38] Williams, G.C. (1977). Sampling Techniques. 3rd edition. John Wiley and Sons Inc. New York. Pp87-97.

[39] Bonotto, D.M., Bueno, T.O., Tessari, B.W., Silva, A. (2009). The natural radioactivity in water by gross alpha and gross beta measurement. Radiat Meas.,44,92-101.

[40] International Organization of Standardization. (1992). Water Quality Measurement of Gross Alpha Activity in Non-Saline Water, Thick Source Method, ISO (9696-1992 revised). Geneva, Switzerland. 13p.

[41] Onoja, R.A., (2010). Total radioactivity count in taps and well water around Zaria area, Kaduna State, Nigeria. Ph.D. thesis, ABU, Zaria. Nigeria.

[42] Saidu, A and Bala, A. (2018). Assessment of the Specific Activity of Alpha- and Beta-emitting Radionuclides in Groundwater, Anka, Nigeria. *Iran J Med Phys* 2018; 15: 285-294. 10.22038/ijmp.2018.26350.1266

[43] UNSCEAR (2000). *United Nations Scientific Committee on the Effect of Atomic Radiation, Radiation sources and Effects of ionizing radiation*. Report to General Assembly, with Scientific Annexes. United Nations, New York.