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Assessment of radioactive contamination in water bodies around mine workings using radiation counter

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Abstract

The vulnerability of water bodies to contamination within the neighbourhood of open mine cast environ cannot be overemphasized. Evidence of radioactive trace elements associated with the target minerals in the Plateau State (Nigeria) showed the extent of this vulnerability. In order to address this challenge, the radioactivity levels of water samples from mine ponds, streams, wells, and boreholes around mine sites in the Plateau State were assessed. The water samples were analysed for gross alpha and beta radiation activities using MPC 2000 radiation counter in accordance with the provisions of International Atomic Energy Agency (IAEA) at the Centre for Energy Research and Training (CERT) Zaria. The mean alpha radiation activity dose for the water samples collected from mine ponds, streams, wells, and boreholes was 0.63 $\pm$ 0.1 Bq/l, 0.13 $\pm$ 0.1 Bq/l, 0.34 $\pm$ 0.1 Bq/l, and 0.51 $\pm$ 0.2 Bq/l, respectively. The mean beta radiation activity dose for the water samples collected from mine ponds, streams, wells and boreholes was 4.1 $\pm$ 1.8 Bq/l, 1.0 $\pm$ 0.7 Bq/l, 2.4 $\pm$1.9 Bq/l, and 2.7 $\pm$ 1.3 Bq/l, respectively. The water bodies were unwholesome for human consumption. The present use of water from the mine ponds for irrigation should be discontinued. The specific activities of alpha and beta radiations in the water samples decreased as distance from the mine increased. It is, therefore, clear that the mine sites were the sources of the high radiation values recorded in the water sources.

Keywords: *Alpha, Beta, Radioactivity, Radiation Counter, Radioactive Trace Elements.*

1. Introduction

Radioactivity is the spontaneous disintegration and emission of one or more of alpha (α), beta (β) or gamma (γ) radiation from unstable nuclei. Radioactivity is part of our earth, and has existed since time immemorial. Natural background radiation is naturally present in our bodies, food, and water. The human population is continuously exposed to ionizing radiation from numerous radionuclides attributed to primordial and cosmogenic sources heightened by anthropogenic activities such as mining operations [1]. Natural ionizing radiation is considered to be the largest contributor to the collective effective dose received by the world population [2]. Radioactivity in the body comes from the primordial elements (^{238}U, ^{232}Th, ^{226}Ra, ^{40}K) that emanate from soils and rocks [2], which are inhaled by humans. Radiation can also be taken up by plants and animals, thus causing most foodstuffs to be replete with natural radioactivity, which are thereafter passed onto humans by ingestion through the food chain. This may increase the long-term incidence of cancer [1].

Water pollution is the leading cause of death and diseases [3]. The quality of drinking water must, therefore, be ensured to guarantee the public health [4]. The greatest threat to the groundwater quality is leachate from waste dumps, as they often contain measurable amounts of toxic substances [5] that may percolate and contaminate the groundwater bodies [1]. Human activities such as mining constantly add wastes to water at an alarming rate [6]. Ground and surface waters are the major sources of water. All water sources contain some level of radiation. Generally, ground waters contain more significant amounts of natural radioactivity than surface waters, as they can be exposed to rock formation [7, 8]. Higher levels of radiological contaminants can be found in groundwater near mining operations or areas where rock and soil have been disturbed [9]. Radiological contamination of water is due to the presence of radionuclides. These radionuclides may contribute appreciably to the dose received by humans. Exposure to radiations could cause leukaemia, chromosomal breakage, bone necrosis, cancer, mutation of genes, and cataract of the eye lens among other diseases [8]. It is known that even a small amount of a radioactive substance may produce a damaging biological effect, as ingested and inhaled radiation can lead to serious health risks. The radionuclides present in water and food can present serious health risks because the radiation is actually ingested, thereby damage the internal tissues. The presence of ionizing radiation in water and the associated health risks should, therefore, be seriously handled. These potential adverse effects from ingestion of radionuclides, through drinking water, necessitates the setting up of a standard in order to protect the human race from radiation exposure above the recommended limit. Unlike many diseases, the biological effects of radiation are not only somatic but also hereditary [10] as the gonads of human have a tissue weighting factor of 0.2 [11]. It is because an annual effective dose limit of 1 mSv/yr was set [11]. Radiation from natural sources gives more than 80% of the total exposure received by an average member of a population [11], and a portion of this comes from dietary intake. Water is, therefore, considered as a potential significant source of radionuclide ingestion.

Dissolved radionuclides in water emit particles (alpha and beta) and photons (gamma) [12]. Though gamma has a higher penetrating power, alpha and beta are the most common ionizing radiations in water [13]. They also have a higher ionizing energy, and hence, the ability to deposit a larger amount of energy within a small distance in a medium due to their high LET nature [13]. The degree of harm to human health depends on the type of radiation, as all radiations do not have the same biological effects. A dosage of gamma radiation will cause much less damage than the same dosage of alpha or beta particles. Thus the alpha and beta particles will cause much more damage than the gamma rays. The radiation exposures due to gross alpha and beta are, therefore, of greater concern in water assessment than that due to gamma for natural radioactivity [1, 13]. The World Health Organization (WHO) guidelines for drinking water quality also recommended the determination of gross alpha and beta activity concentrations in drinking water as the first step of the radiological aspect of the drinking water quality [3]. This is to ensure that the reference dose level (RDL) of 0.1 mSv/yr, which is equal to 10% of the recommended annual effective dose limit for members of the public by [13, 14], is not exceeded. The study, therefore, assessed the level of contamination of water bodies in close proximity to mine sites so that any potential radiological incident can be forestalled.

2. Studied area

2.1. Economic activities

The studied area is known mainly for the mining of tin and columbite with other associated minerals such as tantalum and kaolin. Tin mining flourished in the studied area from the beginning of the twentieth century to the early 1980s, and left behind a post-mining environment scarred by numerous mine ponds surrounded by heaps of mine wastes and a devastated landscape [15-17]. Associated with tin and columbite are the radioactive minerals such as monazite, niobium, zircon, and wolframite. The radioactive accessory minerals to the cassiterite deposit, which are in concentrated form due to the extraction of the non-radioactive components (tin and columbite), are abandoned in many previous mining sites in the studied area [18]. Radioactivity can contaminate water if it is discharged into the environment from industries such as mining that concentrate natural radionuclides. A proper disposal of the wastes is essential to ensure the protection of health and safety of the public and quality of the water supplies and the environment at large [19].

Although Jos is the best known for mining, agriculture is another prominent economic activity that has been providing the means of livelihood for a significant number of the population [20]. There are sizeable pockets of loamy soil of volcanic origin on the Plateau. The people are engaged in small-scale mining activities, farming, and petty trading. They farm on both the low-lying and marginal areas such as steep rocky slopes and fertile mine lands. The crops cultivated in the area include maize, millet, acha, yam, cocoyam, guinea corn, and sweet and irish potatoes. Economic trees such as mangoes, guavas, pea and, oranges are also grown.

Water that accumulates in mine ponds is used for dry season irrigation, for domestic and industrial uses such as drinking and cooking, and in the manufacture of soft and alcoholic drinks [21]. It is also used as recreational facilities such as sailing club and for agricultural purposes such as rock water fish farm. Leachates from the mines can introduce radiation into water bodies [18]. Radioactivity in water can also accumulate in fish and seafood since these aquatic organisms may bio-accumulate certain radionuclides. Radioactive materials pass through the food chain in the same way as the non-radioactive ones [9]. They can thus become incorporated into food as it is taken up by plants and seafood, and ingested by animals and humans. These may find their way into sedentary edible organisms such as oysters in receiving water. These organisms have the ability to accumulate them. The consumption of these organisms by human beings can lead to the accumulation of dangerous levels of radioactivity in the human. There is also the possibility of direct ingestion through water. Hence, the cost of the contamination is transferred to other economic activities (agriculture and fishing) [22]. It is, therefore, necessary to determine the radioactivity levels in the water bodies of the studied area.

2.2. Geology

The geological map of the studied area presented in Figure 1 reveals that the geology of the studied area is that of the Younger Granite series of the Jos Plateau, which intruded the Basement rock, with the lithologic units (Older Granite, Younger Granite, Volcanic, Magmatic Gneiss Complex, and Sedimentary Basin) emplaced during the Jurassic era. The Younger Granite is known for hosting tin [23]. The richest and the most extensive alluvial deposits of cassiterite and columbite in Nigeria have been shed from the biotitic–granite of the studied area [23]. The Younger Granite occurs as ring structures with a sequence of volcanic phase followed by a series of granitic intrusions. These rocks are the source of commercial quantities of tantalite, cassiterite, columbite, zircon, monazite, ilmenite, thorite, molybdenite, and pyrochlore. Tantalite, cassiterite, and columbite mining, mostly from alluvial deposits, and processing of the ores have been taking place for over a hundred years on the Jos-Plateau in the central part of Nigeria. Associated with this activity are extensive mine tailings that have been generated over the years, and these tailings are left either unsorted or separated into zircon, ilmenite, and monazite, which is known to be rich in thorium [16, 24]. The effective dose rates of soil and mine waste from rock strata in the studied area are higher than the acceptable limit of 1 mS/yr. [10]. Enhanced levels of radioactivity are found in water located in areas that are rich in natural radioactivity [15, 25, 26] as the amount of radioactivity depends on the local geology climate and agricultural practices. The water sources in the area may, therefore, be prone to radioactive contamination.

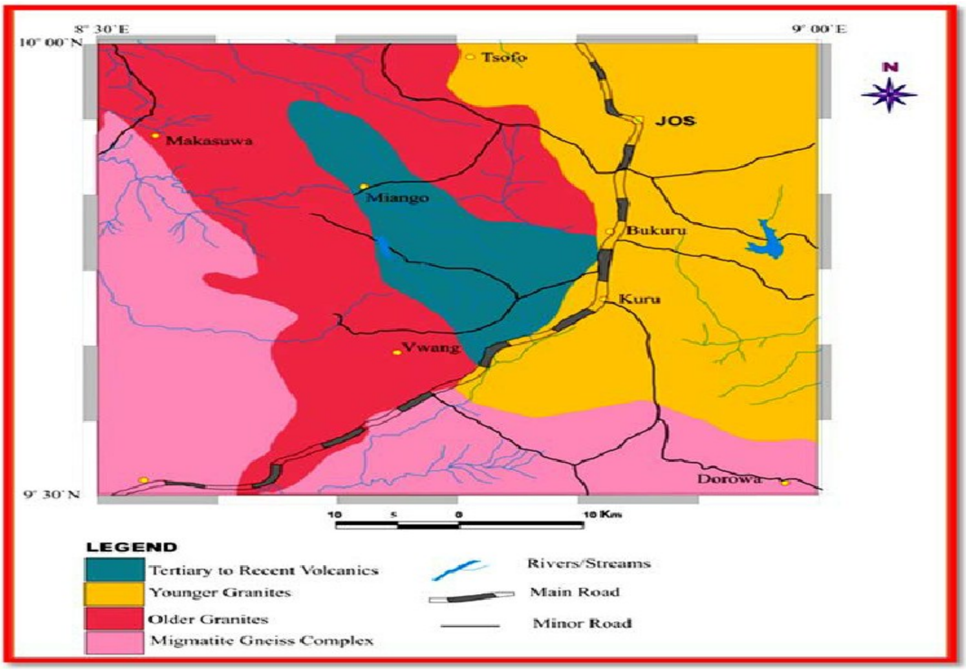

Figure 1. Geological map of studied area [16].

3. Materials and method

3.1. Water sampling and analyses

The water samples were collected from a total of 58 points in the studied area. The samples were collected from 24 mine ponds, 12 streams, 12 wells, and 10 boreholes across the six locations of the studied area. They were labelled according to the sampling location using alphanumeric notations. RW1, …, RW4; GW1, …,GW4; SW, …, SW4; KW1, …, KW4; BW1, …, BW4; and BLW1, …, BLW4 indicate the water samples collected from the mine ponds in Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi, respectively. RW5 and RW6; GW5 and GW6; SW5 and SW6; KW5 and KW6; BW5 and BW6; and BLW5 and BLW6 indicate the water samples collected from streams in Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi, respectively. RW7 and RW8; GW7 and GW8; SW7 and SW8; KW7 and KW8; BW7 and BW8; and BLW7 and BLW8 indicate the water samples collected from wells in Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi, respectively. RW9 and RW10; GW9 and GW10; KW9 and KW10; BW9 and BW10; and BLW9 and BLW10 indicate the water samples collected from boreholes in Rayfield, Gero, Kuru Jantar, Bisichi, and Barkin Ladi, respectively.

Each water sample was treated with 10 mL of concentrated trioxonitrate(v) acid to prevent the absorption by the walls of the containers, minimize precipitation of micro-organisms, and reduce the pH of the samples to a level that will enable counting. The samples were analyzed in accordance with the provisions of IAEA [14] at the Centre for Energy Research and Training (CERT) Zaria using MPC 2000 radiation counter. The resultant net count was converted to count rate using Equation 1, which was subsequently converted to the specific activity for both alpha and beta radiations using Equation 2. Each result was compared with the standard of 0.1 Bq/l and 1.0 Bq/l for the alpha and beta radiation activities, respectively.

$$Count\ rate\ \left(\alpha,\beta\right) = \frac{net\ count}{count\ time\ \left(\min\right)} \tag{1}$$

$$specific\ activity\ \left(Bq\ /\ l\right) = \frac{net\ count\ rate\ \left(\alpha,\beta\right) count\ per\ minute}{Deff\ \left(\alpha,\beta\right) x\ SExSVx\ 60} \tag{2}$$

where:

$Deff\ (\alpha,\beta)$ is the alpha/beta efficiency;

SE is the sample efficiency;

SV is the sample volume

3.2. Data presentation and analysis

Spatial distribution of parameters was plotted using the Surfer 12 software. Analysis of variance (ANOVA) was carried out on the data using the Minitab-17 Software. Tukey test was used for the subsequent post Hoc Tests at 5% level of significance. Pearson correlation coefficient between the alpha and beta radiation activities in water sources with distance was carried out.

4. Results and discussion

4.1. Specific activity of Alpha in water samples collected from studied area

The specific activity of alpha in the water samples collected from mine ponds in the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi mine sites ranged from 0.4 to 0.6 Bq/l (0.55 $\pm$ 0.031 Bq/l), 0.2 to 0.8 Bq/l (0.56 $\pm$ 0.071 Bq/l), 0.6 to 0.9 Bq/l (0.74 $\pm$ 0.044 Bq/l), 0.5 to 0.9 Bq/l (0.71 $\pm$ 0.060 Bq/l), 0.7 to 0.9 Bq/l (0.78 $\pm$ 0.033 Bq/l), and 0.2 to 0.8 Bq/l (0.46 $\pm$ 0.041 Bq/l), respectively (Figures 2a-f, Table 1). These values were higher than the mean value of the control samples (0.05 $\pm$ 0.005 Bq/l) as well as the maximum permissible limit of 0.1 Bq/l for the specific activity of alpha in portable water. The mean specific activity of alpha in the water samples collected from mine ponds in the studied area was also significantly different from the mean control value (Table 1).

The specific activity of alpha in the water samples collected from streams around the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi mine sites ranged from 0.006 to 0.008 Bq/l (0.007 $\pm$ 0.002 Bq/l), 0.03 to 0.04 Bq/l (0.04 $\pm$ 0.004 Bq/l), 0.1 to 0.2 Bq/l (0.15 $\pm$ 0.022 Bq/l), 0.1 to 0.2 Bq/l (0.15 $\pm$ 0.025 Bq/l), 0.2 to 0.3 Bq/l (0.28 $\pm$ 0.031 Bq/l), and 0.01 to 0.012 Bq/l (0.11 $\pm$ 0.003 Bq/l), respectively (Figures 2a-f, Table 1). These values were higher than the mean value of the control samples (0.05 $\pm$ 0.005 Bq/l). They were, however, within the maximum permissible limit of 0.1 Bq/l for the specific activity of alpha in portable water. However, the mean specific activity of alpha in the water samples collected from streams in the studied area was not significantly different from the mean control value (Table 1).

The specific activity of alpha in the water samples collected from wells around the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and

Barkin Ladi mine sites ranged from 0.26 to 0.29 Bq/l (0.28 ± 0.012 Bq/l), 0.09 to 0.010 Bq/l (0.10± 0.005 Bq/l), 0.4 to 0.5 Bq/l (0.43 ± 0.026 Bq/l), 0.4 to 0.5 Bq/l (0.47 ± 0.037 Bq/l), 0.41 to 0.44 Bq/l (0.43 ± 0.050 Bq/l), and 0.3 to 0.4 Bq/l (0.36 ± 0.033 Bq/l), respectively (Figures 2a-f, Table 1). These values were higher than the mean value of the control samples (0.05 ± 0.005 Bq/l). They were, however, within the maximum permissible limit of 0.1 Bq/l for the specific activity of alpha in portable water. The mean specific activity of alpha in the water samples collected from wells in Sabongida Kanar, Kuru Jantar, and Bisichi were significantly different from the mean control value, while the mean specific activity of alpha in the water samples collected from wells in Rayfield, Gero, and Barkin Ladi was not significantly different from the mean control value (Table 1).

The mean specific activities of alpha in the water samples collected from boreholes around the Rayfield, Gero, Kuru Jantar, Bisichi, and Barkin Ladi mine sites were 0.1 to 0.4 Bq/l (0.23 ± 0.061 Bq/l), 0.4 to 0.5 Bq/l (0.45 ± 0.027 Bq/l), 0.5 to 0.7 Bq/l (0.60 ± 0.067 Bq/l), 0.5 to 0.6 Bq/l (0.56 ± 0.033 Bq/l), and 0.5 to 0.9 Bq/l (0.70 ± 0.099 Bq/l), respectively (Figures 2a-f, Table 1). These values were higher than the mean value of the control samples (0.05 ± 0.005 Bq/l). They were equally higher than the maximum permissible limits of 0.1 Bq/l for the specific activity of alpha in portable water, except the water samples collected from boreholes from Rayfield and Gero. The mean specific activity of alpha in the water samples collected from boreholes in the studied area was significantly different from the mean control value, except the water samples collected from boreholes in Rayfield (Table 1).

The overall mean alpha activities for the water samples collected from mine ponds, streams, wells, and boreholes in all locations of the studied area were 0.63 ± 0.1 Bq/l, 0.13 ± 0.01 Bq/l, 0.34 ± 0.1 Bq/l, and 0.51 ± 0.2 Bq/l (Figure 3a). These values were higher than the mean value of the control as well as the maximum permissible limit of 0.1 Bq/l for portable water but for the water samples collected from streams and wells. The mean alpha specific activity in the water samples collected from streams and wells in the studied area was not significantly different from the mean control value (0.053 ± 0.0092 Bq/l), while the mean alpha specific activity of the water samples collected from boreholes and mine ponds was significantly different from the mean control value (Figure 3b). Generally, mine ponds as well as the groundwater bodies (boreholes and wells) in the studied area have a higher alpha activity dose than streams (surface water). This is because they make more contact with the rock strata, and it agrees with the findings of Dowdall et al. [7], and Ogundare and Adekoya [8].

Table 1. ANOVA results for specific activity of Alpha in water samples.

ID	N	Mean	SD	p-value	Min	Max
RW1-RW4	12	$0.55^{f,g,h,i,j,k,l} \pm 0.031$	0.109	0.001	0.40	0.71
GW1-GW4	12	$0.56^{g,h,i,j,k,l} \pm 0.071$	0.246	0.001	0.19	0.89
SW1-SW4	12	$0.74^{k,l} \pm 0.044$	0.152	0.001	0.54	0.94
KW1-KW4	12	$0.71^{j,k,l} \pm 0.060$	0.209	0.001	0.45	1.06
BW1-BW4	12	$0.78^{l} \pm 0.033$	0.115	0.001	0.63	0.95
BLW1-BLW4	12	$0.46^{e,f,g,h,i,j} \pm 0.041$	0.141	0.001	0.26	0.66
RW5-RW6	6	$0.07^{a} \pm 0.002$	0.005	1.000	0.00	0.01
GW5-GW6	6	$0.04^{a,b} \pm 0.004$	0.010	1.000	0.02	0.05
SW5-SW6	6	$0.15^{a,b,c,d} \pm 0.022$	0.055	1.000	0.10	0.21
KW5-KW6	6	$0.15^{a,b,c,d} \pm 0.025$	0.061	1.000	0.09	0.22
BW5-BW6	6	$0.28^{b,c,d,e,f,g} \pm 0.031$	0.076	0.718	0.17	0.35
BLW5-BLW6	6	$0.11^{a,b,c} \pm 0.003$	0.008	1.000	0.10	0.12
RW7-RW8	6	$0.28^{b,c,d,e,f} \pm 0.012$	0.029	0.731	0.25	0.33
GW7-GW8	6	$0.10^{a,b,c} \pm 0.005$	0.012	1.000	0.09	0.12
SW7-SW8	6	$0.43^{e,f,g,h,i} \pm 0.026$	0.063	0.018	0.36	0.52
KW7-KW8	6	$0.47^{e,f,g,h,i,j,k} \pm 0.037$	0.091	0.004	0.33	0.55
BW7-BW8	6	$0.43^{d,e,f,g,h,i} \pm 0.050$	0.121	0.024	0.27	0.59
BLW7-BLW8	6	$0.36^{c,d,e,f,g,h} \pm 0.033$	0.081	0.176	0.24	0.47
RW9-RW10	6	$0.23^{a,b,c,d,e} \pm 0.061$	0.151	0.978	0.08	0.43
GW9-GW10	6	$0.45^{e,f,g,h,i,j} \pm 0.027$	0.065	0.009	0.38	0.57
KW9-KW10	6	$0.60^{h,i,j,k,l} \pm 0.067$	0.164	0.001	0.42	0.85
BW9-BW10	6	$0.56^{h,i,j,k,l} \pm 0.033$	0.080	0.001	0.41	0.63
BLW9-BLW10	6	$0.70^{i,j,k,l} \pm 0.099$	0.242	0.001	0.43	0.97
CONTROL	**9**	$\mathbf{0.05^{a,b} \pm 0.005}$	**0.009**		**0.05**	**0.06**

Means with the same letters are not significantly different.

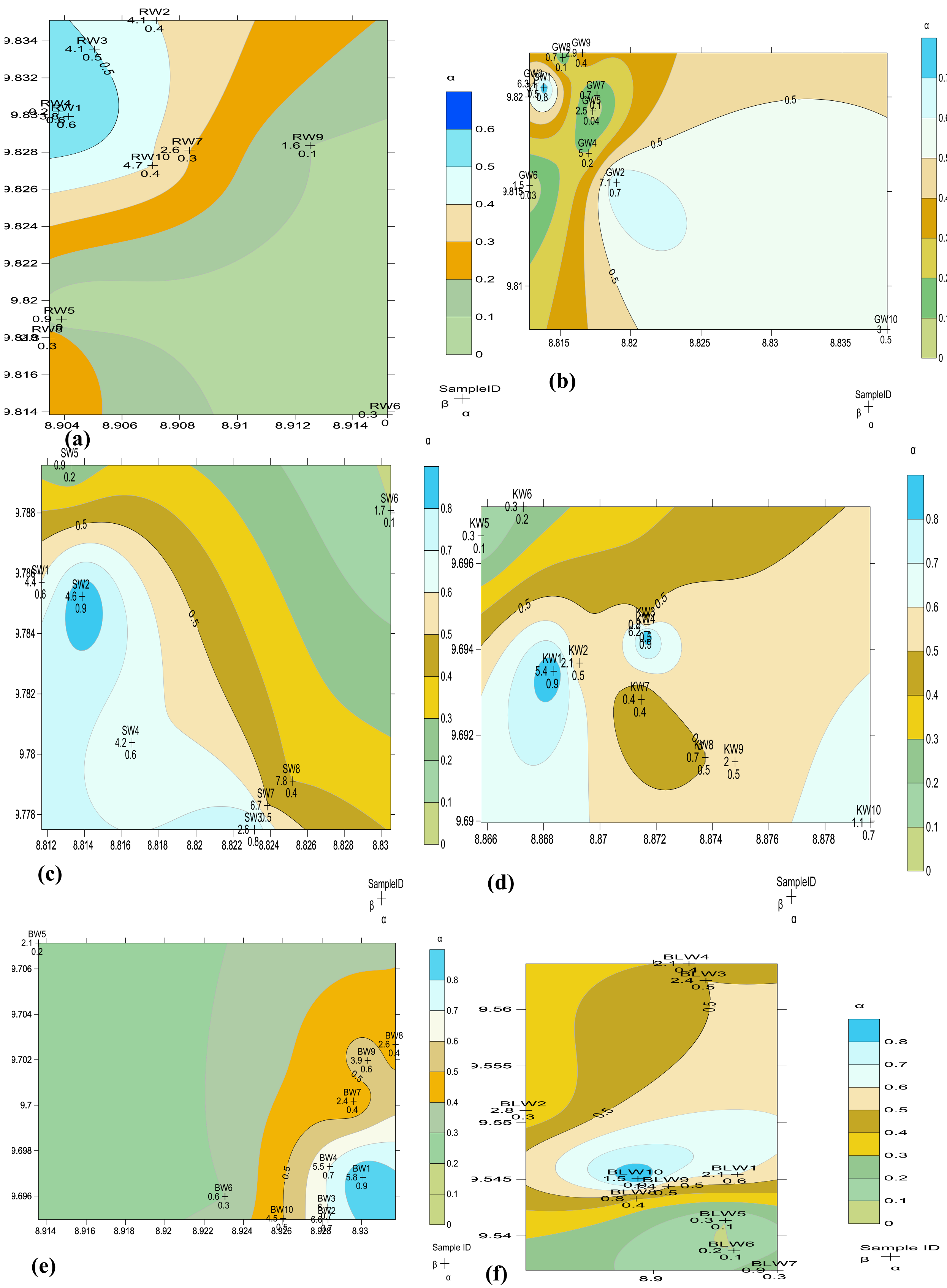

Figure 2. Alpha and Beta activities in water samples collected from a) Rayfield, b) Gero, c) Sabongida Kanar, d) Kuru Jantar, e) Bisichi, and f) Barkin Ladi.

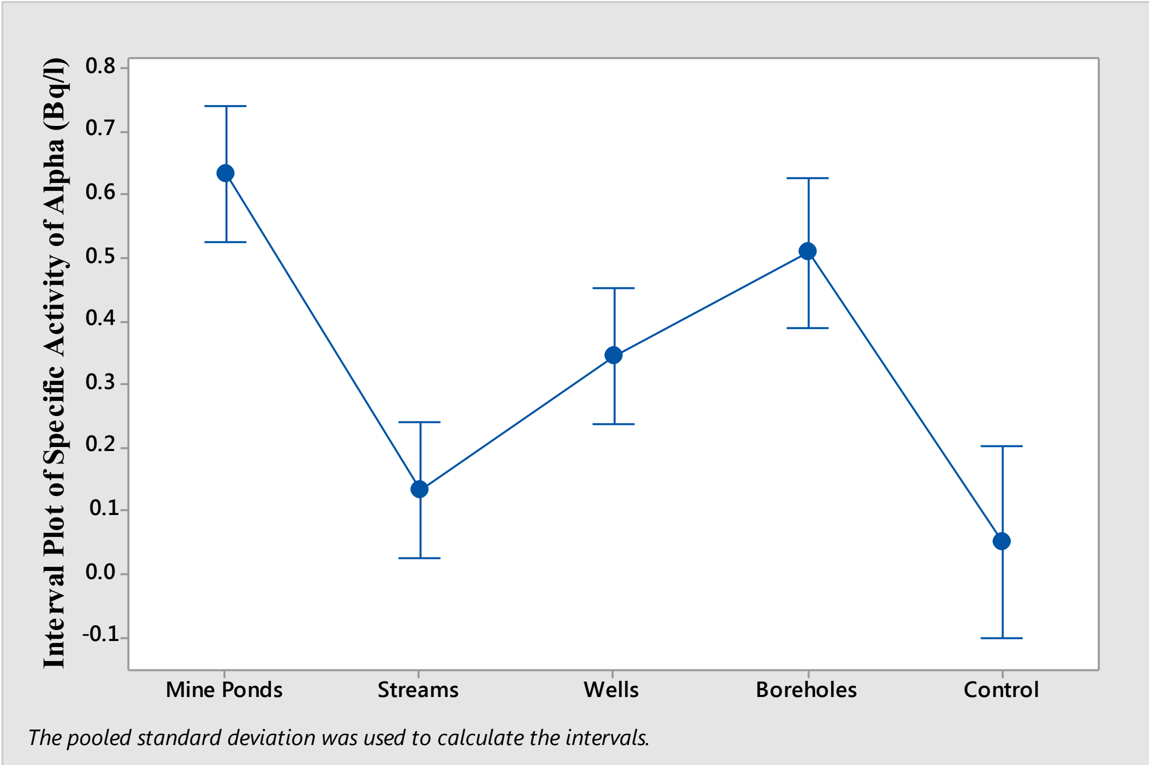

Figure 3a. Interval plot of specific activity of Alpha in water samples collected from mine ponds, streams, wells, and boreholes.

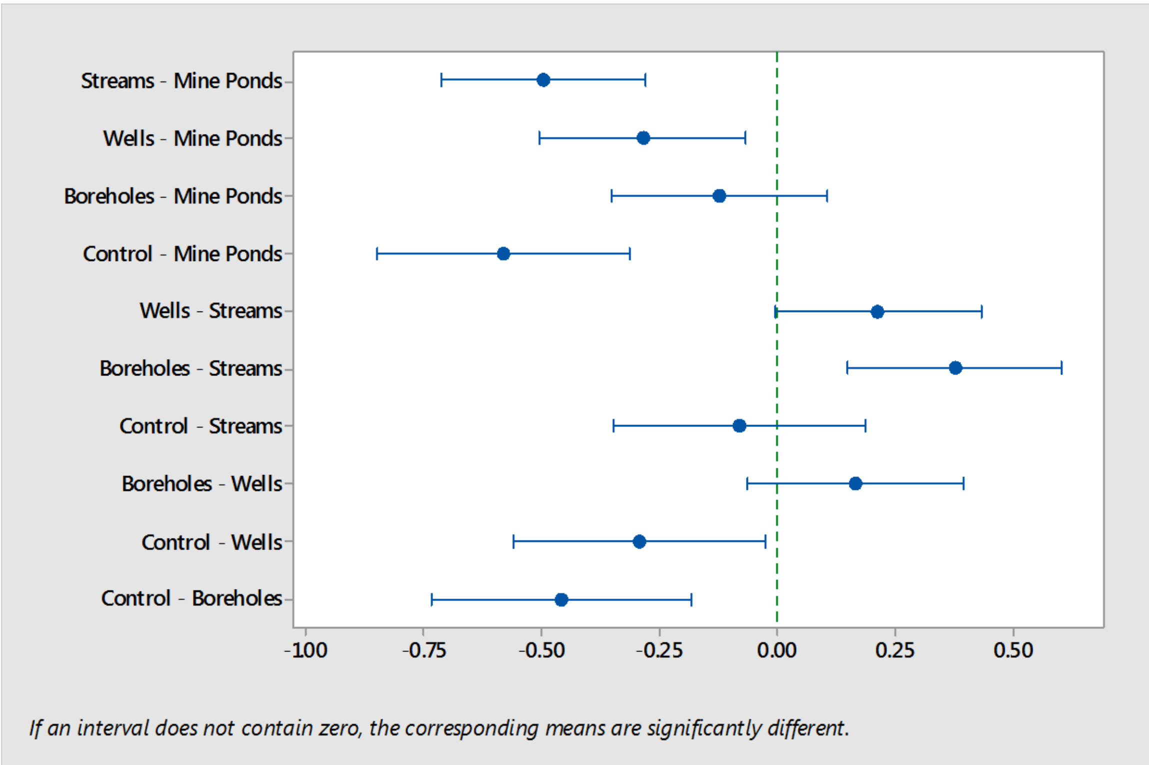

Figure 3b. Tukey plot of specific activity of Alpha in water samples collected from mine ponds, streams, wells, and boreholes.

4.2. Specific activity of Beta in water samples collected from studied area

The mean specific activity of beta in water samples collected from mine ponds in the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi mine sites were 0.2 to 4.1 Bq/l (3.1 ± 0.499 Bq/l), 3.1 to 7.1 Bq/l (5.5 ± 0.522 Bq/l), 2.6 to 4.6 Bq/l (3.9 ± 0.429 Bq/l), 0.8 to 6.2 Bq/l (3.7 ± 0.719 Bq/l), 5.5 to 6.6 Bq/l (5.9 ± 0.214 Bq/l), and 0.2 to 4.1 Bq/l (2.3 ± 0.093 Bq/l), respectively (Figures 2a-f, Table 2). These values were higher than the mean value of the control samples (0.70 ± 0.259 Bq/l) as well as the maximum permissible limit of 1.0 Bq/l for the specific activity of beta in portable water. The mean specific activity of beta in the water samples collected from mine ponds in the studied area was also significantly different from the mean control value, except the water samples collected in mine ponds from Barkin Ladi (Table 2).

The mean specific activities of beta in water samples collected from streams around the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi mine sites were 0.3 to 0.9 Bq/l (0.6 ± 0.149 Bq/l), 1.5 to 2.5 Bq/l (2.0 ± 0.240 Bq/l), 0.9 to 1.7 Bq/l (1.3 ± 0.193 Bq/l), 0.3 Bq/l (0.3 ± 0.010 Bq/l), 0.2 to 2.1 Bq/l (1.4 ± 0.332 Bq/l), and 1.5 to 2.5 Bq/l (0.3 ± 0.052 Bq/l), respectively (Figures 2a-f, Table 2). These specific activities of beta in water samples collected from streams in Gero, Sabongida Kanar, and Bisichi were higher than the mean value of the control samples (0.70 ± 0.259 Bq/l) as well as the maximum permissible limit of 1.0 Bq/l for the specific activity of beta in portable water. There was, however, no significant difference between the mean specific activity of beta in the water samples collected from streams in the studied area and the mean control value (Table 2).

The mean specific activities of beta in the water samples collected from wells around the Rayfield, Gero, Sabongida Kanar, Kuru Jantar, Bisichi, and Barkin Ladi mine sites were 2.3 to 2.6 Bq/l (2.5 ± 0.094 Bq/l), 0.7 Bq/l (0.70± 0.030 Bq/l), 2.6 to 4.6 Bq/l (3.4 ± 0.361 Bq/l), 0.4 to 0.7 Bq/l (0.6 ± 0.068 Bq/l), 2.4 to 2.6 Bq/l (2.5 ± 0.060 Bq/l), and 0.7 Bq/l (0.8 ± 0.053 Bq/l), respectively (Figures 2a-f, Table 2). These values were higher than the mean value of the control samples (0.70 ± 0.259 Bq/l) as well as the maximum permissible limit of 1.0 Bq/l for the specific activity of beta in portable water. The mean specific activity of beta in the water samples collected from wells in the studied area was not significantly different from the mean control value (Table 2).

The mean specific activities of beta in water samples collected from boreholes around the Rayfield, Gero, Kuru Jantar, Bisichi, and Barkin Ladi mine sites were 1.6 to 4.7 Bq/l (3.2 ± 0.707 Bq/l), 2.9 Bq/l to 3 Bq/l (3.0 ± 0.156 Bq/l), 1.1 to 2 Bq/l (1.5 ± 0.208 Bq/l), 3.9 to 4.5 Bq/l (4.1 ± 0.183 Bq/l), and 1.6 to 4.7 Bq/l (1.50 ± 0.051 Bq/l), respectively (Figures 2a-f, Table 2). These values were higher than the mean value of the control samples (0.70 ± 0.259 Bq/l) as well as the maximum permissible limit of 1.0 Bq/l for the specific activity of beta in portable water. The mean specific activity of beta in the water samples collected from boreholes in the study area was significantly different from the mean control value, except the water samples collected from boreholes in Rayfield and Gero (Table 2).

The overall mean beta activity dose for the water samples collected from mine ponds, streams, wells, and boreholes ranged from 4.1 ± 1.8 Bq/l, 1.0 ± 0.7 Bq/l, 2.4 ± 1.9 Bq/l, and 2.7 ± 1.3 Bq/l, respectively (Figure 4a). These values were higher than the mean value of the maximum permissible limit of 1 Bq/l for portable water. They were equally higher than the mean value of the control. There were, however, no significant differences between the mean beta specific activities for the water samples collected from all sources in the studied area and the maximum permissible limit of 1 Bq/l. There were, however, no significant differences between the mean beta specific activity for the water samples collected from all sources in the studied area and the mean control value (Figure 4b). It was discovered that the specific activity in most water samples was above the 0.1 Bq/l and 1 Bq/l limits set by WHO [3] for the alpha and beta activities. Generally, mine ponds as well as the groundwater bodies (boreholes and wells) in the studied area have a higher beta activity dose than streams (surface water). This is because they make more contact with the rock strata, and it agrees with the findings of Dowdall et al. [7], and Ogundare and Adekoya [8].

Table 2. ANOVA results for specific activity of Beta in water samples.

ID	N	Mean	SD	p-value	Min	Max
RW1-RW4	12	$3.1^{c,d,e,f}\pm0.499$	1.727	0.192	0.19	4.15
GW1-GW4	12	$5.5^{g,h}\pm0.522$	1.807	0.001	2.94	8.61
SW1-SW4	12	$3.9^{h}\pm0.429$	1.485	0.001	2.61	4.62
KW1-KW4	12	$3.7^{d,e,f,g,h}\pm0.719$	2.488	0.012	0.65	6.76
BW1-BW4	12	$5.9^{h}\pm0.214$	0.741	0.001	4.62	6.98
BLW1-BLW4	12	$2.3^{a,b,c,d,e,f}\pm0.093$	0.321	0.860	1.87	2.89
RW5-RW6	6	$0.6^{a,b}\pm0.149$	0.364	1.000	0.30	1.05
GW5-GW6	6	$2.0^{a,b,c,d,e,f}\pm0.240$	0.587	0.995	1.51	2.84
SW5-SW6	6	$1.3^{a,b,c,d}\pm0.193$	0.472	1.000	0.87	2.02
KW5-KW6	6	$0.3^{a}\pm0.010$	0.025	1.000	0.24	0.31
BW5-BW6	6	$1.4^{a,b,c,d}\pm0.332$	0.815	1.000	0.57	2.26
BLW5-BLW6	6	$0.3^{a}\pm0.052$	0.128	1.000	0.13	0.44
RW7-RW8	6	$2.5^{a,b,c,d,e}$,f±0.094	0.231	0.854	2.18	2.82
GW7-GW8	6	$0.7^{a,b}\pm0.030$	0.073	1.000	0.62	0.80
SW7-SW8	6	$3.4^{d,e,f,g}\pm0.361$	0.885	0.126	2.52	4.54
KW7-KW8	6	$0.6^{a}\pm0.068$	0.167	1.000	0.34	0.80
BW7-BW8	6	$2.5^{a,b,c,d,e,f}\pm0.060$	0.146	0.864	2.19	2.57
BLW7-BLW8	6	$0.8^{a,b,c}\pm0.053$	0.130	1.000	0.68	0.98
RW9-RW10	6	$3.2^{d,e,f}\pm0.707$	1.733	0.273	1.43	5.05
GW9-GW10	6	$3.0^{b,c,d,e,f}\pm0.156$	0.380	0.428	2.56	3.67
KW9-KW10	6	$1.5^{a,b,c,d,e}\pm0.208$	0.508	0.001	1.01	2.06
BW9-BW10	6	$4.1^{f,g,h}\pm0.183$	0.448	0.008	3.39	4.61
BLW9-BLW10	6	$1.5^{a,b,c,d,e}\pm0.051$	0.125	0.001	1.33	1.66
CONTROL	9	$0.70^{a,b}\pm0.259$	0.448		0.18	0.98

Means with the same letters are not significantly different.

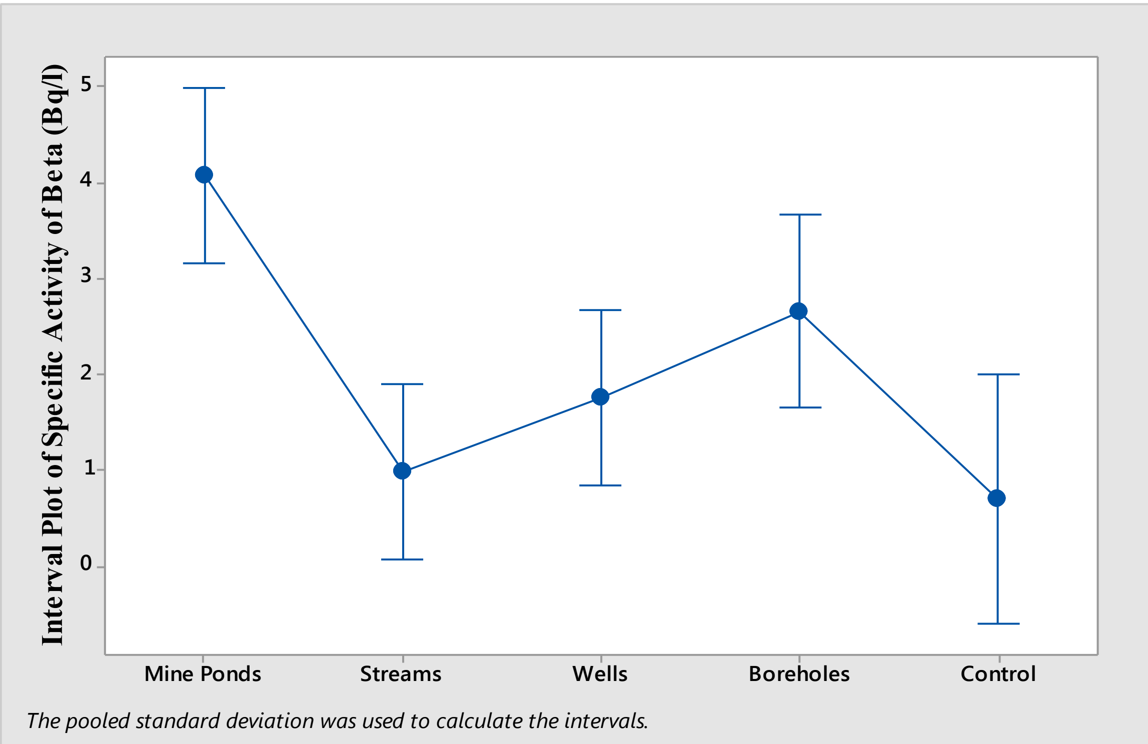

Figure 4a. Interval plot of specific activity of Beta in water samples collected from mine ponds, streams, wells, and boreholes.

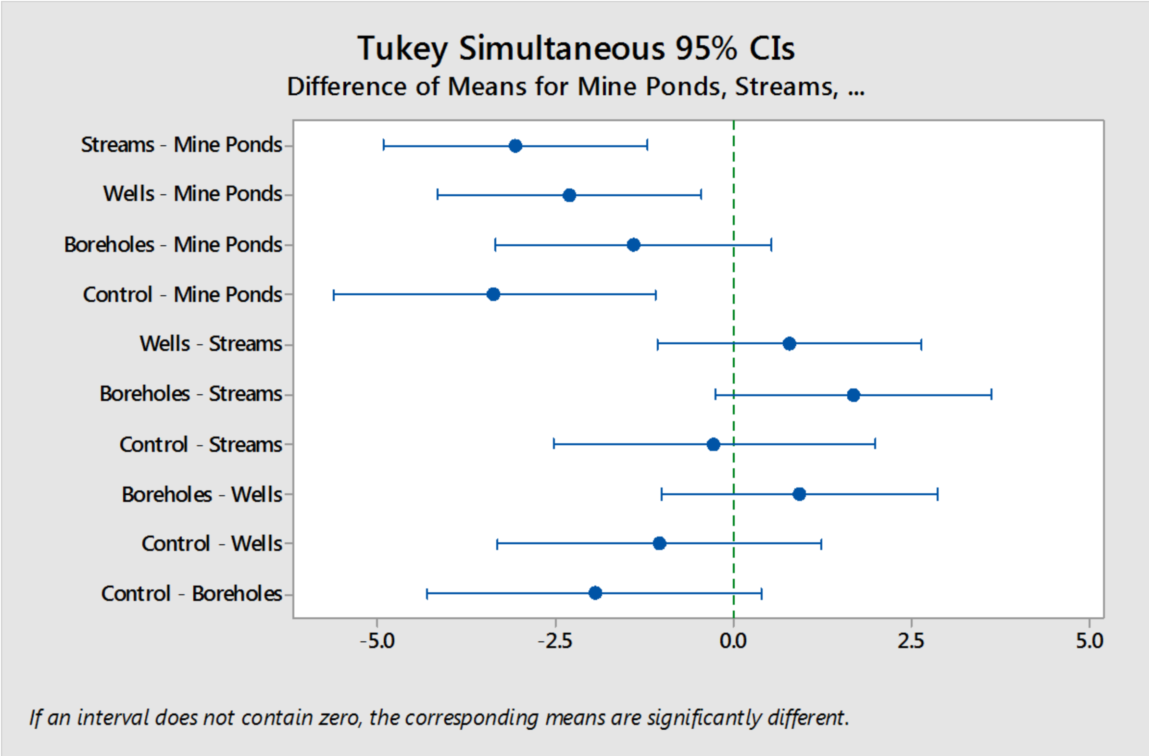

Figure 4b. Tukey plot of specific activity of Beta in water samples collected from mine ponds, streams, wells, and boreholes.

The specific activities of alpha and beta in water sources are negatively correlated with distance (Table 3). This implies that the specific activities of alpha and beta in the water sources decreased as distance from the mine increased. It is, therefore, clear that the mine sites are the sources of high radiation values recorded in the water sources. The coefficient of correlation of alpha and beta in streams (-0.68 and -0.64, respectively) are higher than those of the wells and boreholes. This is because the groundwater sources are not only polluted by the mine sites but also by the rock strata they come in contact with. This agrees with the findings of Dowdall et al. [7], and Ogundare and Adekoya [8].

Table 3. Pearson correlation coefficient between Alpha and Beta activities and distance to water sources.

Water sources	Alpha	Beta
Streams	-0.68	-0.64
Wells	-0.52	-0.51
Boreholes	-0.52	-0.53

5. Conclusions

The mean alpha activity for the water samples collected from mine ponds, streams, wells, and boreholes of 0.63 $\pm$ 0.1 Bq/l, 0.13 $\pm$ 0.1 Bq/l, 0.34 + 0.1 Bq/l, and 0.51 $\pm$ 0.2 Bq/l for the water samples collected from mine ponds, streams, wells, and boreholes, respectively, makes the water samples unwholesome. This is because the values are higher than the mean value of the control as well as the maximum permissible limit of 0.1 Bq/l for portable water but for few of the water samples collected from streams and wells.
The mean beta activity dose for the water samples collected from mine ponds, streams, wells, and boreholes of 4.1 $\pm$ 1.8 Bq/l, 1.0 $\pm$ 0.7 Bq/l, 2.4 $\pm$ 1.9 Bq/l, and 2.7 $\pm$ 1.3 Bq/l for the water samples collected from mine ponds, streams, wells, and boreholes, respectively, equally makes the water samples unwholesome. This is because the values were higher than the mean value of the maximum permissible limit of 1 Bq/l for portable water. They were equally higher than the mean value of the control. It was discovered that the specific activity in most of the water samples were above the 0.1 Bq/l and 1 Bq/l limits set by WHO [3] for the alpha and beta activities. The water is, therefore, not suitable for the domestic or industrial usage. The present use of water from the mine ponds for irrigation and other domestic and industrial purposes should be discontinued as these could result in exposure to radiation. Generally, mine ponds as well as the groundwater bodies (boreholes and wells) in the studied area contain more significant amounts of natural radioactivity than streams (surface water). The specific activities of alpha and beta in the water

samples decreased as distance from the mine increased. It is, therefore, clear that the mine sites are the sources of high radiation values recorded in the water sources.

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ارزیابی آلودگی رادیواکتیو در آب‌های اطراف معادن با استفاده از ضد تابش

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چکیده:

آلودگی آب در نزدیکی معادن روباز باید مورد توجه اساسی قرار بگیرد. شواهدی از عناصر رادیواکتیو همراه با مواد معدنی در ایالت Plateau نیجریه نشان‌دهنده وجود این آلودگی است. برای رسیدگی به این چالش، سطح آب رادیواکتیو از نمونه‌های آب از استخرهای معدنی، جریان‌ها، چاه‌ها و گمانه‌های اطراف معادن در این ایالت مورد ارزیابی قرار گرفت. نمونه‌های آب برای فعالیت‌های پرتوی آلفا و بتا با استفاده از معیارهای MPC 2000 بر اساس مقررات آژانس بین‌المللی انرژی اتمی در مرکز تحقیقات و آموزش انرژی Zaria مورد تجزیه‌وتحلیل قرار گرفت. میانگین مقدار فعالیت تابشی آلفا برای نمونه‌های آب جمع‌آوری شده از حوضچه‌ها، جریان‌ها، چاه‌ها و گمانه‌های معدنی به ترتیب برابر با 0.1 Bq/l ± 0.63، 0.1 Bq/l ± 0.13، 0.1 Bq/l ± 0.34 و 0.2 Bq/l ± 0.51 بود. میانگین مقدار فعالیت تابشی بتا برای نمونه‌های آب جمع‌آوری شده از حوضچه‌ها، جریان‌ها، چاه‌ها و گمانه‌های معدنی به ترتیب برابر با 1.8 Bq/l ± 4.1، 0.7_Bq/l ± 1.0، 1.9 Bq/l ± 2.4 و 1.3 Bq/l ± 2.7 بود. نتایج نشان داد، این آب‌ها با مصرف انسانی سازگاری ندارد و استفاده از آن‌ها باید متوقف شود. با افزایش فاصله از معدن، فعالیت تابش آلفا و بتا در نمونه‌های آب کاهش می‌یابد؛ بنابراین، واضح است که سراچه‌های معدنی منبع مقادیر بالایی از تابش ثبت شده در منابع آبی هستند.

کلمات کلیدی: آلفا، بتا، رادیواکتیو، تابش، عناصر همراه رادیواکتیو.