RADIOLOGICAL IMPACT ASSESSMENT OF THE BOTTOM SEDIMENT SAMPLES AT PORT VICTORIA SHORELINE, KENYA

Masinde T. Sangura

Kenyatta University, Kenya

IJASR 2022
VOLUME 5
ISSUE 1 JANUARY – FEBRUARY **ISSN: 2581-7876**

Abstract: The activity concentration of 40K, 238U, and 232Th in the sediments taken from the Port Victoria shoreline has been carried out using gamma-ray spectroscopy technique. The mean values of 40K, 238U, and 232Th are respectively found to be 523.21±26.53, 66.23±8.55 and 76.23±7.32 Bq/kg, which are comparable with those of other authors. However, the mean values are higher than the world wide accepted mean values of 420, 33 and 45Bq/kg for 40K, 238U, and 232Th respectively, attributed to the technologically enhanced naturally occurring radioactive materials (TENORM) in the Lake Victoria basin. Large variations in activity concentrations are observed at different sampling sites and this is attributed to the different discharge rates by deltas of River Nzoia at Port Victoria shoreline during both dry and wet season as well as due to the dispersion of radionuclides by the water tides. The mean value of radium equivalent activity (Raeq) is 234.45 Bq/Kg, which is below the maximum allowed mean value of 370 Bq/Kg. The dose rate (D) and annual effective dose rate (AED) mean values are approximately twice the worldwide mean values of 57nGyhr-1and 70 μSy-1 respectively. Site I which is characterized by additional discharge from River Ndegwe and site Bu1 which is characterized by naturally decaying igneous rocks, have higher values of radiological parameters; Raeq>300Bq/Kg, D>143 nGyhr-1, AED>175 μSy-1, Hex>0.82, RHex>2.20, and ELCR>0.5 when compared to other sites along the shoreline. Though the calculated hazard indices are found less than unity, the mean of expected life cancer risk is ELCR> 0.4, which is higher when compared to the worldwide mean value of 0.29. Therefore there is need for concerted effort to continuously monitor and control pollution load by radionuclides in the sediments of Port Victoria shoreline.

Keywords: Annual effective dose rate, Dose rate, expected life cancer risk, hazard indices, TENORM;

1.0 Introduction

Natural radioactivity arises from primordial radionuclides; ^{40}K, ^{238}U, and ^{232}Th and their decay products, which occur in trace levels in all ground formations. They are formed by the process of nucleo-synthesis in the stars and they are characterized by half-lives that are comparable to the age of the earth (Tzortzis, 2003). The measurement of activity concentrations in the environmental matrices has become an area of interest due to their carcinogenic nature and their overall effect on the human health (Ibunknle et al., 2016; Radzali et al., 2018). Extensive investigations all over the world has been carried out in view to assessment of public dose rate as well as to keep reference-data records in order to ascertain possible changes in environmental radioactivity due to nuclear, industrial and human activities (UNSCEAR, 2000; Akinyole, 2008). For example; Apaydin et al. (2019) carried out an assessment of natural radioactivity and radiological risk in the sediment samples in Karacaoren II Dam Lake in Turkey and found out that the mean activity values for ^{226}Ra, ^{232}Th and ^{40}K were higher than those of the other studies. This was attributed to excess marble and granitic mines in the region of study. All values of Hazard index were found to be below the criterion values. In India, SureshGandhi et al., (2013) investigated the distribution of natural gamma-ray emitting ^{40}K, ^{238}U, and ^{232}Th in beach sediments along north east coast of Tamilnadu. The annual effective dose rate of 0.62msVyr^{-1}, which is below the worldwide recommended value of 1mSvyr^{-1} (ICRP, 1991) was found in the study. The activity concentrations of terrestrial radionuclides; ^{40}K, ^{238}U, and ^{232}Th and their associated radiological parameters were investigated in the beach sediments taken from Lake Nasser in Egypt (Taleb et al., 2019. The activity concentrations and the radiological parameters; dose rate, annual effective dose rate and hazard indices were found to be below the world wide accepted values, and hence the beach sediments were considered to be safe for agricultural use and construction. Ibikunle et al. (2016) using gamma spectrometry, investigated radiological assessment of Dam water and sediments for natural radioactivity and its overall health detriments in Abeokuta area in the Southwestern Nigeria. They found out a wide disparity in the variation of measured activity concentration with no artificial emitting radionuclides detected in the samples.

In Kenya, Hashim, (2000) measured the levels of terrestrial radionuclides ^{238}U, ^{232}Th and ^{40}K in the sediment, water and plants from Malindi, Mombasa and Gazi along the Kenyan Indian ocean coast. The activity levels were found to be within the accepted range of (22.8 ± 1.8) Bq/kg, (26.2 ± 1.7) Bq/kg and (479.8 ± 24.3) Bq/kg respectively for all sample matrices, with the detection of ^{137}Cs in all the sample matrices from Mombasa being attributed to the contribution by the atmospheric fallouts. Activity concentrations of the terrestrial radionuclides; ^{40}K, ^{238}U, and ^{232}Th in the sediment samples taken from Lake Nakuru were measured (Langat, 2012). A spatial difference in the dose rate was found to exist between the northern and southern sector of the lake, with the northern sector having a much higher value than the southern sector. The annual effective dose rate and the associated hazard indices were found below the world wide accepted limits and hence the external exposure due to the radionuclides in the sediments was regarded insignificant in the study. Evidenced by few radiological studies in the Kenyan environment, particularly in the Lake Victoria shore sediments, this work aimed at assessing the radiological impact due to radionuclides in the shoreline sediments at Port Victoria. The activity concentrations were measured and utilized to determine the radiological parameters; radium equivalent activity (Ra_{eq}), dose rate (D), annual effective dose rate (AED), expected life cancer risk (ELCR), external and internal hazard indices; H_{ex} and (H_{in}) for comparison with the worldwide accepted limits. The acquired data forms the basic data for both current and future monitoring of external exposure by the primordial radionuclides in the Lake Victoria region.

2.0 Materials and Methods

2.1 Sampling and Sample preparation

Figure 2.1 shows twelve sampling sites located by handheld global positioning system (GPS) along the shoreline of Port Victoria. The sites were reached by boat and 2 bottom sediment samples of at least mass 500 g collected at a uniform depth of (0-10 cm) within a sampling area of 1 m². The samples were dried in the open air before being put in well labeled polythene bags and then transported to the laboratory, where they were oven-dried for 48 hrs to a constant weight before being crushed into fine particles in the mortar using a pestle. Sample homogeneity was achieved using a 60 µm sieve to remove pebbles before sample weights of mass 500 g were portioned into well labeled polythene bags which were hermetically sealed to allow attainment of secular equilibrium between ^{226}Ra and its decay products (SureshGandhi et al., 2014). Gamma ray spectrometric determination was carried out after one month.

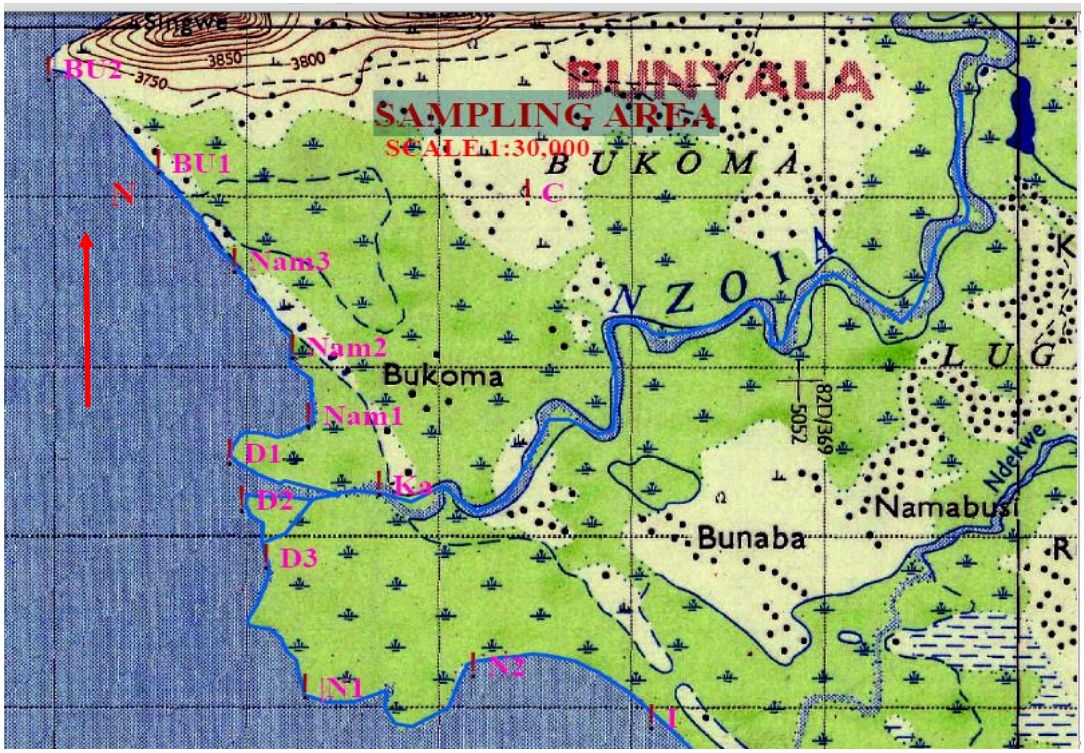

Figure 2.1: Map of Port Victoria shoreline. (The map is drawn to scale by the Institute of Survey Nairobi, Kenya). Ka, D1, D2, D3, N1, N2, I, Nam1, Nam2, Nam3, Bu1 and Bu2 are the sampling sites. The labeling of the sites is as

follows: Ka= Kabras, D1, D2 and D3= Active deltas of River Nzoia, N1and N2= Nanganda, I= Indufu, Nam1, 2, 3= Namugerwa (blocked deltas of River Nzoia), Bu1, 2= Bukoma beaches. Also note River Ndekwe discharging at site I.

2.2 Experimental set up.

To measure and analyze the activity concentration of ^{40}K, ^{238}U, and ^{232}Th in the shore sediments, a gamma-ray spectrometer consisting of a lead shielded 76 mm x 76 mm NaI(TI) detector (capable of shielding background radiations) with an Oxford PCA-P card operating on Windows system was used. The PCAP has a high voltage supply, a charge sensitive pre-amplifier, a shaping amplifier, 80 MHz Wilkinson analogue to digital converter (ADC) with a Multichannel Analyzer (MCA) comprising of 4 k channels with operating resolution (FWHM) of 1.75 eV and efficiency of 7.01% for ^{237}Cs to acquire data. To analyze the spectrum, a computer software program Maestro (EG&GORTEC) was used. At every start of experiment, the output of the detector was adjusted to agree with known values of IAEA standard radionuclides to cater for changes due to weather, vibrations and heating up of the detector. Detector calibration was achieved each time by considering gamma-ray photon energies corresponding to 1460 KeV for ^{40}K, 1765 KeV for ^{214}Bi and 2615 KeV for ^{208}Tl when calculating activity concentrations for ^{40}K, ^{238}U and ^{232}Th respectively. The below detection limits (BDL) for ^{40}K, ^{238}U, and ^{232}Th were 157.83±0.02, 62.13±0.03 and 53.88±0.01Bq/Kg respectively for a counting time of 10,000s.

2.3 Determination of Radioactivity concentration

The specific activity for each detected radionuclide was determined using method of comparison in equation 2.3.

$$\frac{A_s.M_s}{I_s} = \frac{A_R.M_R}{I_R} \qquad (2.3)$$

where, A_S is the activity of the radionuclide in the sample, M_S is the mass of the sample to be analyzed, I_S is the intensity of the radionuclide in the sample to be analyzed, A_R is the activity of the radionuclide in the reference sample, M_R is the mass of the reference sample, I_R is the intensity of the radionuclide in the reference sample.

2.4 Radiological parameters

Ionizing radiations deposit energy when passing in matter (UNCEAR, 1988; 2000). Therefore, the radiation dose likely to be delivered externally to the general public (Ramasany et al., 2011), is estimated by carrying out an assessment of the radiological risk of the shoreline sediments. This is carried out by calculating radiological indices of; radium equivalent (Ra_{eq}), absorbed dose rate (D), annual effective dose rate (AED), excess lifetime cancer risk (ELCR), external hazard index (H_{ex}) and internal hazard index (H_{in}), using equations; 2.4.1, 2.4.2a, 2.4.2b, 2.4.2c, 2.4.3a and 2.4.3b respectively.

2.4.1 Radium equivalent activities (Ra_{eq})

The radium equivalent concept (Mahur et al., 2008) allows one index to describe the gamma output from different mixtures of primordial radionuclides ^{40}K, ^{238}U and ^{232}Th in sediment samples collected from different sites along the shoreline of port Victoria. The index is calculated according to eq (2.4.1).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad (2.4.1)$$

Where, A_{Ra}, A_{Th}, and A_K are the activity concentrations in Bq/Kg of ^{226}Ra, ^{232}Th, and ^{40}K respectively.

2.4.2 Dose Rate (D), Annual Effective Dose Rate (AED), and Excess life Cancer Risk (ELCR)

The guidelines provided by (UNSCEAR, 2000) were utilized in determining the absorbed dose rates and the annual effective dose rates in air above 1m from the ground for the uniformly distributed primordial radionuclides; ^{40}K, ^{238}U and ^{232}Th according to eq (2.4.2a,b).

$$D = DC_F K.C_K + DC_F U.C_U + DC_F Th.C_{Th} \qquad (2.4.2a)$$

$$AED(\mu SVyr^{-1}) = D(nGyhr^{-1}) \times 8760(hrsyr^{-1}) \times 0.2 \times 0.7(SVGy^{-1}) \times 10^{-3} \qquad (2.4.2b)$$

Where DC_F are the dose conversion factors for ^{40}K, ^{238}U and ^{232}Th given as 0.0432, 0.427 and 0.662 $nGyh^{-1}$ per Bq/kg, *C,* is the mean concentration for the radionuclides, 0.2 is the outdoor occupancy factor and f_c = 0.7 nGy/h, is the conversion factor from the absorbed dose rate to the effective dose in human being. The risk, (ELCR) of being at the shoreline is determined by using equation (2.4.2c) (Mustapha, 1999; KNBS, 2014).

ELCR= $ED \times 5\ \%\ Sv^{-1}$ (2.4.2c)

2.4.3 The radiation hazard indices

To establish the radiological impact due to measured radionuclides in the sediments at the shoreline, the radionuclide activities are converted into a single quantity called hazard index (external (H_{ex}) and internal (H_{in})). The aim is to restrict the radiation dose to dose equivalent unit $1msVy^{-1}$ (ICRP, 1992). Both external (H_{ex}) and internal hazard index (H_{in}) are calculated according to equations 2.3a &b respectively (Harb, 2008).

$$H_{ex} = \frac{C_K}{4810} + \frac{C_u}{370} + \frac{C_{Th}}{259} \quad (2.4.3a)$$

$$H_{in} = \frac{C_K}{4810} + \frac{C_u}{185} + \frac{C_{Th}}{259} \quad (2.4.3b)$$

Where, C_K, C_U, and C_{Th} are the measured mean concentrations of 40K, 238U, and 232Th. For the radiation hazard to be negligible at the shoreline, both H_{ex} and H_{in} should not exceed unity.

3.0 Results and Discussion

3.1 Radioactivity Concentration

Table 3.1 and Figure 3.1 present variation of activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in Bq/kg calculated by method of comparison (Section 2, equation 2.3). The activities ranged widely from 209.36±6.05 to 918.64±4.56 for ^{40}K, from 15.55±0.032 to 178.24±1.98 for ^{238}U, and from 36.68±0.29 to 135.56±0.06 for ^{232}Th, respectively translating into mean values of 523.21±26.53, 66.23±8.55 and 76.23±7.32 Bq/kg for ^{40}K, ^{238}U, and ^{232}Th. The mean values were found to be comparable with those of other authors (Hashim, 2000; Ramasamy *et al.* 2009; Murgesan *et al.*, 2011), but were higher than the globally accepted mean values of 420, 33 and 45Bq/kg respectively for ^{40}K, ^{238}U, and ^{232}Th (UNSCEAR, 2000). This is an indication of technologically enhanced naturally occurring radioactive materials (TENORM) particularly from the extensive use of phosphatic fertilizers in farming in the lake basin (Bliss, 1978).

Table 3.1: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th

Site	^{40}K	^{238}U	^{232}Th
Ka	659.59±17.69	47.26±0.77	125.74±6.83
D1	568.23±16.45	77.52±7.97	81.53±4.43
D2	918.64±26.53	BDL(62.13±0.01)	70.06±2.72
D3	209.36±6.05	BDL(62.13±0.01)	BDL(53.88±0.03)
N1	218.97±6.33	BDL(62.13±0.01)	BDL(53.88±0.03)
N2	605.18±17.49	79.15±8.14	112.18±6.06
I	627.33±18.13	178.46±18.29	60.59±3.27
Nam1	500.98±14.48	83.13±8.55	80.91±4.37
Nam2	465.96±13.47	57.36±5.97	74.67±4.63
Nam3	230.22±6.68	74.84±7.69	BDL(53.88±0.03)
Bu1	733.79±21.21	53.91±5.51	135.56±7.32
Bu2	540.23±15.61	BDL(62.13±0.01)	96.99±3.08
Mean	**523.21±26.53**	**66.23±8.55**	**76.52±7.32**
Hashim, 2000[11]	**479.8**	**22.8**	**26.2**
Ramasamy et al., 2009[20]	**212-423**	**<30**	**<218**
Murgesan et al., 2011[16]	**401.11**	**5.31**	**34.04**

Worldwide	**400**	**30**	**35**

The large variations observed in the activity concentrations at different sampling points yet in the same shoreline (Fig 3.1), is attributed to different discharge rates by the three deltas; (D1, D2 and D3 in Fig 2.1) of River Nzoia, during both wet and dry seasons and the influence of water tides which results in fresh deposition and sweeping away of light materials that are sinks for the radionuclides (Ramasamy *et al.*, 2008). During transportation of the radionuclides in the riverine system, the hydraulic processes as well as the variation in the grain size distribution also contribute to variations in activity concentration levels at different sampling points (Axtman and Luoma, 1991). Elevated levels of ^{232}Th at site Bu1 is attributed to the natural decay of igneous rocks bordering the main beach while the elevated levels of ^{238}U at site I is attributed to the anthropogenic discharge by River Ndekwe as shown in Fig 2.1.

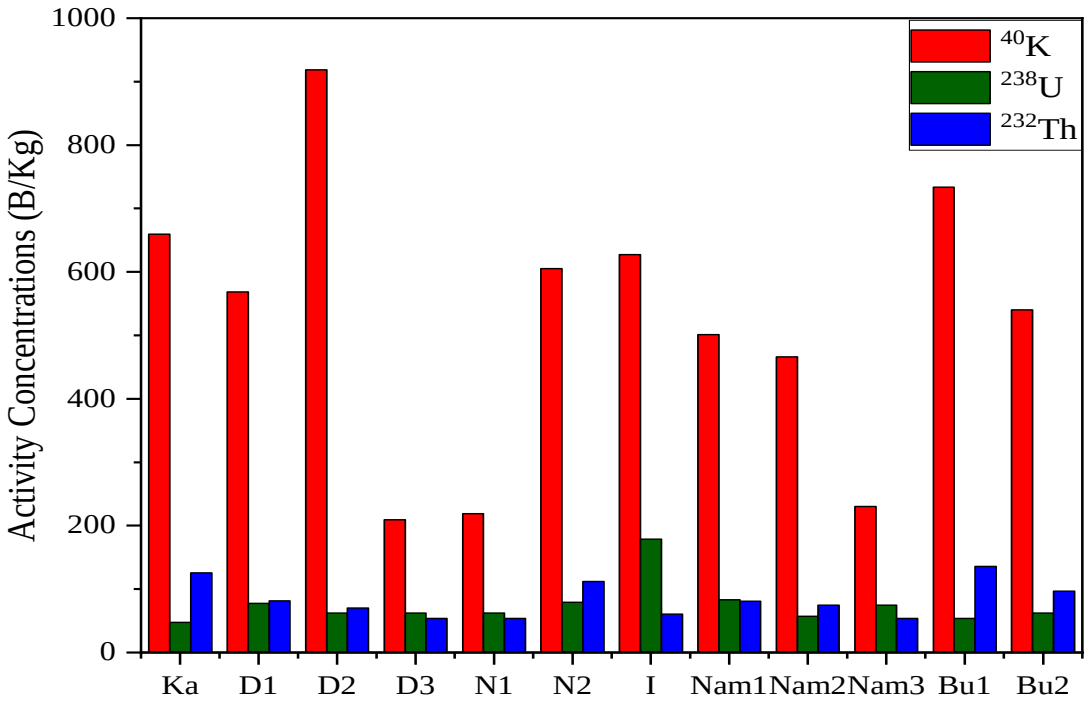

Figure 3.1: Variation of activity concentrations at the sites

3.2 Radiological parameters

In Table 3.2 and Figure 3.2, the values of radium equivalent (Ra_{eq}), dose (D), annual effective dose (AED), hazard indices (H_{ex} and H_{in}) and excess life cancer risk (ELCR) calculated using appropriate equations in section 2, are summarized. The spatial values of Ra_{eq} were found to range from 155 to 314 Bq/Kg with a mean activity of 234.45 Bq/Kg, which is below the maximum allowed radium equivalent activity of 370 Bq/Kg (UNCEAR, 2000). The dose rate (D) and annual effective dose rate (AED) varied from 71 to 145nGyhr^{-1} and from 87 to 178 μSvyr^{-1}, respectively with peak values of 144nGyhr^{-1}and 177.17 μSvy^{-1} found at site Bu1. The mean values for the dose rate and annual effective dose rate were found to be approximately double the worldwide mean values of 57nGyhr^{-1}and 70 μSvy^{-1}respectively. Site I and Bu1 which are characterized by a nearby discharging river Ndegwe and the surrounding igneous rocks respectively (Fig 2.1), were found with higher values of Ra_{eq}>300Bq/Kg, D>143 nGyhr^{-1}, AED>175 μSvy^{-1}, H_{ex}>0.82, H_{in}>1, and ELCR>0.5 when compared to other sites along the shoreline. Though the mean values of H_{ex}<1, H_{in}<1 which is an indicator of a non significant radiation hazard at the shoreline of Port Victoria (Harb, 2008), there is need to control pollution load by radionuclides in the sediments. This is evidenced by the mean of ELCR> 0.4, which was found higher when compared to the worldwide mean value of 0.29 (Orgun et al., 2007).

Table 3.2: Spatial variation of radiological parameters

Site	Ra_{eq} (B/Kg)	D (nGyhr^{-1})	AED(μSvy^{-1})	H_{ex}	H_{in}	ELCR×10^{-3}
Ka	277.86	131.91	160.66	0.75	0.87	0.533
D1	237.86	111.62	136.89	0.64	0.85	0.454
D2	233.05	112.59	137.36	0.63	0.80	0.456
D3	155.30	71.24	87.37	0.42	0.59	0.290
N1	156.04	71.66	87.88	0.42	0.59	0.291
N2	286.17	134.20	164.58	0.77	0.99	0.546
I	**313.41**	**143.41**	**175.88**	**0.85**	**1.33**	**0.583**
Nam1	237.41	110.70	135.76	0.64	0.87	0.540
Nam2	200.02	94.05	115.34	0.54	0.69	0.381
Nam3	169.62	77.57	95.13	0.46	0.66	0.316
Bu1	**304.27**	**144.46**	**177.17**	**0.82**	**0.96**	**0.588**
Bu2	242.42	114.07	139.90	0.65	0.82	0.464
Mean	**234.45**	**109.79**	**134.65**	**0.60**	**0.84**	**0.447**
Worldwide [18]	**370**	**57**	**70**	**≤1**	**≤1**	**0.29**

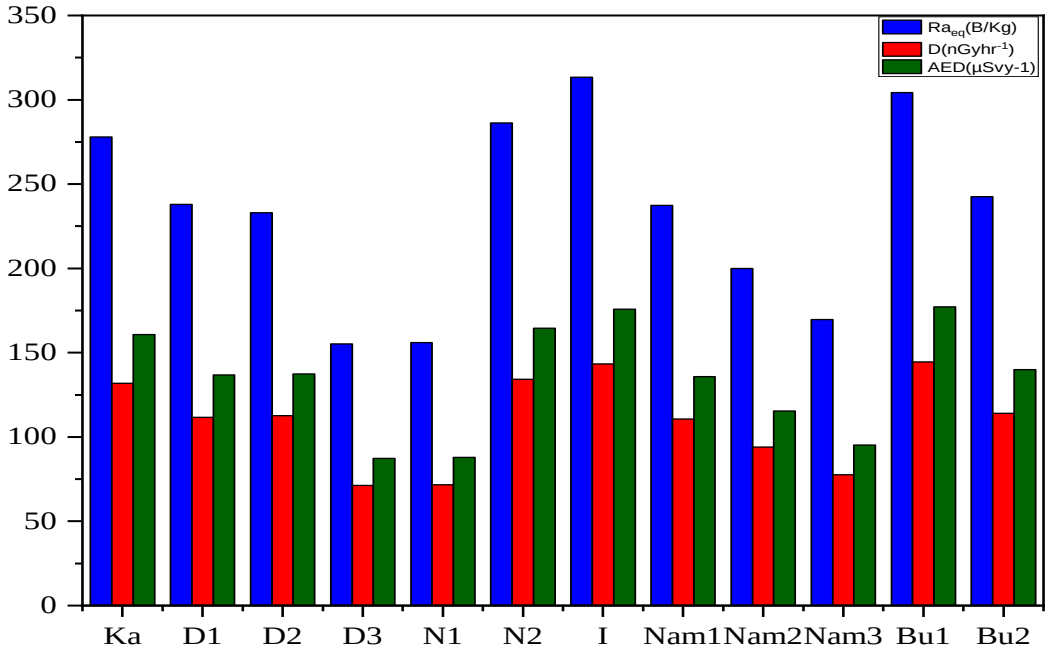

Figure 3.2: Variation of Radiological parameteres at the sites

4.0 Summary and Conclusions

In this study, a total of twenty four sediment samples (two from each site) each weighing 500g, were taken for measurement of radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th. The aim was to determine radiological parameters; radium equivalent activity (Ra_{eq}), dose rate (D), annual effective dose rate (AED), expected life cancer risk (ELCR) and hazard indices (H_{ex} and H_{in}) and asses their health effect implication on the population living around the shoreline of Port Victoria. The major findings in this study are;

1. The activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in Bq/kg were found to range widely from 209.36±6.05 to 918.64±4.56 for ^{40}K, from 15.55±0.032 to 178.24±1.98 for ^{238}U, and from 36.68±0.29 to 135.56±0.06 for ^{232}Th. The large variations observed in the activity concentrations at different sampling sites in the same

shoreline was attributed to different discharge rates by the three deltas (D1, D2 and D3 in Fig 2.1) of River Nzoia, during both wet and dry seasons as well as due to the influence of water tides in dispersion of radionuclides (Axtman and Luoma, 1991; Ramasamy *et al*., 2008).

2. The shoreline mean activity values of 523.21±26.53, 66.23±8.55 and 76.23±7.32 Bq/kg respectively for ^{40}K, ^{238}U, and ^{232}Th, were found to be comparable with those of other authors (Hashim, 2000; Ramaswamy *et al.* 2009; Murgesan *et al*., 2011), but higher than the globally accepted mean values of 420, 33 and 45Bq/kg respectively for ^{40}K, ^{238}U, and ^{232}Th (UNSCEAR, 2000). This is attributed to the technologically enhanced naturally occurring radioactive materials (TENORM) that results from the extensive use of phosphatic fertilizers in farming in the lake basin (Bliss, 1978).
3. Spatial variation of radium equivalent activity (Ra_{eq}) values were found to range from 155 to 314 Bq/Kg with a mean activity of 234.45 Bq/Kg, which is below the maximum allowed radium equivalent activity of 370 Bq/Kg (UNCEAR, 2000). The dose rate and annual effective dose rate mean values were found to be approximately twice the worldwide mean values of 57nGyhr^{-1}and 70 μSy^{-1} respectively.
4. Higher values of radiological parameters; Ra_{eq}>300Bq/Kg, D>143 nGyhr^{-1}, AED>175 μSy^{-1}, H_{ex}>0.82, RH_{ex}>2.20, and ELCR>0.5 were found at sites I and Bu1 when compared to other sites along the shoreline. Site I is characterized by a nearby discharging river Ndegwe, while site Bu1 is surrounded by igneous rocks that decays to increase the naturally occurring radioactive materials (NORM) in the adjacent bottom sediments (Achola et al., 2010).
5. There is no significant radiation hazard at the shoreline of Port Victoria as the calculated representative hazard indices are less than unity (Harb, 2008). However, the mean of expected life cancer risk ELCR> 0.4, which is higher when compared to the worldwide mean value of 0.29 (Orgun et al., 2007) and therefore this calls for concerted effort to control pollution load by radionuclides in the Lake Victoria basin.

Acknowledgement

My sincere appreciation goes to Dr. Bramuel Musambaki who facilitated the sampling process at Port Victoria and the Kenyatta University physics laboratory technologists who inducted and supervised me during sample analysis.

References

1. Achola, S.O, Patel, J.P., Mustapha, A.O. and Angeyo, H.K. (2010). "Natural Radioactivity and Associated Radioactivity Characteristics of the New High Background Radiation Area of Lambwe East, Southwestern Kenya". *Proceedings of 3rd African International Radiation Protection Association (IRPA) Congress* 13-17th September, Nairobi, Kenya.
2. Axtmann, E. and Luoma, S. (1991). "Large scale distribution of metal contamination in the fine grained sediments of the Clark Fork River, USA". *Journal of Applied Geochemistry* 6:75-88.
3. Akinyole, M. (2000). Radioactivity in LAUTECH Water Supplies. Nigerian Journal of Physics. 20(1), 29-37.
4. Apaydin, G., Koksal, O.K., Cengiz, E., Tirasogul, E., Baltas, H., Karabulut, K. and Sogut, O. (2019). Assessment of natural radioactivity and radiological risk of sediment samples in Karacaoren II Dam Lake, Isparta, Turkey. ALKU Journal of Science, Special Issue (NSP 2018), 28-35.
5. Bliss, J.D. (1978). "Radioactivity in selected mineral extraction industries: A literature review". *U.S. Environmental Protection Agency* Technical Note ORP/LV 79- 153.
6. El Mamoney, M.H. and Khater, A.E.M. (2004). Environmental characterization and radio-ecological impact of non-nuclear industries on the Red Sea Coast. Journal of Environmental Radioactivity, 73,151-168.
7. Ibikunle, S.B., Ajayi, O.S., Aragunjo, A.M. and Salami, A.A. (2016). Radiological Assessment of Dam Water and Sediments for Natural radioactivity and its overall health Detriments. Ife Journal of Science, Vol 18, no (2), 551-559.
8. International Commission on Radiological Protection (ICRP, 1992). "Recommendations of the International Commission on Radiological Protection". *ICRP Publication 60* Oxford: Pentagon press.
9. International Atomic Energy Agency (1987). "Preparation and Certification of IAEA gamma Spectrometry Reference Material". Vienna RL/148.

10. Harb, S. (2008). "Natural radioactivity and external gamma radiation exposure at the coastal Red Sea in Egypt". *Journal of Radiation Protection dosimetry* 130:376-384.
11. Hashim, N.O. (2000). "The levels of radionuclides and trace elements in selected Kenyan coastal ecosystem. *M. Sc. thesis*. Kenyatta University.
12. Kenya National Bureau of statistics (KNBS, 2014). Demographic and Health Survey.
13. Langat, K.W. (2012). Gamma ray spectrometric analysis of sediment deposits at the shores of Lake Nakuru, Kenya. A thesis submitted in partial fulfillment of the requirement for the award of the degree of Master of Science in the school of pure and applied science of Kenyatta University.
14. Mahur, A.K., Kumar, R., Sonkawade, R.G., Sengupta, D. and Prasad, R. (2008). Measurement of natural radioactivity and radon exhalation rate from rock samples of Jaduguda uranium mines and its radiological implications. Journal of Nuclear Instruments and Methods in Physics Research Section B, 266, 1591-1597.
15. Masinde, T.S. and Nakitare, M.W. (2019). Gamma-Ray Spectrometric Determination and Multivariate Analysis of Radionuclide Fluxes in the shore sediment at Port Victoria, Kenya. Journal of Multidisciplinary Engineering Science and Technology. Vol 6 (1), 9433-9438.
16. Murgesan, S., Mullainathan, S., Ramasamy, V. and Meenakshisundaram, V. (2011). "Radioactivity and radiation hazard assessment of Cauvery River, Tamilnadu, India". *Iranian Journal of Radiation Research* 8 (4):211-222.
17. Mustapha, A.O. (1999). Assessment of human exposures to natural sources of radiation in Kenya. *Ph.D Thesis*. University of Nairobi. Kenya.
18. Orgun, Y., Altinsoy, N., Sahin, S.Y., Gungor, Y., Gultekin, A.H., Karaham, G., Karaak, Z. (2007). Natural and anthropogenic radioactivity in rocks and beach sands from Ezine region (Canakkale), western Anatolia, Turkey. Journal of Applied Radiation and Isotopes. 65,739-747.
19. Radzali, N.A.M., Hidzir, N.M. and Rahman, J.A.(2018). Determination of natural radioactivity and heavy metals at the former mining site of Koles Universiti Islam Antarabangsa Selangor (KUIS). Malaysian Journal of Analytical Science. 22(5), 828-838.
20. Ramasamy, V., Senthil, S., Meenakshisundaram, V. and Gajendran.V. (2009). "Measurement of Natural Radioactivity in Beach Sediment from North East Coast of Tamilnadu, India". *Research Journal of Applied Sciences, Engineering and Technology* 1(2):54-58.
21. Ramasany,V., Murugesan, S. and Mullainathan, S. (2004). Gamma ray spectrometric analysis of primordial radionuclides in sediments of Cauvery River in Tamilnadu, India. Journal of Ecologica. 21, 83-88.
22. Ramasamy, V., Suresh, G., Meenakshisundaram, V. and Ponnusany,V. (2011). Horizontal and Vertical characteristics of radionuclides and minerals in the river sediments. Journal of Applied Radiation and Isotopes.69, 184-195.
23. SureshGandhi, M., Ravisankar, R., Rajalakshmi, A., Sivakumar, S., Chandrasekaran, A. and Anand, D.P. (2014). Measurement of natural gamma radiation in beach sediments of North East Coast of Tamilnadu, India by gamma ray-spectrometry with multivariate statistical approach. Journal of Radiation Research and Applied Sciences, 7-17.
24. Taleb, A.A., Abbady, A. and Harb,S. (2019). Assessment of Natural radioactivity level in shore sediment samples from Nasser Lake at Aswan, Egypt. International Journal of Biomedical Engineering and Science (IJBES). 6(2),1-11.
25. Tzortzis, M.T., Haralabos, S.C. and George, C. (2003). Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks. Journal of radiation measurements, 37,222-229.
26. Windom, H., Schropp, S., Calder, F., Ryan, J., Smith, R., Burney, L., Lewis, F. and Rawlinson, C. (1989). "Natural trace metal concentrations in estuarine and Coastal Marine Sediments of the South eastern United States". *Journal of Environmental Science and Technology* 23:314-320.
27. United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR, 1988). Sources, Effects and Risks of Ionizing Radiation. Report to the general Assembly, 32nd Session, United Nations, New York, 183-184.

28. United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR, 2000). Sources and Biological effects of ionizing radiation, United Nations, New York.