

Annual effective dose and radiological risk assessment from selected salt pans from the lagoon of Erongo region, Namibia.

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ABSTRACT

Radioactivity levels in salt pans from the Erongo region of Namibia have been investigated. Ten composite salt samples, collected from salt pans of the Walvis Bay lagoon were analyzed for activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K. This was done using a high-resolution gamma-ray spectrometer. The average activity concentrations in (Bq.kg⁻¹) of ²²⁶Ra, ²³²Th and ⁴⁰K were found to be 2.17 ± 0.19 , 0.20 ± 0.02 and 2.28 ± 0.39 , respectively. These activity concentrations were used to calculate the annual effective dose and radiological health risk from the ingestion of salt for the different age groups. The average annual effective dose in (μSv/yr) for the age ranges (2-7 years), (7-12 years), (12-17 years) and ≥ 17 years were found to be 2.67 ± 0.22 , 3.33 ± 0.28 , 6.08 ± 0.53 and 1.22 ± 0.10 , respectively. All these were lower than the worldwide average of 0.29 mSv/yr as reported by UNSCEAR in 2000. The total average radiological risk (unitless $\times 10^{-8}$) for the age ranges (2-7 years), (7-12 years), (12-17 years) and ≥ 17 years were found to be 30.15 ± 2.48 , 60.30 ± 4.96 , 89.8 ± 7.44 and 422.09 ± 34.75 , respectively. All these were lower than the recommended limit of between 1×10^{-6} to 1×10^{-4} as reported by USEPA in 1991. Therefore, the results from this study indicated that the salt samples do not pose a radiological risk to members of the public.

Keywords: Radiological risk, Salt, Effective dose, Average daily Intake, Erongo region.

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1. INTRODUCTION

Humans are continuously exposed to naturally occurring radioactive materials (NORM) that originate from either natural or man-made radiation sources (Lin et al., 2015; Vives I Batlle et al., 2018). In recent years, radiological effects of naturally occurring radiation has received considerable attention in many countries around the world (UNSCEAR, 2000; Zivuku et al., 2018; Xinming and Wuhui, 2018; Harikrishnan et al., 2018). This has been due to their acute or chronic health effects (Reda et al., 2018; Sahin Bal, 2018; Faisal et al., 2015). Beyond certain limits, radiation can cause long-term health effects such as cancer and cardiovascular diseases (William, et al., 2000; Busby, 2010; Innocent et al., 2013; Onjefu et al., 2020). Irrespective of NORM origin, internal exposure to radiation is mainly through ingestion and inhalation of radionuclides (UNSCEAR, 2008; Uwatse et al., 2015).

It is therefore imperative to monitor the levels of radiation that humans are exposed to through the different pathways. One of the exposure pathways is through the ingestion of salt. Salt plays an important role in our diet for preserving and flavouring food. It is found naturally in seas or underground as rock salt deposits (Kansaana, et al., 2012).

There has been great interest expressed worldwide for the study of radiological impact due to the ingestion of NORM from salt. In 2012, Kansaana and others (Kansaana et al., 2012) investigated radioactivity levels in salt from Panbros Salt Industry Limited in Accra, Ghana and discovered that the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in salt samples varied from 1.12–1.91, 2.11–3.47 and 30.25–47.65 mBq/l, respectively. The annual effective dose calculated for the salt samples varied from 0.00202 to 0.00305 mSv/yr with a mean value of 0.0025 ± 0.00053 mSv/yr. In studies carried out in Pakistan at the Khewera Salt Mines, the mean activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in salt samples were found to be 790 ± 262 , 640 ± 162 and $23\,000 \pm 6000$ mBq/kg, respectively (Tahir and Alaamer, 2008). The mean annual effective dose due to the intake of these natural radionuclides from the rock salt were estimated to be 0.0638 ± 0.015 mSv, a value lower than the worldwide average of 0.29 mSv/yr as reported by UNSCEAR in 2000 (Tahir and Alaamer, 2008). In a related study on radioactivity measurements of different types of salt using SSNTD in Egypt, it was found that the annual effective dose calculated from the corresponding radon concentration ranged between 10.47–13.69 mSv which was higher than the recommended value (Shabaan, D.H., 2018). Salt samples were also collected from different areas in the western desert of Egypt and analysed for natural radionuclides. An absorbed dose rate of gamma radiation from ^{226}Ra , ^{232}Th and ^{40}K was estimated to be 1.46–16.13 nGy/h (El-Bahi,

2003).

In Namibia, several studies have looked at the measurement of natural and artificial radioactivity in soils to evaluate the potential health hazards on the local population (Oyedele et al., 2010; Onjefu et al., 2017; Zivuku et al., 2018). However, no data has been reported concerning concentrations of natural radioactivity in salt mined and salt consumed in Namibia. It was therefore, the aim of the study to determine the activity concentrations of Naturally Occurring Radioactive Materials (NORMS) in salt from Walvis Bay lagoon and to calculate the radiological risk associated with the salt consumed by the population. It was also the aim of the research to evaluate the annual effective dose and the risk to the population according to the different age groups. The outcome of the study would form part of baseline values for the Regulatory Authorities to enable them develop national safety guidelines as a result of consumption of salt in Namibia.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was undertaken along the coastline of the Erongo region of Namibia and lies between Latitude $22^{\circ}57'27''\text{S}$ and Longitude: $14^{\circ}30'19''\text{E}$. It is bounded by the Walvis Bay lagoon on the south and on the north and east by the Atlantic Ocean (Fig. 1). The study area is made up of vast areas of flat land surrounded by low dykes and covers a total area of 4000 ha which has been developed into pans (Fig. 2). The region has a rainfall pattern, which ranges from 200 mm to 350 mm per year, with average maximum temperatures of between 28°C to 32°C and average minimum temperatures of 2°C to 8°C .

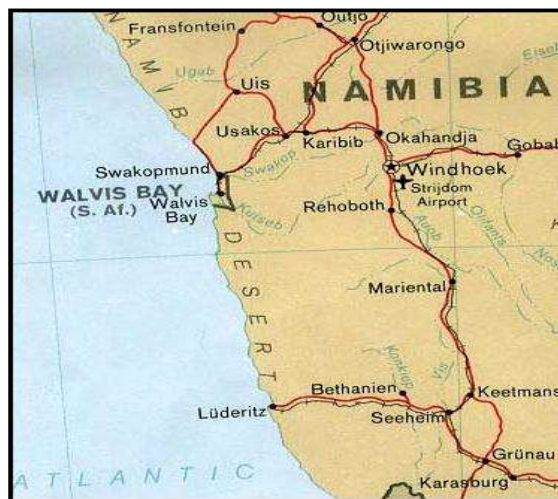


Fig. 1. Map of Namibia showing Walvis Bay

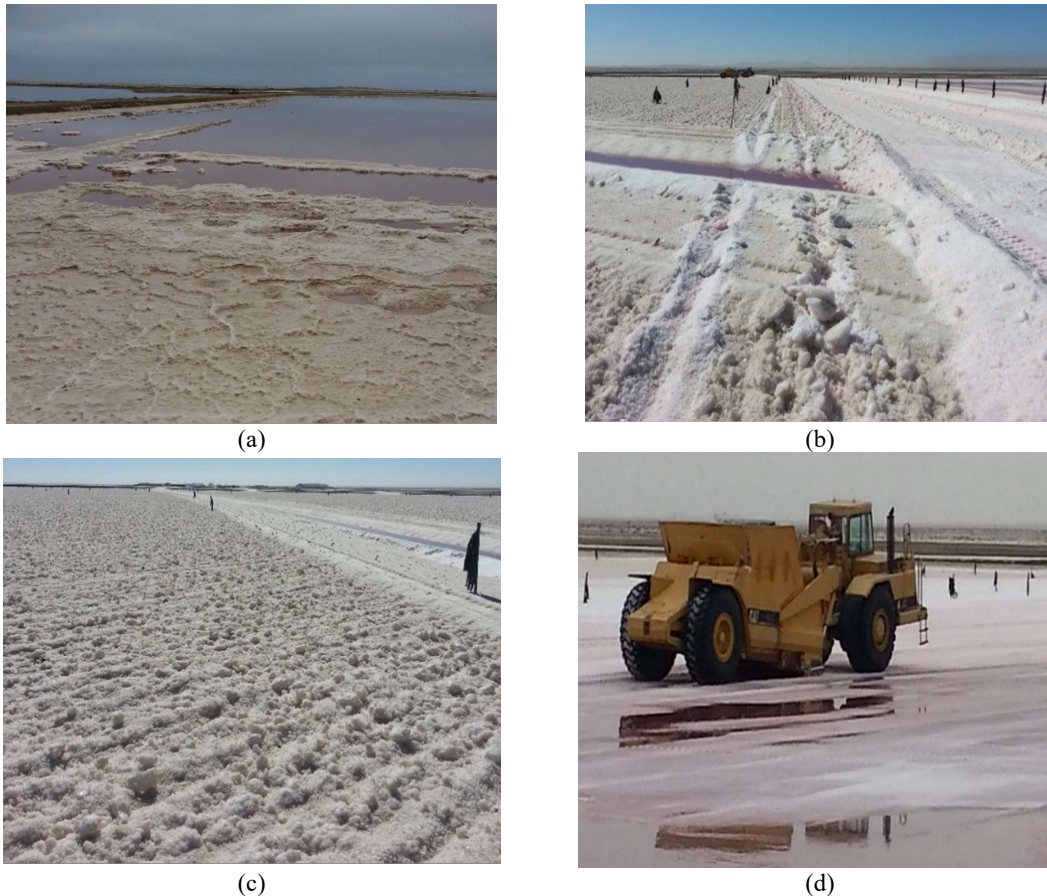


Fig. 2. (a) The evaporative pans in the early stages, (b) the evaporated saltpan with dry salt almost ready for harvesting (c) the evaporative pan totally evaporated with very little water at the edges and (d) shows a truck used to harvest the dry salt.

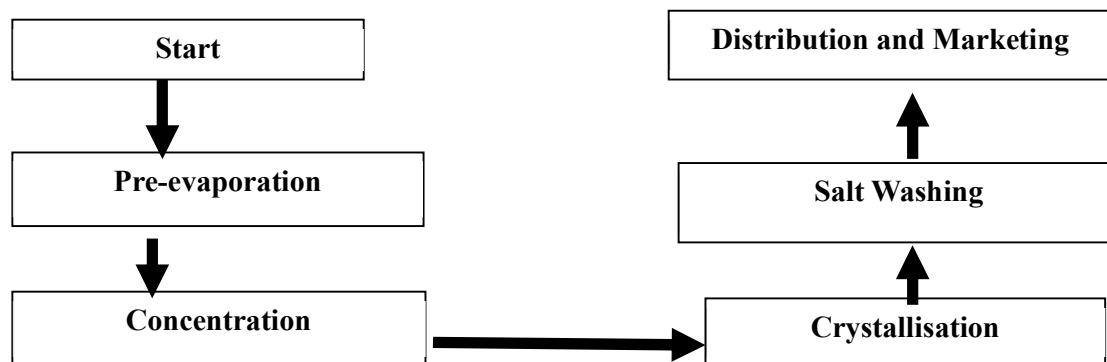


Fig. 3. Stages involved in salt production process

2.2 Salt Production Process

In Namibia, sea water from Walvis Bay lagoon provides the source of salt. Fig. 3 shows the processes involved in salt production.

2.2.1 Pre-evaporation

During this stage, seawater is pumped from a natural

lagoon at a rate of 240 m³ per minute into a series of pre-evaporation ponds, changing the salinity of seawater from 3.5 % to 15 %.

2.2.2 Concentration

Stimulated by wind and sun the brine salinity (concentrated salt water) content gradually increases until it

reaches 25 %, at this stage. A wide range of impurities, including gypsum settles at the pan floors.

2.2.3 Crystallisation

During this stage, the concentrated brine with salinity greater than 25 % is pumped into crystallisation ponds. Sodium Chloride crystallizes to form a layer of crystals on the various crystallizer pavements in readiness for harvesting. Unwanted chemical impurities are removed through evaporation.

2.2.4 Salt Washing (Processing)

During this stage, harvested crude salt is then transported to the processing plant. The crude salt is washed and dried in order to remove some more chemical impurities. Calcium sulphate and magnesium that adheres to the salt are removed during the washing process. The final product, Sodium Chloride at this stage will be more than 99 % pure.

2.2.5 Distribution and Marketing

After washing and drying, the salt is then stockpiled in readiness for marketing and distribution.

2.3 Sampling and Sample Preparation

A hand auger was used to collect five samples from each of the 10 salt pans. The samples were then transferred in polyethylene zipper bags and labelled accordingly. All 5 samples from each pan were mixed together thoroughly, to obtain 10 composite salt samples representing each pan. All samples were then transported to the laboratory where the samples were kept to dry in the oven at 100°C. The dry salt samples were then transferred into 500 ml Marinelli beakers and firmly sealed and stored for 31 days for secular equilibrium to be reached (Onjefu et al, 2017).

2.4 Experimental Radiometric Analysis

The counting of radionuclides present in salt samples were analysed with a high-resolution gamma-ray spectrometer using a coaxial (62.80 X 64.80 mm) Canberra high purity germanium (HPGe) detector Model No. GC4520 SN 10882 with 45% relative efficiency and resolution of 2.00 keV full width at half maximum (FWHM) at 1.33 MeV peak of ⁶⁰Co and 1.200 keV (FWHM) at 122 keV (Uwatse, 2015). The detector was shielded with 15 cm

lead encasement to reduce the background radiation and cooled using liquid nitrogen. A computer-based Multichannel Analyser (MCA) Genie 2000 software from Canberra was used for data acquisition and analysis of gamma spectra. Each marble samples were counted for 53200 s in a reproducible sample detector geometry, and the same configuration and geometry was used throughout the analysis. The gamma spectrometry system was energy and efficiency calibrated using a range of gamma-ray energies ranging from 0.060 MeV to 2 MeV mixed radionuclides standard in a 500 ml Marinelli beaker. This energy range was analysed for the absolute photo-peak efficiency and energy calibration of the HPGe detector using a multi-nuclide calibration standard with an initial activity of 40 kBq homogeneously distributed in silicone matrix, which was supplied by Eckert & Ziegler Nuclitec GmbH, Germany, SN. AM 5599. The 295.22 keV, 351.93 keV for ²¹⁴Pb and 609.32 keV, 1120.29 keV and 1764.49 keV for ²¹⁴Bi gamma lines were used in the assessment of activity concentration of ²²⁶Ra, while 911.21 keV for ²²⁸Ac and 968.97 keV and 238.63 keV for ²¹²Pb were used for ²³²Th. The ⁴⁰K activity was obtained from the measurement of the single gamma line at 1460.8 keV. The background activity counting due to naturally occurring radionuclides in the room housing the detector was subtracted from obtained peak of each samples. Equation (1) (Caridi, 2016) was used to calculate the activity concentration A_R in Bq kg⁻¹ of the level of the radioactivity of ²²⁶Ra, ²³²Th and ⁴⁰K found in each sample.

$$A_R = \frac{C_{net}}{\epsilon(E) \times I_\gamma \times t \times m} \quad (1)$$

where C_{net} is the counting rate for a specific gamma line given in count per second corrected for background, $\epsilon(E)$ represent absolute photopeak efficiency, I_γ is the intensity of gamma-ray line, t is the time for data collection in seconds and m is the mass of each samples in kg.

The Annual Effective Dose owing to ingestion of ²²⁶Ra, ²³²Th and ⁴⁰K in salt was calculated using Equation (2) (Poltabtim, 2019).

$$AED = A_R \times I_R \times F_R \quad (2)$$

where A_R is the activity concentration of radionuclides (Bq/kg), I_R is the annual intake of salt (5 g per day, which is equivalent to 1.825 kg/yr) (WHO, 2012), F_R is the dose conversion factor (SvBq⁻¹). Table 1 shows the dose conversion factors that were used in calculating Annual Effective Dose.

Table 1. Effective dose conversion factors (Sv.Bq⁻¹) for ingestion of radionuclides for members of the public of different age groups (ICRP, 2012)

Radionuclide	(2 – 7) years	(7 – 12) years	(12 - 17) years	≥ 17 years (Adult)
²²⁶ Ra	6.2×10^{-7}	8.0×10^{-7}	1.5×10^{-6}	2.8×10^{-7}
²³² Th	3.5×10^{-7}	2.9×10^{-7}	2.5×10^{-7}	2.3×10^{-7}
⁴⁰ K	2.1×10^{-8}	1.3×10^{-8}	7.6×10^{-9}	6.2×10^{-9}

2.5 Determination of Radiological Health Risk

The radiological risk associated with salt ingestion for different age groups was calculated from Equation (3) (Poltabtim, 2019).

$$\text{Risk} = D_{\text{int}} \times \text{SF} \times t \quad (3)$$

where D_{int} = average daily intake of salt ($\text{pCi} \cdot \text{day}^{-1}$), SF = slope risk factor or the morbidity risk of each radionuclide ($\text{risk} \cdot \text{pCi}^{-1}$), and t = exposure duration (days). The values of the slope risk factors ($\text{risk} \cdot \text{pCi}^{-1}$) used for ^{226}Ra , ^{232}Th and ^{40}K were 5.14×10^{-10} , 1.33×10^{-10} and 3.43×10^{-11} , respectively (Uwatse, 2015). The exposure duration used for the various age groups were 5 years for (2-7 years), 10 years for (7-12 years), 15 years (12-17 years) and 70 years for ≥ 17 years (Adults) (ICRP, 2012).

D_{int} was calculated using Equation 4 (Poltabtim, 2019).

$$D_{\text{int}} \left(\frac{\text{pCi}}{\text{day}} \right) = \frac{A_R \times I}{365} \times 27.027 \quad (4)$$

where A_R is the activity concentrations in Bq/kg and I is the ingestion rate (kg/yr) taken as 5 g per day (WHO, 2012).

3. RESULTS AND DISCUSSION

The activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in salt samples are presented in Table 2. The table also presents average daily intake values due to ingestion of salt. The average activity concentrations in ($\text{Bq} \cdot \text{kg}^{-1}$) of ^{226}Ra , ^{232}Th and ^{40}K were found to be 2.17 ± 0.19 , 0.20 ± 0.02 and 2.28 ± 0.39 , respectively. The result showed a range of variation in the activities of the radionuclides (Fig. 4). This variation may be attributed largely on the geographical and geological setting of the location and also to the extent of anthropogenic activity in the study area (Turekian, 1970; NCRP, 1975; Ravisankar et al., 2007; Folkner and Williams, 2008; Paschoa and Steinhausler, 2010; El-Taher, 2010). ^{40}K had the highest average value followed by ^{226}Ra while ^{232}Th had the least value (Fig. 4). This was the same trend with average daily intake values. The high concentrations of ^{40}K is because of its dominance in ocean owing to its natural relative abundance (NCRP, 1987). According to UNSCEAR (2000) these average activity concentrations of radionuclides were much lower than the worldwide average of 32, 45 and 420 for ^{226}Ra , ^{232}Th and ^{40}K , respectively. The activity concentrations of the radionuclides were then used to calculate the annual effective dose ($\mu\text{Sv}/\text{yr}$) due to ingestion of salt for the different age groups.

Table 3 presents the annual effective dose ($\mu\text{Sv}/\text{yr}$) due to ingestion of salt for the different age groups. The average annual effective dose for the age ranges (2-7 years), (7-12 years), (12-17 years) and ≥ 17 years were found to be 2.67 ± 0.22 , 3.33 ± 0.28 , 6.08 ± 0.53 and 1.22 ± 0.10 , respectively. The age range (12-17 years) had the highest annual effective dose followed by the 7-12 years range. The ≥ 17 (Adult) year age group had the minimum average annual effective dose. All these values were however much lower than the average worldwide exposure of 0.29 mSv due to ingestion (UNSCEAR, 2000). The average daily intake values presented in Table 2 were used to calculate the radiological health risk. Table 4 shows results of radiological health risk calculations made due to ingestion of natural radionuclides ^{226}Ra , ^{232}Th and ^{40}K from salt for members of the public of different age groups. The total average radiological risk ($\times 10^{-8}$) for the age ranges (2-7 years), (7-12 years), (12-17 years) and ≥ 17 years were found to be 30.15 ± 2.48 , 60.30 ± 4.96 , 89.8 ± 7.44 and 422.09 ± 34.75 , respectively. The risk was mostly pronounced in the ≥ 17 years age group (adults). Although the risk is higher in this age group, it is still much lower than the recommended limit between 1×10^{-6} to 1×10^{-4} as reported by USEPA in 1991. This allowable limit means that 1 person in 1 million to 1 person in 10,000 is acceptable according to USEPA (1991). These results therefore indicate that there is no radiological risk that may be posed through the ingestion of salt by members of the public.

Comparing the measured values of activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K from this study with some studies around the world showed that the average concentration of ^{226}Ra from this study is greater than the activity of ^{226}Ra from Romania, Ghana and Pakistan but less than the activity of ^{226}Ra obtained from the study in India (Table 5). The average concentration of ^{232}Th in this present study is less than those obtained from Romania, Ghana and India. Similarly, the average activity concentration of ^{40}K in this present study was found to be higher than the value obtained for ^{40}K from Romania but lower than the value for ^{40}K from Ghana, India and Pakistan, respectively (Table 5). The performed correlation between the specific activities of ^{226}Ra , ^{232}Th , and ^{40}K as presented in Figures 4, 5 and 6, showed weak positive correlations with coefficient ($R^2 = 0.05$) for ^{40}K and ^{226}Ra , weak negative correlation ($R^2 = 0.08$) for ^{232}Th and ^{226}Ra , and a strong negative correlation ($R^2 = 0.09$) for ^{40}K and ^{232}Th , respectively.

Table 2. Activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in salt samples and their corresponding average daily intakes (D_{INT}) due to ingestion of salt for all age groups

Sample ID	Activity concentrations (Bq/kg)			Average daily intake D_{int} (pCi day^{-1})		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
WBS-1	2.93 ± 0.23	0.17 ± 0.01	2.56 ± 0.41	0.40 ± 0.03	0.02 ± 0.00	0.35 ± 0.06
WBS-2	1.97 ± 0.18	0.20 ± 0.04	1.80 ± 0.41	0.27 ± 0.02	0.03 ± 0.01	0.24 ± 0.06
WBS-3	2.16 ± 0.19	0.18 ± 0.01	2.83 ± 0.42	0.29 ± 0.03	0.02 ± 0.00	0.38 ± 0.06
WBS-4	2.04 ± 0.18	0.17 ± 0.01	2.79 ± 0.42	0.28 ± 0.02	0.02 ± 0.00	0.38 ± 0.06
WBS-5	2.03 ± 0.20	0.20 ± 0.02	2.56 ± 0.36	0.27 ± 0.03	0.03 ± 0.00	0.35 ± 0.05
WBS-6	1.96 ± 0.18	0.22 ± 0.02	1.97 ± 0.35	0.26 ± 0.02	0.03 ± 0.00	0.27 ± 0.05
WBS-7	2.54 ± 0.23	0.22 ± 0.02	2.05 ± 0.35	0.34 ± 0.03	0.03 ± 0.00	0.28 ± 0.05
WBS-8	2.09 ± 0.18	0.20 ± 0.01	2.51 ± 0.42	0.28 ± 0.02	0.03 ± 0.00	0.34 ± 0.06
WBS-9	2.05 ± 0.18	0.23 ± 0.01	1.65 ± 0.41	0.28 ± 0.02	0.03 ± 0.00	0.22 ± 0.06
WBS-10	1.98 ± 0.19	0.19 ± 0.02	2.08 ± 0.35	0.27 ± 0.03	0.03 ± 0.00	0.28 ± 0.05
Minimum	1.96 ± 0.18	0.17 ± 0.01	1.65 ± 0.35	0.26 ± 0.02	0.02 ± 0.00	0.22 ± 0.05
Maximum	2.93 ± 0.23	0.23 ± 0.04	2.83 ± 0.42	0.40 ± 0.03	0.03 ± 0.01	0.38 ± 0.06
Average	2.17 ± 0.19	0.20 ± 0.02	2.28 ± 0.39	0.29 ± 0.03	0.03 ± 0.00	0.31 ± 0.05

Table 3. Annual effective dose ($\mu\text{Sv/yr}$) due to ingestion of natural radionuclides ^{226}Ra , ^{232}Th and ^{40}K from salt for the different age groups

Age group years		^{226}Ra ($\mu\text{Sv/yr}$)	^{232}Th ($\mu\text{Sv/yr}$)	^{40}K ($\mu\text{Sv/yr}$)	Total (AED)
2 – 7	Minimum	2.22 ± 0.20	0.11 ± 0.01	0.06 ± 0.01	2.67 ± 0.22
	Maximum	3.32 ± 0.26	0.15 ± 0.03	0.11 ± 0.02	
	Mean	2.46 ± 0.22	0.13 ± 0.01	0.09 ± 0.01	
7 – 12	Minimum	2.86 ± 0.26	0.09 ± 0.01	0.04 ± 0.01	3.33 ± 0.28
	Maximum	4.28 ± 0.34	0.12 ± 0.02	0.07 ± 0.01	
	Mean	3.18 ± 0.28	0.10 ± 0.01	0.05 ± 0.01	
12 – 17	Minimum	5.37 ± 0.49	0.08 ± 0.00	0.02 ± 0.00	6.08 ± 0.53
	Maximum	8.02 ± 0.63	0.10 ± 0.02	0.04 ± 0.01	
	Mean	5.95 ± 0.53	0.09 ± 0.01	0.03 ± 0.01	
≥ 17 years	Minimum (Adult)	1.00 ± 0.09	0.07 ± 0.00	0.02 ± 0.00	1.22 ± 0.10
	Maximum	1.50 ± 0.12	0.10 ± 0.02	0.03 ± 0.00	
	Mean	1.11 ± 0.10	0.08 ± 0.01	0.03 ± 0.00	

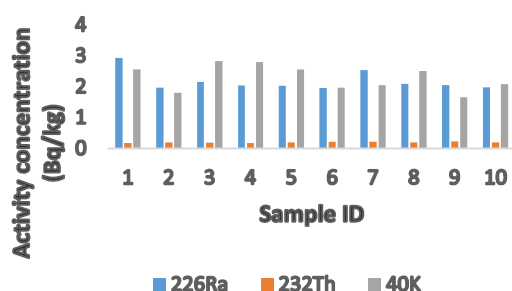
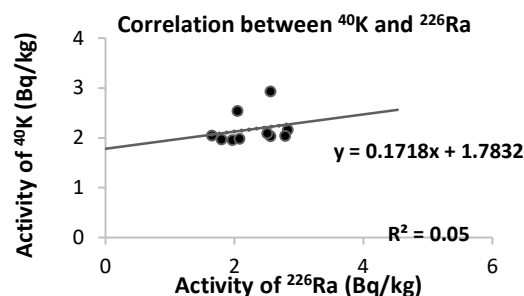
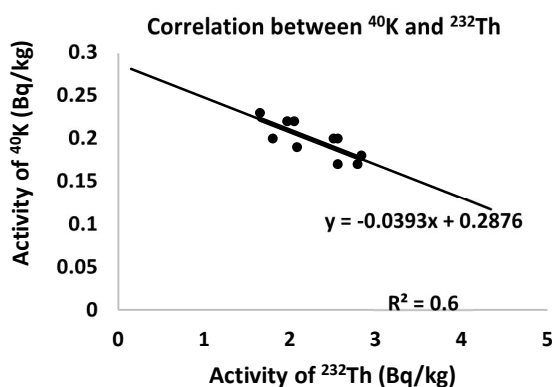
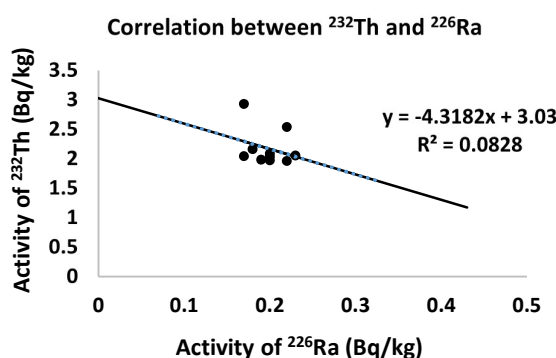
Table 4. Radiological health risk due to ingestion of natural radionuclides ^{226}Ra , ^{232}Th and ^{40}K from salt for members of the public of different age groups

Age group years		Radiological Health Risk ($\times 10^{-8}$)			Total Risk ($\times 10^{-8}$)
		^{226}Ra	^{232}Th	^{40}K	
2 – 7	Minimum	24.85 ± 2.28	0.56 ± 0.03	1.40 ± 0.30	30.15 ± 2.48
	Maximum	37.14 ± 2.92	0.75 ± 0.13	2.39 ± 0.36	
	Mean	27.57 ± 2.46	0.65 ± 0.06	1.93 ± 0.33	
7 – 12	Minimum	49.69 ± 4.46	1.12 ± 0.07	2.79 ± 0.59	60.30 ± 4.96
	Maximum	74.28 ± 5.83	1.51 ± 0.26	4.79 ± 0.71	
	Mean	55.14 ± 4.92	1.30 ± 0.11	3.86 ± 0.66	
12 – 17	Minimum	74.54 ± 6.85	1.67 ± 0.10	4.19 ± 0.89	89.8 ± 7.44
	Maximum	111.43 ± 8.75	2.26 ± 0.39	7.18 ± 1.07	
	Mean	82.71 ± 7.38	1.95 ± 0.17	5.79 ± 0.99	
≥ 17 years	Minimum (Adult)	347.84 ± 31.94	7.81 ± 0.46	19.54 ± 4.14	422.09 ± 34.75
	Maximum	519.98 ± 40.82	10.56 ± 1.84	33.52 ± 4.97	
	Mean	385.99 ± 34.42	9.09 ± 0.78	27.00 ± 4.62	

Table 5. Comparison of average/range activity concentration of ^{226}Ra , ^{232}Th and ^{40}K in Bq/kg with literature values

Country	^{226}Ra	^{232}Th	^{40}K	References
Namibia	2.17 ± 0.19	0.20 ± 0.02	2.28 ± 0.39	Present Study
Romania	0.60	0.30	1.3	Calin <i>et al.</i> , 2020
Ghana*	1.39	2.91	37.88	Kansaana <i>et al.</i> , 2012
India	3.81	35.96	271.78	Ravisankar <i>et al.</i> , 2007
Pakistan	0.5 – 1.3	0.4 – 0.9	15.0 – 34.0	Tahir and Alaamer, 2008

*Measurement in mBq/l.


Fig. 4. Activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in the salt samples

Fig. 5. ^{40}K versus ^{226}Ra in the salt samples

Fig. 6. ^{40}K versus ^{232}Th in the salt samples

Fig. 7. ^{232}Th versus ^{226}Ra in the salt samples

4. CONCLUSION

In this study, ten composite salt samples were collected from salt pans of the Walvis Bay Lagoon in Namibia. These salt samples were analyzed for activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K with the aim to estimate the radiological risk associated with a number of different age categories. The analysis was done using HPGe gamma spectrometry. The average activity concentrations (Bq.kg^{-1}) of ^{226}Ra , ^{232}Th and ^{40}K in salt due to ingestion were found to be 2.17 ± 0.19 , 0.20 ± 0.02 and 2.28 ± 0.39 , respectively. These activity concentrations were used to calculate the annual effective dose and radiological health risk as a result of ingestion of salt for the different age groups. The average annual effective dose in ($\mu\text{Sv/yr}$) for the age ranges 2-7 years, 7-12 years, 12-17 years and ≥ 17 years were found to be 2.67 ± 0.22 , 3.33 ± 0.28 , 6.08 ± 0.53 and 1.22 ± 0.10 ,

respectively. All these were lower than the world wide average of 0.29 mSv/yr as reported by UNSCEAR in 2000. The total average radiological risk (unit less $\times 10^{-8}$) for the age ranges 2-7 years, 7-12 years, 12-17 years and ≥ 17 years were found to be 30.15 ± 2.48 , 60.30 ± 4.96 , 89.8 ± 7.44 and 422.09 ± 34.75 , respectively. All these were lower than the recommended limit of between 1×10^{-4} to 1×10^{-6} as reported by USEPA in 1991. Therefore, these results do not pose any radiological risk to members of the public.

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