Soil Radioactivity Levels And Associated Hazards In Selected Towns In Uranium-Rich Western Namibia

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Abstract

Soil samples from three major towns and a holiday settlement in uranium-rich western Namibia have been analysed using a HPGe detector for radioactivity due to ^{238}U, ^{232}Th and ^{40}K. The average activity concentrations of the radionuclides in the towns and settlement vary from a low of 18.6 ± 4.6 to a high of 69.6 ± 26.3 Bq kg^{-1} for ^{238}U, 23.8 ± 8.4 to 91.1 ± 41.0 Bq kg^{-1} for ^{232}Th and 460.3 ± 76.2 to 959.5 ± 194.7 Bq kg^{-1} for ^{40}K. In order to evaluate the associated health hazard, the concentrations were used to calculate the mean annual effective dose, radium equivalent activity (Ra_{eq}) and external hazard index (H_{ex}) for the towns and settlement. The values of 0.11 mSv, 195.3 Bq kg^{-1} and 0.53 obtained respectively for the mean annual effective dose, Ra_{eq} and H_{ex} are, however, below their permissible limits thus implying that radiation hazard is negligible.

Keywords: Swakopmund; Soil; Gamma spectroscopy; Natural radioactivity; Namibia.

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1 Introduction

Naturally occurring radiation is a continuous inescapable feature of life on earth and it is determined by the level of the background radiation for a specific environment. The two

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most significant contributors to the level of background radiation is cosmic radiation and radiation from natural radionuclides in the soil. These radionuclides are the radioactive elements of the uranium series, the thorium series and radioactive potassium (Abusini et al. 2008; Alatise et al. 2008; Sahin et al. 2008; Mujahid et al. 2011; Kapdan et al. 2012; Al-Sharkawy et al. 2012; Radi Dar et al. 2013). If the concentrations of the radionuclides in the soil of a given location are high, the background radiation will be high and could pose health problems to the inhabitants of the area (Ghiassi-nejad et al. 2002; Ramli et al. 2005). For this reason, many researchers in different countries measure the concentrations of the radionuclides ^{238}U, ^{232}Th and ^{40}K in their soils. In western Namibia, there are many uranium deposits and many well-known uranium mines such as Langer Heinrich Uranium, Reptile Uranium, Rössing Uranium, Tjrekkope, Uramin Inc. and Valencia Uranium Project. Consequently, the concentrations of the radionuclides ^{238}U, ^{232}Th and ^{40}K in the soils may be high in some locations that are even far from the mines thereby making such places area of high background radiation. It is therefore desirable to determine the concentrations of the radionuclides in the relatively densely populated areas of western Namibia. The baseline data obtained will be useful for studies on public dose rates. Also, as the country is considering the option of building nuclear power reactors to generate electricity, the baseline data will be useful as a reference in assessing changes in environmental radioactivity due to nuclear activities in future. It is therefore important to determine the concentrations of the radionuclides ^{238}U, ^{232}Th and ^{40}K in the soils of Western Namibia and investigate the associated health hazard.

The uranium mining area of Namibia is in the western part of the country and three major towns and holiday settlement in the area are Walvis Bay, Swakopmund, Wlotzkasbaken, and Usakos as shown in the insert in Figure 1. These towns are well known for mining, fishing and livestock farming activities and their inhabitants include the Indigenous people, Western descendants and Europeans. Also, the towns are very popular with both local and international tourists and business people. Walvis Bay, the harbor town and naval base, is situated at latitude 22°57'S and longitude 14°30'E and is an entry and exit point for most import and exports from Namibia and some land-locked countries in southern Africa. The town of Swakopmund, a popular tourist destination and home to many people working at nearby uranium mines, is located at latitude 22°41'S and longitude 14°32'E. Wlotzkasbaken, a holiday settlement on the coast of the Atlantic ocean, is at latitude 22°25'S and longitude 14°27'E, while the town of Usakos, a tourism hub through which many travelers - both locals and foreign visitors - pass through en route to the coastal towns, is at latitude 22°0'S and longitude 15°36'E.

The onshore coastal geology of western Namibia consists of old crystalline rocks that form the basement to the Permo-Triassic Karoo Sequence and young deposits of the Namib Dessert. The crystalline basement in this region is presented by rocks of the Abbabis Complex and the Nosib and Swakop Groups of the Damara Sequence that comprises mostly a thick pile of metasedimentary rocks. Based on stratigraphy, structure and metamorphic

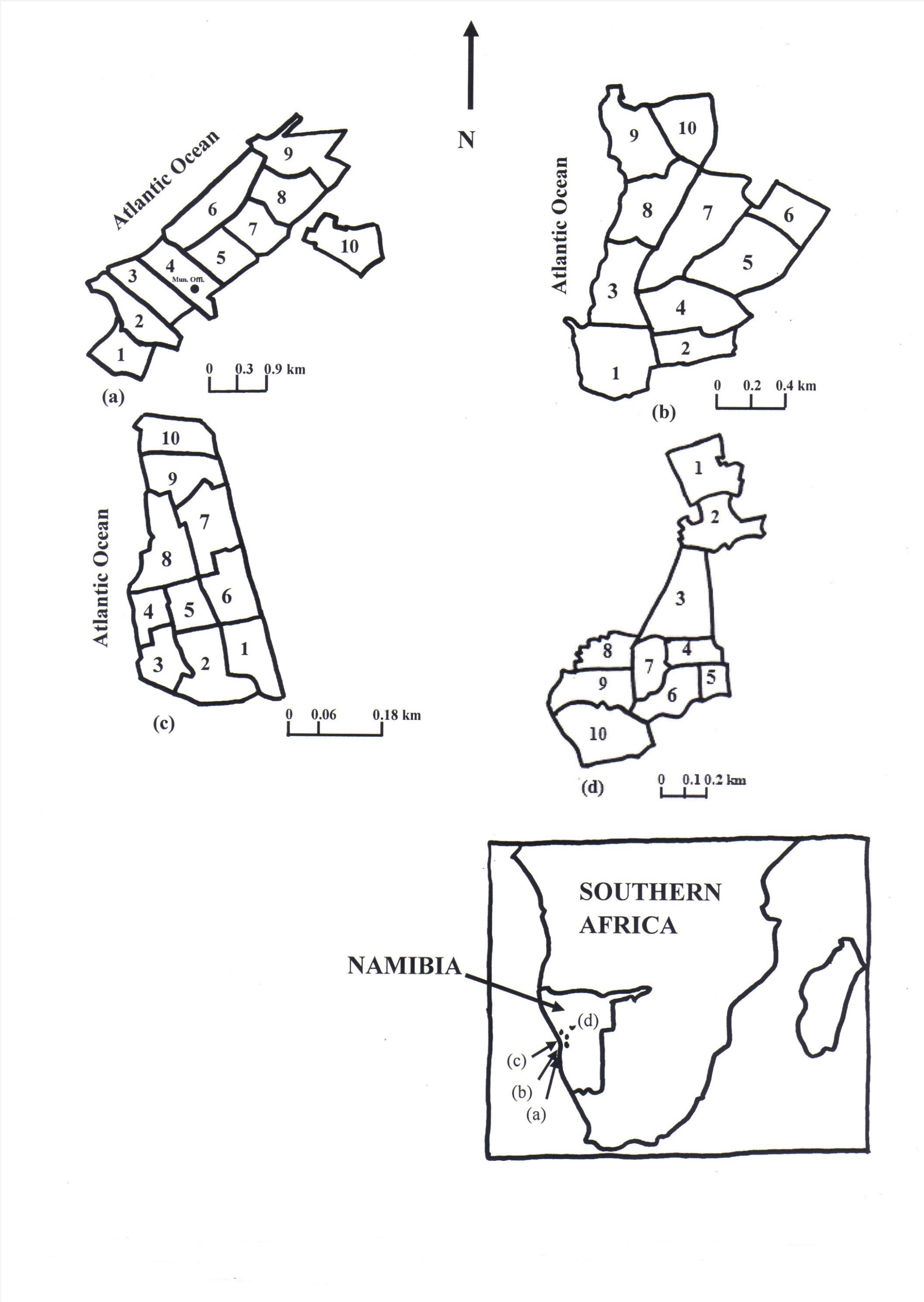

Figure 1: Map showing the areas where soil samples were taken in (a) Walvis Bay (b) Swakopmund (c) Wlotzkasbaken and (d) Usakos.

grade, the Damara Orogen is subdivided into zones, which comprise of the Central Zone, the Northern Zone and the Southern Kaoko Zone (Schreiber 1996; Shimboyo 2013).

The aim of this study was to determine the activity concentrations of the radionuclides ^{238}U, ^{232}Th and ^{40}K in soil samples collected across the towns of Walvis Bay, Swakopmund, Usakos and the settlement of Wlotzkasbaken in western Namibia and use the results to calculate the mean absorbed dose rate, the mean effective dose rate, the radium equivalent activity and external hazard index for each town and settlement. This study will provide the needed information on whether or not the towns and settlement have normal (or high) background radiation and will also form an important baseline for the determination of radioactivity level in Namibia.

2 Materials and Methods

A total of 200 soil samples were collected from the towns and settlement. The samples were taken from ten geographical areas (five samples/area) in each of the towns and settlement as shown in Figure 1 and listed in Table 1. All the sites chosen were away from roads, buildings, railway lines, trees and rivers. The samples were dried under laboratory temperature, and each sample was subsequently passed through a 2-mm mesh screen and sealed in a plastic bottle for one month to allow the radionuclides in the sample to reach secular equilibrium with their corresponding progeny.

A calibrated vertical Canberra HPGe detector that was well-shielded was used to measure the gamma-ray spectra for the soil samples. The calibration was done using certified reference materials RGU-1 (U-ore), RGTh-1 (Th-ore) and RGK-1 (K_2SO_4) provided by the International Atomic Energy Agency (IAEA). The geometry and counting time (10 800 s) used for the reference materials were the same as those used for the samples. The details of the measurement procedure have been discussed elsewhere (Shimboyo 2013).

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K were respectively determined from the intensities of the gamma lines 0.609 MeV of ^{238}U, 0.911 MeV of ^{232}Th and 1.465 MeV of ^{40}K. These concentrations were subsequently used to calculate the average absorbed dose rate, the mean effective dose per year, the radium equivalent activity and the external hazard index for each geographical area and each town and settlement.

Table 1: Geographical areas where soil samples were collected in three towns and a holiday settlement (H.S.) in western Namibia.

Town / H.S.	Area	Name	‡dose in mSv
Walvis Bay	1	Meersig residential area	(0.05 ± 0.01)
	2	Golf course area	(0.05 ± 0.01)
	3	Walvis Bay State Hospital area	(0.05 ± 0.00)
	4	Municipality of Walvis Bay civic centre area	(0.06 ± 0.01)
	5	Post Office CBD Area	(0.05 ± 0.01)
	6	Heavy Indst. - Nam. Ports Auth. area (Namport) area	(0.05 ± 0.01)
	7	Light Industrial Export Processing Zone (E.P.Z) area	(0.05 ± 0.00)
	8	Kuisebmond civic centre area	(0.04 ± 0.01)
	9	Kuisebmond residential area	(0.05 ± 0.01)
	10	Naraville residential area	(0.08 ± 0.00)
Swakopmund	1	Swakopmund Jetty area	(0.12 ± 0.03)
	2	Haus Petman/ Municipal Graveyard area	(0.10 ± 0.02)
	3	Welwitscha Sports grounds area	(0.10 ± 0.02)
	4	Transnamib Train Station area	(0.11 ± 0.01)
	5	Mondesa residential area	(0.14 ± 0.04)
	6	DRC residential area	(0.20 ± 0.03)
	7	Tamariskia residential area	(0.12 ± 0.02)
	8	Vineta residential area	(0.09 ± 0.02)
	9	Ocean View suburb area	(0.15 ± 0.03)
	10	Hage Heights area	(0.13 ± 0.03)
Wlotzkasbaken	1	Area around the sewerage/recycling house	(0.11 ± 0.04)
	2	House number 57,60,33 and 102 area	(0.13 ± 0.04)
	3	TownâĂŹs security building area	(0.11 ± 0.01)
	4	Area close to house numbers 26,54,and 92	(0.11 ± 0.02)
	5	Area around house number 79 and 53	(0.10± 0.03)
	6	MTC solar panel tower area	(0.12 ± 0.02)
	7	House number 50 and 78 area	(0.13 ± 0.04)
	8	Houses close to Water point area	(0.19 ± 0.06)
	9	House number 9 - 14 area	(0.20 ± 0.05)
	10	House number 1- 8 area	(0.16 ± 0.06)
Usakos	1	Hakaseb (Elifas Goseb Primary School) area	(0.18 ± 0.03)
	2	Hakaseb Community Centre/Hall area	(0.10 ± 0.01)
	3	Usakos (Welcome sign)/Erongo road area	(0.10 ± 0.01)
	4	Keets Scrap area	(0.12 ± 0.01)
	5	Wallis/ Conradie Street area	(0.13 ± 0.02)
	6	Bo-dorp area	(0.12 ± 0.03)
	7	Railway station (Bahnhof) area	(0.14 ± 0.05)
	8	Church area in Third Street	(0.12 ±0.01)
	9	Usakos Municipality area	(0.16 ± 0.02)
	10	Usakos Children /Education Centre area	(0.12 ± 0.001)

‡The mean annual effective dose (in mSv) in each area is given in parentheses.

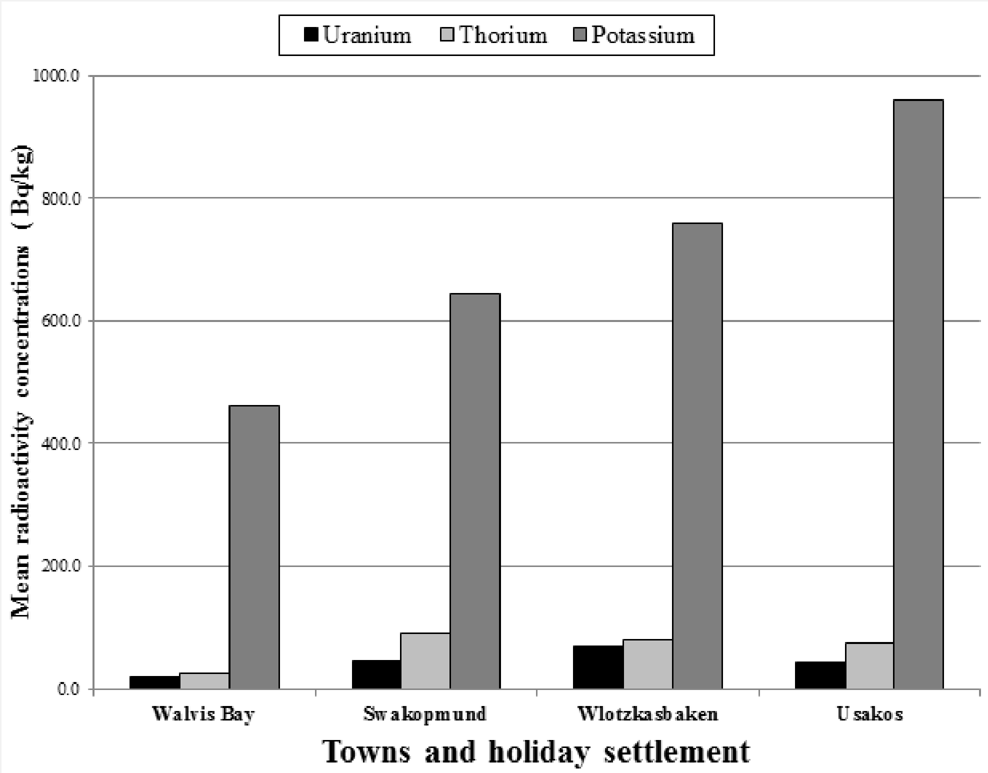

Figure 2: Comparison of the mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in three towns and a holiday settlement. (The towns and settlement are arranged in decreasing latitude but not to scale).

3 Results and Discussion

The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the soil samples collected from the different geographical areas, towns and settlement are summarized in Table 2 and shown in Figure 2. As could be observed in the Table and Figure, the activity concentration of ^{238}U is highest in Wlotzkasbaken with an average of 69.6 $\pm$ 26.3 Bq kg^{-1} (and varies from 51.5$\pm$ 6.2 to 104.1$\pm$28.1 Bq kg^{-1}) but lowest in Walvis Bay with an average of 18.6 $\pm$ 4.6 Bq kg^{-1} (and varies from 14.5 $\pm$ 2.5 to 27.2 $\pm$ 1.8 Bq kg^{-1}). Similarly, the activity concentration of ^{232}Th is highest in Swakopmund with an average of 91.1 $\pm$ 41.0 Bq kg^{-1} (and varies from 55.0 $\pm$ 17.9 to 167.6 $\pm$ 32.4 Bq kg^{-1}) while it is again lowest in Walvis Bay with an average of 23.8 $\pm$ 8.4 Bq kg^{-1} (and varies from 18.0 $\pm$ 3.0 to 39.7 $\pm$ 7.2 Bq kg^{-1}). Also, the activity concentration of ^{40}K is highest in Usakos with an average of 959.5 $\pm$ 194.7 Bq kg^{-1} (and varies from 774.6 $\pm$ 127.4 to 1336.5 $\pm$ 142.0 Bq kg^{-1}) but it is again lowest in Walvis Bay with an average of 460.3 ± 76.2 Bq kg^{-1} (and varies from 363.2 ± 50.8 to 586.9 ± 44.8 Bq kg^{-1}) as shown in Table 2 and Figure 2.

Table 2: Average (± standard deviation) radionuclide concentrations in three towns and a holiday settlement (H.S.) in western Namibia.

Town/H.S	Radionuclides concentration (Bq kg^{-1})		
	^{40}K	^{232}Th	^{238}U
Walvis Bay	460.3 ± 76.2	23.8 ± 8.4	18.6 ± 4.6
	(363.2 - 586.9)	(18.0 - 39.7)	(14.5- 27.2)
Swakopmund	645.5 ± 69.5	91.1 ± 39.6	46.4 ± 14.2
	(572.0 - 747.3)	(55.0 - 167.6)	(34.9- 68.1)
Wlotzkasbaken	759.2 ± 68.4	79.5 ± 44.1	69.6 ± 26.3
	(659.2 - 810.2)	(53.6-133.2)	(51.5-104.1)
Usakos	959.5 ± 194.7	74.8 ± 30.2	44.2 ± 9.7
	(774.6- 1336.5)	(45.7 -118.9)	(33.1- 52.9)
All samples	**706.1 ± 214.6**	**67.3 ± 42.5**	**44.7 ± 24.0**
	(363.2 - 1336.5)	**(18.0 - 167.6)**	**(14.5 - 104.1)**

‡The corresponding range of mean values from the different geographical areas in a given town or holiday settlement is given in parentheses.

It therefore follows that Walvis Bay has the lowest activity concentrations of the primordial radionuclides in the soil while Wlotzkasbaken, Swakopmund and Usakos have the highest activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. Also, ^{40}K has the highest activity concentration in each town and settlement while ^{238}U has the lowest activity concentration in each town and settlement as could be seen in Figure 2. With the exemption of Walvis Bay, the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the towns and settlement are much higher than the world-wide average activity concentrations of 35 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively (UNSCEAR 2000). Also, with the exemption of Walvis Bay, the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the towns and settlement are much higher than those measured earlier in the Capital city, Windhoek, which is about 350 km to the east of Swakopmund with average concentrations of 24.8 ± 5.1 Bq kg^{-1}, 35.2 ± 9.9 Bq kg^{-1} and 517.9 ± 117.4 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively (Oyedele 2006). The relatively high concentration of ^{238}U in the soils is a reflection of the fact that the towns and holiday settlement are in a uranium-rich region. It should be mentioned that the relatively high concentrations of ^{40}K in the towns have also been observed in some other African countries such as Algeria, Botswana, Egypt and Kenya (UNSCEAR 2000; Hashim et al. 2004; Murty et al. 2008).

The absorbed dose rates in air due to the radionuclides at each of the sites where samples were collected were calculated using the following equation (Arogunjo et al. 2004;

UNSCEAR 2000)

$$D = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (1)$$

where A_U,A_{Th} andA_K are the activity concentrations (in Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K respectively in each sample and D is in nGy h^{-1}. These rates were used to calculate the average dose rate in each town and holiday settlement. The results obtained are shown in Table 3 (column 2). As could be observed in the Table, the average absorbed dose rate is highest in Wlotzkasbaken with a value of 110.8 ± 40.3 nGy h^{-1} - which is more than double the world average of 51 nGy h^{-1} (UNSCEAR 2000; Shimboyo 2013) - while it is lowest in Walvis Bay with a value of 42.1 ± 9.2 nGy h^{-1}. These results reflect the fact that Walvis Bay has the lowest concentrations of the radionuclides while Wlotzkasbaken has very high concentrations of the radionuclides. The annual effective dose at each site where samples were collected was calculated from the corresponding absorbed dose rate using a conversion factor of 0.7 Sv Gy^{-1} and an occupancy factor of 0.2 (Arogunjo et al.2004; UNSCEAR 2000). The results obtained were subsequently used to calculate the average annual effective dose for each geographical area and for each town and settlement.

A summary of the results obtained is shown in Table 3 (column 3) and in Figure 3(a). The average annual effective dose is highest in Wlotzkasbaken with a value of 0.14 ± 0.05 mSv and lowest in Walvis Bay with a value of 0.05 ± 0.01 mSv. The resulting average annual effective dose for the towns and settlement is 0.11 ± 0.03 mSv as shown in Table 3 (column 3, bottom row). These results confirm that Wlotzkasbaken is having the highest natural radioactivity among the towns and settlement while Walvis Bay is having the lowest radioactivity. Also, the average annual effective dose increases as one move up from Walvis Bay to Swakopmund

Table 3: Average dose rate, annual effective dose, radium equivalent activity and external hazard index in three towns and a holiday settlement (H.S.) in western Namibia. Town / H.S.

Town/H.S	Absorbed dose rate (nGy h^{-1})	Annual effect. dose (mSv)	Radium equiv. activity (Bq kg^{-1})	Ext. hazard index
Walvis Bay	42.1 ± 9.2	0.05 ± 0.01	88.0 ± 16.6	0.24 ± 0.04
	(32.7 -61.0)	(0.04 - 0.08)	(68.2 -129.1)	(0.18 - 0.35)
Swakopmund	103.4 ± 30.9	0.13 ± 0.04	226.4 ± 60.5	0.61 ± 0.16
	(78.0 - 160.3)	(0.09 - 0.20)	(163.5- 358.8)	(0.44 - 0.97)
Wlotzkasbaken	110.8 ± 40.3	0.14 ± 0.05	241.6 ± 62.3	0.65 ±0.17
	(84.8 - 160.0)	(0.10 - 0.20)	(187.6 - 352.7)	(0.51-0.95)
Usakos	105.7 ± 23.9	0.13 ± 0.03	225.1 ± 39.6	0.61 ± 0.11
	(84.4 -142.8)	(0.10 - 0.18)	(182.1- 306.0)	(0.49 - 0.83)
All samples	**90.5 ± 39.8**	**0.11 ± 0.05**	**195.3 ± 79.3**	**0.53 ± 0.21**

‡The corresponding range of mean values from the different areas in a given town or holiday settlement is given in parenthesis.

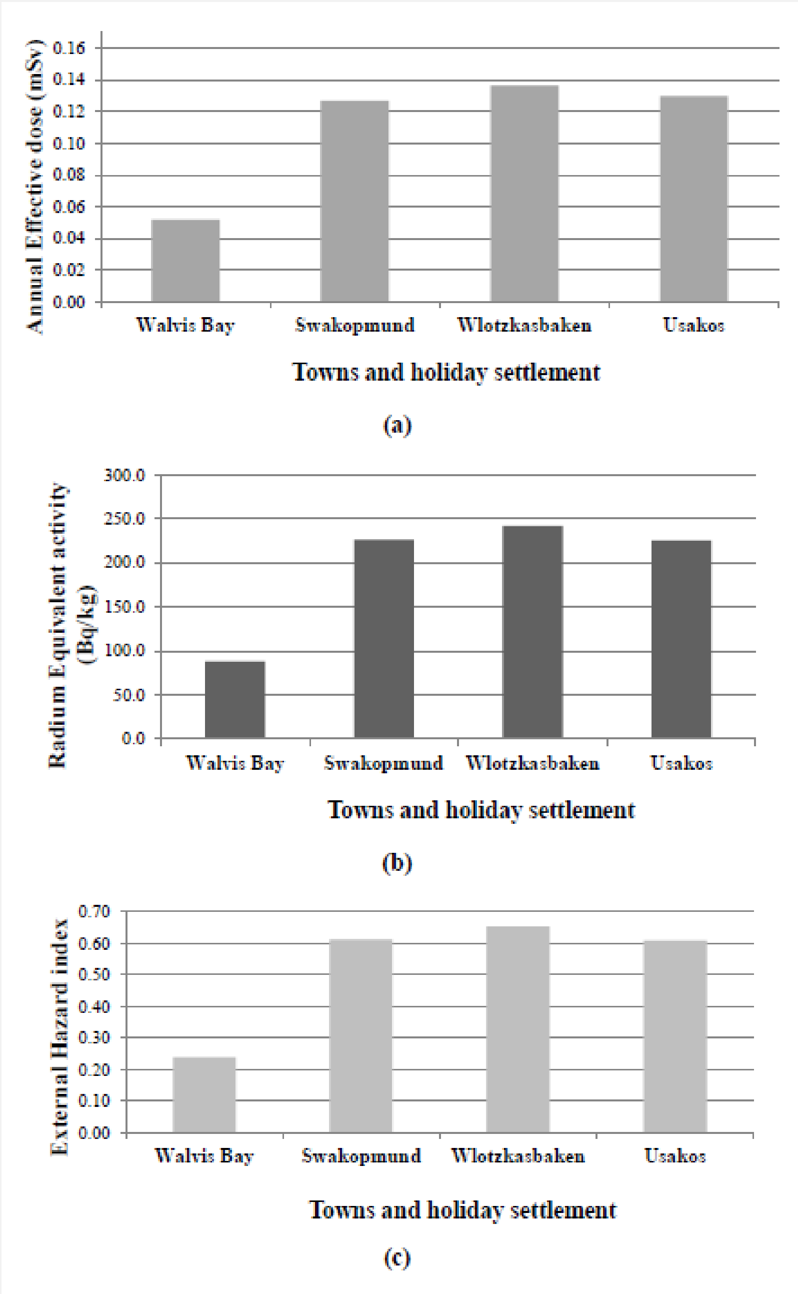

Figure 3: Comparison of average (a) Annual effective dose (b) Ra_{eq} and (c) H_{ex} for three towns and a holiday settlement in western Namibia.

and to Wlotzkasbaken (Figure 3(a)). However, all the values obtained for the average annual effective dose in the towns and holiday settlement are still below the maximum permissible annual dose of 1.0 mSv recommended for the public by the International Commission on Radiological Protection, ICRP (Wrixon 2008).

The measured concentrations of ^{238}U, ^{232}Th and ^{40}K in each soil sample were used to calculate the radium equivalent activity (Ra$_{eq}$), a hazard index, for each sample using the expression (Al-Sharkawy et al. 2012; Beretka et al. 1985; Wang et al. 2012)

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \tag{2}$$

where A_{Ra}, A_{Th} andA_K are respectively the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and it was assumed that there was secular equilibrium between ^{238}U and ^{226}Ra. The results obtained were subsequently used to find the average radium equivalent activity for each geographical area and for each town and settlement as summarized in Table 3 (column 4) and shown in Figure 3(b). As could be seen in the Table and Figure, the average radium equivalent activity ranged from a relatively low value of 88.0 ± 16.6 Bq kg^{-1} in Walvis Bay to a high value of 241.6 ± 62.3 Bq kg^{-1} in Wlotzkasbaken. These results confirm that Walvis Bay is having the lowest radioactivity among the towns and settlement while Wlotzkasbaken is having the highest radioactivity. However, all the average values obtained for Ra$_{eq}$ in the different areas and towns are below the recommended maximum of 370 Bq kg^{-1}.

An external hazard index (H$_{ex}$), that reflects external exposure was calculated for each sample using the equation (Al-Sharkawy et al. 2012; Beretka et al. 1985; Mutuk et al. 2014)

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \tag{3}$$

where A_{Ra}, A_{Th} andA_K are as defined above and secular equilibrium between ^{238}U and ^{226}Ra was assumed. The results obtained were used to find the average hazard index for each area and for each town and settlement. These average values are summarized in Table 3 (column 5) and shown in Figure 3(c). As could be seen in the Table and Figure, the average external hazard index for the towns and settlement varies from a minimum of 0.24 ± 0.04 in Walvis Bay to a relatively high value of 0.65 ±0.17 in Wlotzkasbaken. These results again confirm that Walvis Bay has the lowest radioactivity among the towns while Wlotzkasbaken has the highest radioactivity. However, all the average values obtained for H$_{ex}$ in the different areas in the towns and settlement are less than the maximum limit which is unity in this case. Since the average effective dose rates (mSv y^{-1}), radium equivalent activities and external hazard indices in the towns and settlement are all below their respective maximum permissible limits, then the radiation hazard in these towns and settlement is negligible so that the towns and holiday settlement are not areas of high background radiation.

4 Conclusion

The mean activity concentrations of the primordial radionuclides ^{238}U, ^{232}Th and ^{40}K in the soils of most of the major towns and holiday settlement in western Namibia are much higher than the world-wide average concentrations in soils. This is a reflection of the fact that western Namibia is rich in uranium and other minerals. However, the average effective dose rates, radium equivalent activities and hazard indices calculated for the towns are below their respective maximum permissible limits. These results imply that radiation hazard is negligible in the towns and holiday settlement so that they are not areas of high background radiation.

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