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Health Risk Assessment of Natural Radioactivity in Wasteland Soils in Okakarara, Namibia

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ABSTRACT

Human activities such as waste disposal tend to impact negatively on the environment. Some waste products are associated with elevated levels of natural radioactivity. It was therefore, the aim of the study to investigate the health risk associated with natural radioactivity from Okakarara municipal waste dumpsite. In this study, gamma spectrometric analysis was used to determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in 18 soil samples. From these activity concentrations, some radiological parameters were calculated. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in (Bq.kg^{-1}) were 15.45±0.47, 18.00±0.55, and 215.73±4.29, respectively. The average Ra_{eq} value was 57.80±0.98 Bq.kg^{-1}. In all the samples, Ra_{eq} values were found to be lower than the worldwide value of 370 Bq.kg^{-1}. The absorbed dose rate was found to be 27.00±0.44 nGy.h^{-1}, whereas an average value of 0.03 mSv.y^{-1} for AEDE was noted, which is less than 0.48 mSv, the worldwide average. The Annual Gonadal Dose Equivalent (AGDE) was 190.89 µSv.y^{-1}, a value less than the world average of 298 µSv.y^{-1}. The average values of the Representative Level Index (RLI) and the External Hazard Index (H_{ex}) was found to be 0.43 and 0.16., respectively. These indices were less than unity. The average value of the excess lifetime cancer risk (ECLR) was 1.16 x 10^{-4} ?? units. This value was lower than the internationally acceptable limit of 2.9 x 10$^{-4??}$. From these results it can be concluded that natural radioactivity from the wasteland area of Okakarara was not an issue of health concern.

INTRODUCTION

In 1896, A. H. Becquerel discovered radioactivity. Since then, several studies on radioactivity have been undertaken [1]. Radiation and radioactivity constitute a major part of human existence. This process is both statistical and natural that describes the change of unstable nuclei with a release of energy by parent nuclei into daughter nuclei which are more stable [2]. The energy released during the transformation process result in the emission of nuclear particles or waves in the form of beta particles, alpha particles and gamma rays. The emissions are referred to as ionizing radiations. [3]. Ionizing radiations are radiations that produces charge when the pass through biological matter. This ionizing property makes them hazardous to biological tissues.

As early as 1920s to 1930s, the radiological hazardous nature of ionizing radiation has been the subject of discussion amongst the science world [4]. Both empirical and epidemiological findings has pointed to the carcinogenic properties of radioactive materials. A study by United States Food and Drug Administration (USFDA) said that since the beginning of this century, there has been increased cases of bone sarcomas and other malignancies to individuals who had ingested radium paint [5]. In addition to skin cancer which was also prominent among early dentists and radiologists from exposure to radioactive materials. Also, those who survived the Hiroshima atomic bomb were reported to have suffered from leukaemia because of exposure to radiation above 100 rem [5].

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The damage to biological cells from ionizing radiation are classified as short term or long term. The radioactive short-term effects could arise after short time exposure to radiation, while those of long-term effects only show up after many years [5]. After exposure, interaction of ionizing radiation with cells and tissues may lead to alterative processes in mitosis, destruction of chromosomal arrangement that may ultimately occasion the development of cancerous cells. The damage from this ionizing radiation can be temporary or life-long depending on the severity of the exposure. In some cases, the damaged cell and tissues may recover from the effects of radiation only when such exposure is of smaller magnitude [6]. If the exposure is on a large scale, it become important from the point of view of health physics because it carries more degree of harm.

Human exposure to naturally occurring radionuclides comes from either man-made or natural sources. Study have shown that about 80 % of these ionizing radiations comes from natural background radiation, which include cosmic rays, radon gas and terrestrial radionuclides [7]. That which forms terrestrial radionuclides are series radionuclides of uranium-radium (^{238}U-^{226}Ra), Thorium (^{232}Th) together with non-series radionuclides of potassium (^{40}K). The levels of ionizing radiations may be exacerbated by man-made activities. Human induced activities such as waste disposal tend to impact negatively on the environment and public health. Some waste products are radioactive in nature and may have originated from industrial activities. Wastes associated with these activities can enhance levels of natural radioactivity in the environment [8]. They pollute water resources, air, plants, animals and soil. Soil is one of the major recipients of these waste products and the main reservoir of these naturally occurring radionuclides. They are transferred to humans through a number of pathways such as ingestion, dermal contact and inhalation of radon gas [9]. Radionuclides may pose a long-term risk even in very low concentrations. This study is aimed at carrying out measurements of the activity concentrations of radionuclides from the wasteland soils of Okakarara. The activity concentrations were then used to carry out health risk assessment in terms of radium equivalent activity, absorbed dose rate in air, annual gonadal dose equivalent, the annual effective dose equivalent, and excess lifetime cancer risk. Other radiological parameters that were considered are gamma representative level index and external hazard index.

Materials and Methods

The Study Area

The research was carried out in January 2019 with samples collected from the Okakarara municipal waste dumpsite. The sampling waste dumpsite is located in the Okakarara Constituency (Figure 1). The town covers a land mass of 18,951 km^2 and is inhabited by 21, 000 people dominated by the livestock farming by Herero communities. The dumpsite is located at $20^{O}35'9''$S latitude and $17^{O}27'28''$E longitude. The perimeter fence around the dumpsite has being vandalised which has made scavenging in the dumpsite a common practice as shown in Figure 2.

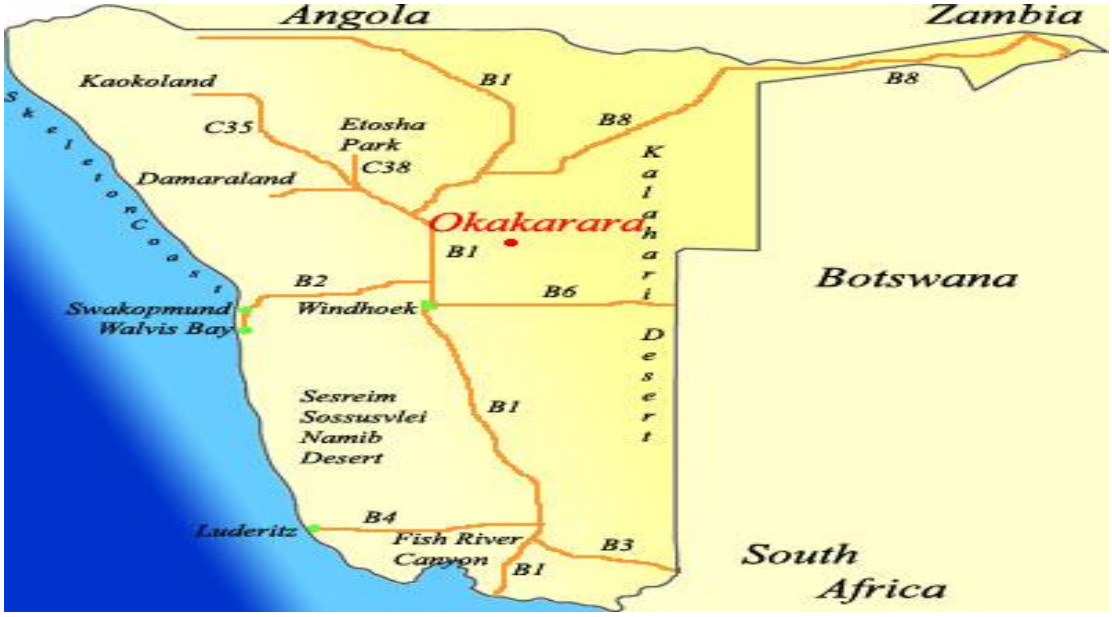

Fig. (1): Location map of Okakarara

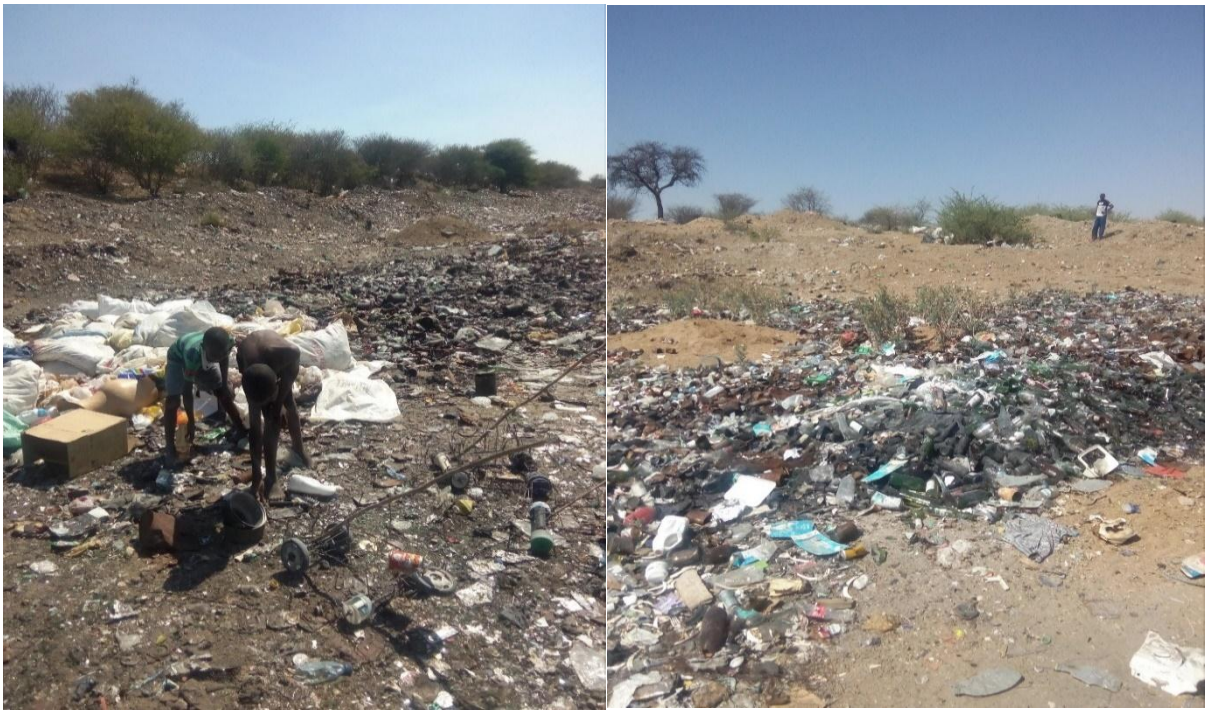

Fig. (2): Part of Okakarara dumpsite with Children scavenging

Sample Collection and Preparation

Eighteen samples of soil were collected from a depth of 20-50 cm with a soil auger from different locations in the waste dumpsite using purposive random sampling. The soil samples were pound and dried in the oven at $120\ ^{O}C$ to remove moisture. Each sample was then homogenized and sieved to about 200-mesh size. The samples weighing 1 kg were then put into a marinelli beaker and sealed for approximately 30 days to allow radioactive secular equilibrium to be attained between ^{238}U, ^{232}Th and their corresponding daughters [10].

Gamma-ray Spectrometry

The radioactivity in the collected soil samples was measured using a coaxial (62.80 X 64.80 mm) Canberra gamma-ray spectrometer high purity germanium (HPGe) detector Model No. GC4520 SN 10882 with a resolution of 2.00 keV full width at half maximum (FWHM) at 1.33 MeV peak of ^{60}Co, 45 % relative efficiency and 1.200 keV (FWHM) at 122 keV. The detector is covered with lead shielding to reduce background radiation and cooled by liquid nitrogen. A computer-based software, Genie 2000 from Canberra was used for data acquisition and analysis. The samples were counted for 53200 s in a reproducible manner with the configuration and geometry maintained throughout the analysis. The gamma spectrometry system was energy and efficiency calibrated using gamma-ray energies between 0.060 MeV to 2 MeV mixed radionuclides standard in a 500 ml Marinelli beaker. The 295.22 keV, 351.93 keV for ^{214}Pb and 609.32 keV, 1120.29 keV and 1764.49 keV for ^{214}Bi gamma lines were used in the assessment of activity concentration of ^{226}Ra, while 911.21 keV for ^{228}Ac and 968.97 keV and 238.63 keV for ^{212}Pb were used for ^{232}Th. The isotope of ^{40}K was obtained from the single 1460 keV Gamma-line of ^{40}K.

Risk Assessment of Radionuclides

Risk assessment was done using the following radiological parameters; Radium Equivalent Activity (Ra_{eq}), Annual Effective Dose Equivalent (AEDE), Absorbed Dose rate (D_R), Annual Gonadal Dose Equivalent (AGDE), Representative Level Index (RLI), External Hazard Index (H_{ex}) and Excess Lifetime Cancer Risk (ELCR).

Radium Equivalent Activity (Ra_{eq})

The natural radioactivity in soil, ^{226}Ra, ^{232}Th and ^{40}K are not uniform in their distribution. To get uniformity with respect to radiation exposure, the Radium equivalent activity Ra_{eq} is used [11]. It is the weighted sum of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations, which assumes that 370 $Bq.kg^{-1}$ of ^{226}Ra, 259 $Bq.kg^{-1}$ of ^{232}Th and 4810 $Bq.kg^{-1}$ of ^{40}K produce the same dose rate. It can be calculated using Equation 2.

$$Ra_{eq} = \left(\frac{AC_{Ra}}{370} + \frac{AC_{Th}}{259} + \frac{AC_{K}}{4810}\right) \times 370 \qquad \textbf{(1)}$$

which is equivalent to

$$Ra_{eq} = AC_{Ra} + 1.43AC_{Th} + 0.077AC_{K} \quad \textbf{(2)}$$

where AC_{Ra}, AC_{Th} and AC_{K} are the activity concentrations in Bq kg^{-1} of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

Absorbed Dose Rate in Air (D_R)

The absorbed dose rate depends on the specific activity of ^{226}Ra, ^{232}Th and ^{40}K in soil with the assumption that other radioactive isotopes are negligible. Since contributions from these radionuclides are very small to the overall contribution to total background radiation [12]. The absorbed dose rate was calculated using the relation in equation 3.

$$D_R(nGy.h^{-1}) = 0.462AC_{Ra} + 0.604AC_{Th} + 0.0417AC_{K} \quad \textbf{(3)}$$

where D_R is the absorbed dose rate, and AC_{Ra}, AC_{Th} and AC_{K} have the same meaning as in equation 2.

Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent was measured in unit of mSv y^{-1}. This is the dose received by the general public from radioactivity concentrations in the soil and was calculated using equation 4.

$$AEDE(mSv.y^{-1}) = D(nGy.h^{-1}) \text{ x } 8760 \text{ (h) x } 0.2 \text{ x } 0.7 \text{ (Sv.Gy}^{-1}) \text{ x } 10^{-6} \quad \textbf{(4)}$$

Where D is absorbed dose rate ($nGy\,h^{-1}$), and 0.7 SvGy^{-1} is the conversion coefficient from absorbed dose to effective dose. The number 0.2 represent the occupancy factor for outdoor [13], and 8760 hours is the time for one year while 10^{-6} is the conversion factor.

Annual Gonadal Dose Equivalent (AGDE)

According to UNSCEAR (2010) gonads are considered as organs of interest for dosimetry purposes. These are primary reproductive organs; testes in the male and the ovaries in the female. The International Commission for Radiation Protection [14] gave the number 0.2 as the Tissue Weighting Factor for Gonads. Because gonads are highly radio-sensitivity, every effort must be done to reduce gonadal dose to the general population. An elevation of the levels of AGDE is also known to affect the bone marrow that produces red blood cells. This may lead to cancer of the blood called leukaemia, which is often fatal. Other organs of interest are the thyroid, lungs, liver, colon, and bladder [15]. The annual gonadal dose equivalent (AGDE) in μSv.y^{-1} is determined using the formula in Equation 5 [16]:

$$AGDE(\mu Sv.y^{-1}) = 3.09AC_{Ra} + 4.19AC_{Th} + 0.314AC_{K} \quad \textbf{(5)}$$

where AC_{Ra}, AC_{Th} and AC_{K} have the same meaning as in equation 2.

Representative Level Index (RLI)

The gamma radioactivity Representative Level Index associated with naturally occurring radioactive elements and can be measured using the following formula [8]:

$$RLI = \frac{1}{150}AC_{Ra} + \frac{1}{100}AC_{Th} + \frac{1}{1500}AC_{K} \quad \textbf{(6)}$$

The RLI values were calculated and the results shown in Table 3.

External Hazard Index (H_{ex})

Different radionuclides contribute to the total gamma dose received by man. To quantify radiological hazards as a single quantity, the hazard index is used [17]. The External hazards index was computed using the relation in equation 7 [13]. For radiological purposes, the H_{ex} has to be less than one in order to keep exposure to radiation hazard negligible [18].

$$H_{ex} = \left(\frac{AC_{Ra}}{370} + \frac{AC_{Th}}{259} + \frac{AC_{K}}{4810}\right) \leq 1 \quad \textbf{(7)}$$

Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk (ELCR) for outdoor exposure, gives the probability for an individual to develop cancer over a lifetime at a given exposure. The ELCR was estimated using the assumption that there is a linear relationship between dose and the corresponding stochastic effects. This was calculated using equation 8.

$$ELCR = AEDE \times DL \times RF \quad \textbf{(8)}$$

where AEDE, DL and RF are the Annual Effective Dose Equivalent, Duration of Life (70 years) and RF is the risk factor (Sv^{-1}). The International Commission on Radiological Protection (ICRP) employed the value 0.05 for stochastic effects for the public [19].

RESULTS AND DISCUSSIONS

Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K analyzed from the soil in the dumpsite are presented in Table 1. Also presented in Table 1 are the results of the Radium Equivalent Activity (Ra_{eq}) together with the Absorbed Dose Rate in Air (D_R).

The average activity concentrations in (Bq.kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K were 15.45±0.47 ranging from 8.13±0.31 to 33.57±0.83, 18.00±0.55, ranging from 10.59±0.33 to 30.79±0.73 and 215.73±4.29 ranging from

124.00±2.53 to 383.79±7.15, respectively. It is clear that the concentrations of ^{226}Ra, ^{232}Th and ^{40}K were below the critical values of 35, 30 and 400 Bq.kg^{-1}, respectively[13].

The values of Ra_{eq} from the Wasteland soil ranged from 39.57±0.65 to 87.16±1.28 Bq.kg^{-1} with an average of 57.80±0.98 Bq.kg^{-1}. The estimated values of Ra_{eq} were below the world acceptable limit of 370 Bq.kg^{-1} [20]. When the average value was compared with those from other studies, the value of this study was lower than those measured in Ondo city, Southwestern Nigeria of 119.11 Bq.kg^{-1} [20].

The result of the outdoor absorbed dose rate ranged from 18.44±0.29 to 40.86±0.57 nGy.h^{-1} with an average of 27.00±0.44 nGy.h^{-1}. This value was found lower than the internationally acceptable value of 59 nGy.h^{-1}. [13].

Table (1): Activity Concentrations (^{226}Ra, ^{232}Th and ^{40}K), Radium Equivalent Activity (Req) and Absorbed Dose Rate (D_R) from Okakarara Wasteland Soils, Namibia

Sample ID	Activity Concentrations (Bq kg^{-1})			(Req) (Bq kg^{-1})	(D_R) (nGy.h^{-1})
	^{226}Ra	^{232}Th	^{40}K		
Ok-01	26.14 ± 0.69	14.63 ± 0.54	156.08 ± 3.30	59.08±1.07	27.42±0.48
Ok-02	8.13 ± 0.31	11.77 ± 0.48	194.23 ± 3.93	39.92±0.81	18.96±036
Ok-03	24.09 ± 0.65	11.36 ± 0.47	153.09 ± 3.24	52.12±0.97	24.37±0.43
Ok-04	12.00 ± 0.40	19.02 ± 0.55	233.38 ± 4.60	57.17±0.95	26.76±0.43
Ok-05	13.76 ± 0.46	30.79 ± 0.73	381.48 ± 7.11	87.16±1.27	40.86±0.57
Ok-06	11.15 ± 0.38	20.90 ± 0.58	242.10 ± 4.75	59.68±0.98	27.87±0.44
Ok-07	33.57 ± 0.84	11.69 ± 0.44	159.57 ± 3.34	62.57±0.78	29.22±0.35
Ok-08	10.28 ± 0.36	18.26 ± 0.53	217.92 ± 4.34	53.17±0.90	24.87±0.40
Ok-09	10.52 ± 0.37	19.85 ± 0.55	210.44 ± 4.21	55.11±0.93	25.62±0.41
Ok-10	11.15 ± 0.38	20.81 ± 0.57	219.66 ± 4.37	57.82±0.96	26.88±0.43
Ok-11	12.49 ± 0.83	19.56 ± 0.64	207.94 ± 4.17	56.47±1.28	26.26±0.57
Ok-12	13.36 ± 0.43	19.21 ± 0.64	204.20 ± 4.11	56.55±1.06	26.29±0.47
Ok-13	30.02 ± 0.82	19.35 ± 0.65	209.69 ± 4.20	73.84±1.28	34.30±0.57
Ok-14	10.10 ± 0.36	16.86 ± 0.51	203.71 ± 4.10	49.90±0.87	23.34±0.39
Ok-15	13.61 ± 0.43	15.96 ± 0.50	200.96 ± 4.05	51.91±0.89	24.31±0.40
Ok-16	13.67 ± 0.44	29.63 ± 0.71	383.97 ± 7.15	85.61±1.24	40.22±0.56
Ok-17	9.21 ± 0.34	13.70 ± 0.45	180.77 ± 3.71	42.72±0.78	20.07±0.35
Ok-18	14.88 ± 0.41	10.59 ± 0.33	124.00 ± 2.53	39.57±0.65	18.44±0.29
Minimum	**8.13 ± 0.31**	**10.59 ± 0.33**	**124.00 ± 2.53**	**39.57±0.65**	**18.44±0.29**
Maximum	**33.57 ± 0.83**	**30.79 ± 0.73**	**383.97 ± 7.15**	**87.16±1.28**	**40.86±0.57**
Average	**15.45 ± 0.47**	**18.00 ± 0.55**	**215.73 ± 4.29**	**57.80±0.98**	**27.00±0.44**
World Average (13)	**35**	**30**	**400**	**370**	**59**

The results of Annual Effective Dose Equivalent (AEDE), Representative level index, The Annual Gonadal Dose Equivalent (AGDE), External Hazard index (H_{ex}) and Excess Lifetime Cancer Risk (ELCR) of Okakarara Wasteland Soils were calculated as presented in Table 2.

The AEDE range from 0.02 to 0.05 $mSv.y^{-1}$ and average value was found to be 0.03 $mSv.y^{-1}$ for the wasteland soil. The average value of AEDE was found to be below the worldwide average of 0.48 mSv (13).

The Annual Gonadal Dose Equivalent (AGDE) values for Wasteland Soils were in the range 129.29 to 291.31 $\mu Sv.y^{-1}$ with an average of 190.89 $\mu Sv.y^{-1}$. This value was less than the world average value of 298 $\mu Sv.y^{-1}$ [21].

On the other hand, the Representative Level Index (RLI) was found to be in the range 0.29 to 0.65 Bq kg^{-1} with an average value of 0.43 Bq kg^{-1}. Clearly, the RLI values obtained in the present work did not exceed the value of unity, which is the critical value. [22].

The results of the External Hazard Index (H_{ex}) ranged from 0.11 to 0.24 with an average of 0.16. The calculated results showed that all the values for H_{ex} were lower than unity, which is the maximum permissible value by UNSCEAR [13], making the wasteland soil safe to the population in the area.

The excess lifetime cancer risk (ECLR) ranged from 0.79×10^{-4} to 1.75×10^{-4}, with a mean of 1.16×10^{-4}. This evaluated result was found to be lower than the world critical value of 2.9×10^{-4} [23].

Table (2): Annual Effective Dose Equivalent (AEDE), Representative level index (RLI), The Annual Gonadal Dose Equivalent (AGDE), External Hazard index (H_{ex}) and Excess Lifetime Cancer Risk (ELCR) Okakarara Wasteland Soils, Namibia.

Sample ID	(AEDE) ($mSv.y^{-1}$)	(RLI) (Bq kg^{-1})	(AGDE) ($\mu Sv.y^{-1}$)	(H_{ex})	(ELCR) x 10^{-4}
Ok-01	0.03	0.42	191.08	0.16	1.18
Ok-02	0.02	0.30	135.43	0.11	0.81
Ok-03	0.03	0.38	170.11	0.14	1.05
Ok-04	0.03	0.43	190.06	0.15	1.15
Ok-05	0.05	0.65	291.31	0.24	1.75
Ok-06	0.03	0.44	198.04	0.16	1.20
Ok-07	0.04	0.45	202.82	0.17	1.25
Ok-08	0.03	0.40	176.70	0.14	1.07
Ok-09	0.03	0.41	181.76	0.15	1.10
Ok-10	0.03	0.43	190.62	0.16	1.15
Ok-11	0.03	0.42	185.84	0.15	1.13
Ok-12	0.03	0.42	185.89	0.15	1.13
Ok-13	0.04	0.53	239.68	0.20	1.47
Ok-14	0.03	0.37	165.82	0.13	1.00
Ok-15	0.03	0.38	172.03	0.14	1.04
Ok-16	0.05	0.64	286.96	0.23	1.73
Ok-17	0.02	0.32	142.62	0.12	0.86
Ok-18	0.02	0.29	129.29	0.11	0.79
Minimum	**0.02**	**0.29**	**129.29**	**0.11**	**0.79**
Maximum	**0.05**	**0.65**	**291.31**	**0.24**	**1.75**
Average	**0.03**	**0.43**	**190.89**	**0.16**	**1.16**
World Average [13]	**0.48**	**1**	**298**	**1**	**2.90**

CONCLUSIONS

Health Risk Assessment of Natural Radioactivity in Wasteland Soils of Okakarara was carried out with the help of a gamma-ray spectrometer. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were found to be 15.45±0.47, 18.00±0.55, and 215.73±4.29, respectively. These values were below the acceptable concentrations of 35, 30 and 400 $Bq.kg^{-1}$ [13]. The average Ra_{eq} value from the Wasteland soil was 57.80±0.98 $Bq.kg^{-1}$. In all the soil samples, Ra_{eq} values were below the worldwide value of 370 $Bq.kg^{-1}$ [20]. The absorbed dose rate in air (outdoor) because of terrestrial gamma rays was found to be 27.00±0.44 $nGy.h^{-1}$. This value was also lower than the world recommended average of 59 $nGy.h^{-1}$ [13]. It was also discovered that the average AEDE value was 0.03 $mSv.y^{-1}$, which is less than the world recommended value of 0.48 mSv [13], The Annual Gonadal Dose Equivalent (AGDE) value from the Wasteland soil was 190.89 $\mu Sv.y^{-1}$, and was found to be lower than the world critical value of 298 $\mu Sv.y^{-1}$ [20]. The average values of RLI and H_{ex} were found to be 0.43 and 0.16, respectively. These indices were less than unity, thereby presenting no significant radiological concern to the people in the study area [13, 21]. The average value of the excess lifetime cancer risk (ECLR) was found to be 1.16×10^{-4} and lower than world average of 2.9×10^{-4} by a factor of 0.4 [22]. From the results, it can be concluded that natural radioactivity at the wasteland area of Okakarara was not an issue of health concern.

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