THE BACKGROUND RADIATION AND EXPOSURE LEVELS AT VARIOUS SOUTH AFRICAN WEST COAST MILITARY UNITS

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Abstract

The West Coast of South Africa between St Helena Bay to the north and Langebaan Lagoon to the south is characterised by numerous granite protrusions. These outcrops are elements of the underlying Cape Granite Suite, which forms the bedrock of a large part of the Western Cape. Granite contains high levels of natural radionuclides, which results in high levels of natural background radiation in the surrounding area. The impacts of these high levels of radiation exposure on military personal are of concern. There are four military units located in this part of the West Coast, namely SAS Saldanha, 4 Special Forces Regiment, Langebaan Road Air Force Base and the Military Academy. Different sites in and around these military units were selected and soil samples were taken. Laboratory gamma ray measurements were done to determine the levels of natural radioactive nuclides in the soil samples. The radioactive nuclide concentrations were interpolated and then mapped with the help of geographic information systems (also known as geospatial information systems or GIS) software. An evaluation of the annual dose rate of military personnel at the units on the West Coast was made and found to range between 0,017 mSv/y and 0,163 mSv/y. These values were mapped and compared to the average global annual dose rate of 0,070 mSv/y. This article reports on an investigation of these results and the overall exposure levels of personnel from the various military units on the West Coast of South Africa.

Introduction

All humans are exposed to some natural background level of radiation. This it is unavoidable and continuous. Natural background radiation exists in soils, rocks, sand, water, air and even living organisms. Radiation can cause various health effects, which include, amongst other, numerous cancers, chronic lung diseases, anaemia and leukaemia.[2] According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report,[3] the dominant contribution to human exposure is due to natural background

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radiation. The report further states that high natural background radiation can mainly be attributed to high levels of the primordial nuclides. Numerous studies have consequently been done in order to estimate the health risk of high background radiation, and the work by Sohrabi reviews and summarises most of these studies.[4] Some of these studies investigated areas or environments where high background radiation levels were caused by granite.[5]

The coastal area of South Africa between St Helena Bay to the north and the Langebaan Lagoon to the south is known for its rocky environment. The underlying bedrock of this area is granite. This is clearly visible in resistant headlands on long parts of this coastline and in large hills in this area. These protrusions of intrusive rocks belong to the Late Precambrian to Cambrian Cape Granite Suite.[6] The upper layers of soil in the alluvial fans on the slopes of these hills are also mainly broken-down granite rock.[7] Granite contains relatively high concentrations of primordial radioactive nuclides, which in turn contribute to high levels of natural background radiation.[8] These primordial radioactive elements consist of uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K) of which potassium is by far the most abundant.[9] All of these nuclides emit radiation that would ultimately interact with the surrounding environment and this produces elevated levels of natural background radiation. Humans who work and reside in granite-rich environments would consequently also receive high doses of background radiation. This is specifically true for occupations where the outdoors occupancy factor is quite high.

The military personnel in the granite areas of the West Coast of South Africa are exposed to high natural background radiation that results from broken-down granite and granite rocks on a daily basis. The nature of the military occupation can further result in additional exposure of personnel due to field training and outdoor exercises. The military personnel on the West Coast of South Africa are affiliated to four military training units. These four military units are however spread over a large area with variations in the lithology. The concentrations of radionuclides may therefore vary substantially over the area, with the result that some military personnel would be more prone to exposure than other. This difference in radiation exposure and maximum levels of human exposure therefore needs investigation.

Historical perspective on geographical locations of military units on the West Coast

The geographical nature of Saldanha Bay makes it an ideal harbour, and it was for this reason that Saldanha Bay was used as an assembly point for the formation of naval convoys during the Second World War.[10] The strategic nature of the bay motivated military occupation and subsequent fortification of the northern and southern headlands. The naval military occupation continued after the war and later culminated in the founding of SAS Saldanha that currently provides basic training to all members of the South African Navy.

Aerial coverage against submarines was also planned during the Second World War, and the building of an aerodrome consequently started in 1942 at Langebaan Road. The aerodrome was however only completed after the war and the first aircraft landed at the base during February 1946. The base is currently a fully operational training unit of the South African Air Force and is known as Air Force Base Langebaan Road. A crash boat facility was also founded at Langebaan to support aircraft during maritime patrols. This unit was however disbanded and a special forces regiment later occupied the facilities in the town of Langebaan, as well as an old whaling station on the peninsula across the lagoon from Langebaan. All of these areas are currently still occupied by the military and large parts of the land are managed as military nature reserves.

Figure 1: Google Earth image of Saldanha Bay, indicating the current locations of the four military units

In 1957, the South African Military Academy also found a new home on the slopes of Malgaskop hill that borders the northern part of Saldanha Bay. The Military Academy and SAS Saldanha share a large military area that borders the town of Saldanha. This area is known as the Saldanha Military Area. The current locations of the four units are indicated on the Google Earth image in Figure 1.

Lithology of the study area

The four military units on the West Coast of South Africa are located over a large area with varying lithology. SAS Saldanha is situated on a fossilised dune on the shore of the smaller inner bay of the Saldanha Bay system. The outer surface of this fossilised dune is covered by a hardened calcrete layer. A large part of this layer was removed during the construction of the base. There is however no visible granite protrusions in the proximity of the naval base. The Military Academy is in the same military area as SAS Saldanha but in a vastly different geological setting from that of the naval base. The buildings of the Military Academy are situated on the slope of a large granite hill, named Malgaskop. The area around the buildings is subsequently covered with granite outcrops and rocks, and the top soil on the slope comprises mainly broken-down granite.[11]

Granite protrusion is common on the hills around the town of Langebaan were one section of the 4 Special Forces Regiment unit is situated. The other military area of 4 Special Forces Regiment is situated on a peninsula across the lagoon from Langebaan. The lithology in this area ranges from large granite hills to fossilised dunes and very sandy areas. Sections of the 4 Special Forces Regiment are therefore similar in geology to that of the Military Academy. Air Force Base Langebaan Road is positioned in a large sandy area with no visible granite protrusions in any proximity to the base.

Method

More than 50 soil and sand samples were collected from various locations in and around the four military units on the West Coast of South Africa. The samples were collected at a depth of 15 cm, and small stones and plant material were removed. Polypropylene pill containers were used for both the standards and the sample materials. A volume of 100 ml was adopted with sample mass ranging from 0,110 kg to 0,180 kg. The samples were taken at more or less equal distances from one another and most of the accessible parts of each military unit were sampled. The sampling areas which coincided with the four military units are indicated on a geological map of the study area (see Figure 2). The geological map that displays the prevalence of granite was obtained from Scheepers and Armstrong, and adapted for the purpose of this article.[12]

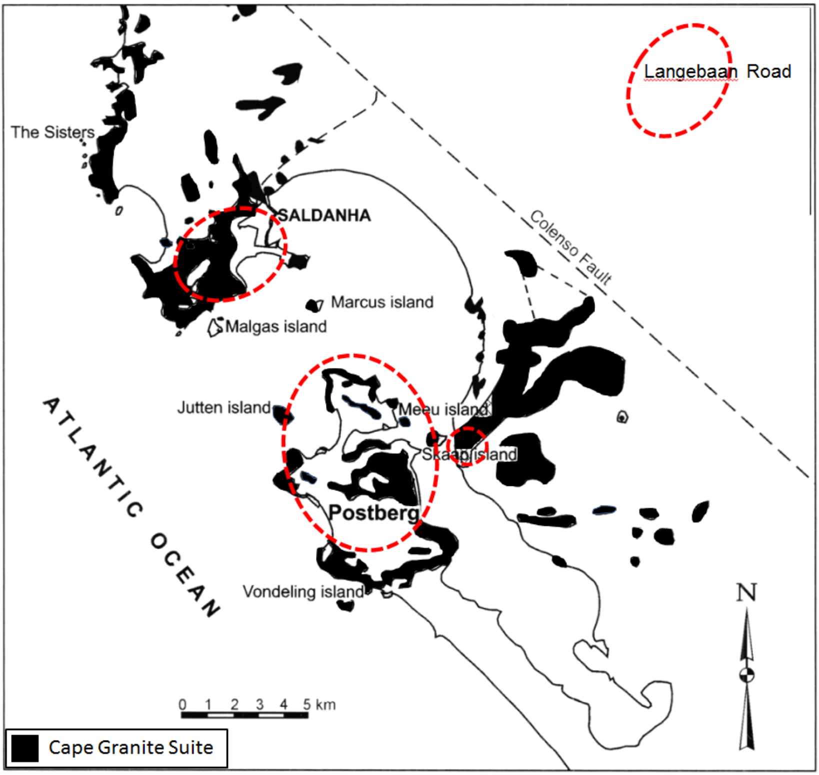

Figure 2: Geological map of Saldanha Bay, indicating the distribution of granite and displaying the sampling areas with red circles[13]

A NaI(*Tl*) detector (7,62 x 7,62 cm) coupled to a scintiSPEC® Multi-Channel Analyser (MCA) was used to record the laboratory gamma-ray spectra of these samples. The system settings and spectrum acquisition were controlled by winTMCA32 software (with 1 024 channels), which is produced by ICX Technologies. The detector was surrounded by 15 cm thick lead shielding, which substantially reduced and smoothed the background radiation.

The system calibration was done by using three reference materials. A uranium and a thorium standard material was obtained from the International Atomic Energy Agency. The third, a potassium calibration standard of extra-pure potassium chloride (99,98%), was obtained from and certified by the Dead Sea Works Ltd. Energy calibration was performed in the energy range of 0,3 to 2,7 MeV using anthropogenic nuclides and natural soil samples. The photon emissions that were used for calibration were ^{214}Pb (351,3 keV), ^{137}Cs (661,7 keV), ^{60}Co (1173,2, 1332,5 keV), ^{40}K (1460,8 keV), ^{214}Bi (609,3, 1120,3, 1764,5 keV) and ^{208}Tl (583,2, 2614.5 keV). The measurement procedure described by Rybach was adopted for the three regions of interest (ROIs) and implemented with some alterations to the calibration aspects and the width of the ROIs, which were suggested by Chiozzi, De Felice, Fazio, Pasquale and Verdoy and Bezuidenhout, respectively.[14,15,16,17] Three counting windows or ROI centred on the three photo peaks of ^{214}Pb (351,3 keV), ^{40}K (1460,8 keV) and ^{208}Tl (2614,5 keV) corresponding with the ^{238}U, ^{40}K and ^{232}Th decay series, respectively. The activity concentrations of ^{232}Th, ^{238}U and ^{40}K, denoted by C_{Th}, C_U and C_K respectively, where then extracted from these ROIs.

The dose rates were calculated by means of the method described by Agbalagba, Avwiri and Chad-Umoreh.[18] The absorbed dose rate (D) was calculated by

$$D = (0.621C_{Th} + 0.462C_U + 0.0417C_K) \text{ nGy/h},$$

where C_{Th}, C_U and C_K are the activity concentrations of ^{232}Th, ^{238}U and ^{40}K in Bq/kg. The effective dose rate ($E_{ff}Dose$) was then calculated by

$$E_{ff}Dose = (\textit{hours in a year} \times \textit{absorbed dose in air} \times \textit{outdoor occupancy factor} \times \textit{absorbed dose rate}) \text{ mSv/y},$$

reducing to

$$E_{ff}Dose = (1.23\times10^{-3} \times \textit{absorbed dose rate}) \text{ mSv/y}.$$

This calculation assumed an outdoor occupancy factor of 0,2. The effective dose rate of the various sample points were then plotted, interpolated and overlaid on a topographical map, as well as Google Earth images of the units. The interpolations and overlays were constructed with the help of ArcGIS software.

Results

The different nuclide concentrations for the samples in that area were interpolated and overlaid on Google Earth images. Large variations in the concentrations of the ^{238}U, ^{232}Th and ^{40}K nuclides were found in most of the military areas. The largest variations were however found in the military areas of 4 Special Forces Regiment. These variations are clearly visible in the Google Earth images with concentration overlays that are displayed in Figure 3. The military area of 4 Special Forces Regiment is characterised by different types of lithology, which range from large granite hills to very sandy areas. The high concentrations correlated well with areas where granite protrusions were prevalent. The highest concentrations were measured on the slopes of granite hills in the most western part of the military area.

An inter-correlation amongst the concentrations of three nuclides was also notable. The sandy areas had relatively low nuclide concentrations, with the exception of two locations where relatively high uranium levels were measured. Both of these samples were taken on sandy outcrops that stretched into the Langebaan Lagoon. The nuclide concentration levels in the town of Langebaan on the mainland were found to be very low. This was evident when investigating the eastern part of all the Google Earth images with the various concentration overlays.

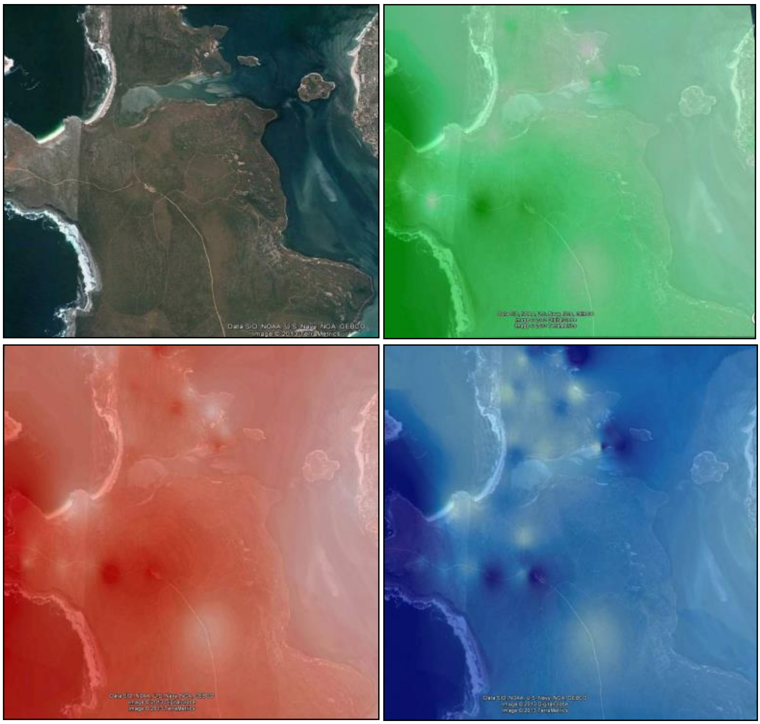

Figure 3: Google Earth images of the military area of 4 Special Forces Regiment

(The first Google Earth image has no overlay and the next three have overlays of the interpolated concentrations of ^{232}Th (green), ^{40}K (red) and ^{238}U (blue). The darker shades correspond with higher concentrations and all values are expressed in relative scales in order to illustrate corresponding variations better.)

The concentrations of the three nuclides were combined and the annual effective dose rate was calculated by means of the equations that are provided in the section on Methods. The estimated annual effective dose rate for the military area of 4 Special Forces Regiment was overlaid on a topographic map and is shown in Figure 4. The maximum estimated annual effective dose rate was 0,228 mSv/y, and was found to be in the granite hill on the far most western side of this military area. The lowest estimated annual effective dose rate was 0.031 mSv/y, and was associated with the area of the unit that lies in the town of Langebaan.

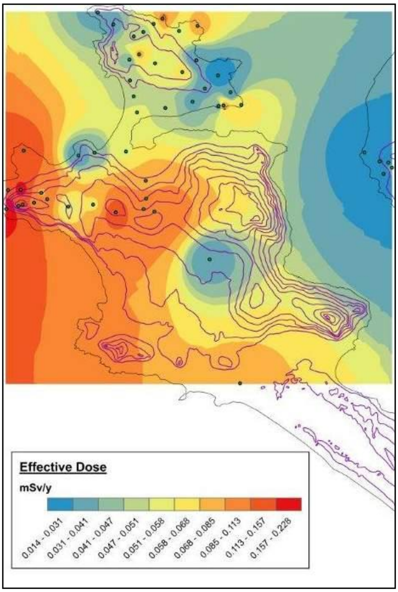

Figure 4: Topographic map with overlay of the estimated annual effective dose rate of the military area of 4 Special Forces Regiment
(Sample points are also indicated in black.)

The Saldanha Military area – which includes SAS Saldanha and the Military Academy – was investigated in combination with the town of Saldanha. Large variations in the concentrations of the ^{238}U, ^{232}Th and ^{40}K nuclides were also found in this area. This consequently resulted in substantial variations in the estimated annual effective dose rate of the area. These variations are clearly visible in the

Google Earth image and the topographic map that are overlaid with an estimated annual effective dose rate layer (see Figure 5).

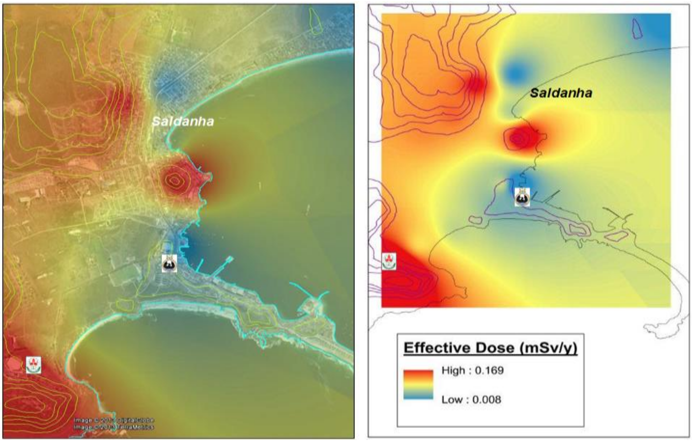

Figure 5: Google Earth image and topographical map with overlays of the annual effective dose rate

(The Military Academy ( ), SAS Saldanha ( ) and Saldanha town are indicated.)

All the hills in the images showed elevated effective dose rates as a result of the presence of broken-down granite that originated from weathering of the granite protrusions. The Military Academy is situated on the slope of such a granite hill and displayed an estimated annual effective dose rate of 0,163 mSv/y at the time of the study (2012). The dune area of SAS Saldanha, on the other hand, is characterised by very low concentrations of nuclides with a resultant low effective dose rate. Estimated annual effective dose rates consequently differed significantly between these two units, notwithstanding their close proximity. The maximum estimated annual effective dose that was extracted in the larger Saldanha area was 0,169 mSv/y at the time of the study, but that level was still below the highest value that was extracted at 4 Special Forces Regiment (0,228 mSv/y).

The Air Force Base Langebaan Road is situated in a very sandy area without granite nearby, which resulted in very low concentrations of ^{238}U, ^{232}Th and ^{40}K nuclides. The estimated annual effective dose rates were consequently also very low and without significant variation. At the time of the study, the minimum annual effective dose rate for Air Force Base Langebaan Road was estimated at 0,011 mSv/y and the maximum annual effective dose rate was estimated at 0,029 mSv/y.

Discussion

The annual estimated effective dose rate for personnel in all the military training units of the West Coast and the world average are listed in Table A. The activity concentration values that were measured and utilised in the estimation of these effective dose rates are also listed in Table A. The lowest level of exposure of military personnel was estimated at Air Force Base Langebaan Road and the highest level at the Military Academy. These large variations can be ascribed to the fact that the units on the West Coast are spread over a large area with some parts not being in close proximity to granite, while other parts of units are on or near granite (see the geological map in Figure 2). Areas which exhibited high and low levels of annual effective dose rates closely coincided with granite and non-granite areas, respectively.

Military unit	**C_K (Bq/kg)**	**C_U (Bq/kg)**	**C_{Th}, (Bq/kg)**	**Effective dose rate (mSv/y)**
SAS Saldanha	114,5	19,8	20,3	0,038
Military Academy	1235,7	46,8	100,9	0,163
4 Special Forces Regiment (base on peninsula)	345,8	21,0	19,0	0,041
4 Special Forces Regiment (base in town)	131,9	14,2	17,9	0,028
4 Special Forces Regiment (other areas)	126,2	29,1	91,6	0,139
Air Force Base Langebaan Road	95,5	13,6	9,3	0,017
World average value for outdoor exposure	–	–	–	0,070

Table A: Average activity concentrations of ^{40}K (C_K), ^{238}U (C_U), ^{232}Th (C_{Th}) and the estimated annual effective dose rates of personnel for the various military units on the West Coast of South Africa

The 4 Special Forces Regiment also displayed areas where high levels of annual effective dose rates were estimated, but these high levels were limited to remote areas of a nature reserve (see Figure 4). These areas of 4 Special Forces Regiment are rarely accessed by personnel, contrary to the high dose rate area of the Military Academy, where personnel work and reside on a permanent basis. The

Military Academy is located on the slope of a large granite hill and the effective dose rate in and around this unit is subsequently very high. There are also several military accommodation facilities around the Military Academy, which include dwellings where staff reside on a permanent basis. The continuous exposure of these residents to high levels of background radiation is of concern.

The estimated outdoor effective dose rates of all the units are however comparable with the average worldwide outdoor background exposure of 0,070 mSv/y. The indoor effective dose rates might however have been elevated due to elevated radon levels that originated from the progeny of ^{232}Th and ^{238}U. The levels of indoor radon were however not determined. The exposure of personnel in the units would however be below the estimated average worldwide background of 1 mSv/y, which was presented by UNSCEAR,[19] if the indoor effective dose rates are assumed to be average. Radon measurements would however have to be conducted to confirm this assumption.

There exists a direct relationship between the effective dose rates and the outdoor occupancy factor. It is important to note that the annual outdoor effective dose rates were calculated by utilising an outdoor occupancy factor of 0,2. This factor is accepted in most studies and proposed by UNSCEAR[20] as a good average for civilian populations. Personnel under military training however tend to spend more time outdoors, and this may require an increase in the outdoor occupancy factor. The effective dose rates would double for military personnel if their outdoor occupancy factor is increased to 0,4. Applying this increase to the effective dose rates of the various military units that are listed in Table A would however still result in levels that compare to the world average value, except for the Military Academy. Training at the Military Academy, where the highest annual effective dose rate was estimated, however mainly takes place indoors, which would consequently not necessitate a change in the outdoor occupation factor. Contrary to that, training at 4 Special Forces Regiment and SAS Saldanha mainly takes place outdoors. Given the low levels of exposure at those units, an increase in the outdoor occupation factor would result in estimations of overexposure of military personnel at those units.

A large portion of the residential population of Saldanha as well as the town centre is situated amongst prominent granite protrusions, which results in very high levels of radiation exposure in those areas, contrary to the situation at SAS Saldanha. It would, however, be safe to accept the outdoor occupancy factor of 0,2 for these citizens, which implies that their exposure would be similar to the estimated outdoor effective dose rate of the personnel of the Military Academy (see Figure 5). The indoor effective dose rates may however also be elevated due to radon levels which would increase the combined effective dose rates substantially. The influence of long-term exposure to these moderate levels of background radiation combined with the possibility of elevated radon levels may be significant for humans who reside in these areas for long periods of time.

Conclusion

The granite on the West Coast has high concentrations of radioactive nuclides, which results in high levels of natural background radiation. Some of the towns and the military units on the West Coast are positioned amongst granite protrusions. The concentrations of radioactive nuclides in and around these units were determined by sampling and interpolation methods. The effective outdoor dose rates of personnel at these units were then estimated from these nuclide concentrations, and the levels varied between 0,017 mSv/y and 0,163 mSv/y. These values were comparable with the average outdoor effective dose rate value for the world of 0,070 mSv/y.[21]

The lowest exposure levels were measured at the Air Force Base Langebaan Road, which is situated in a sandy area, whereas the highest exposure levels were measured at the Military Academy, which is built on the slope of a granite hill. The total effective dose rates for members at these units could however not be estimated from nuclide concentration measurements due to the uncertainty of indoor radon concentrations. The indoor radon concentrations were assumed to be normal, which produced total exposure levels of less than 1,0 mSv/y, as recommended by UNSCEAR.[22] The results therefore showed that estimated exposure levels were within accepted limits at the time of the study. Long-term residents and indoor radon levels however need further investigation.

Endnotes

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