Influence of climate and weather on the mitigation of radon exposure in two towns of the Western Cape, South Africa

H.A.P. Smit & J. Bezuidenhout

Faculty of Military Science, Stellenbosch University, Stellenbosch, South Africa

ABSTRACT

Globally, exposure to high levels of radon gas is a known health risk. Granite commonly contains high concentrations of uranium and subsequently high exhalation of radon gas. In the Saldanha Bay area of South Africa, granites dominate the underlying geology as well as the surface characteristics of the area. This implies that elevated levels of radon gas may exist in houses in the area. However, a survey of indoor radon concentrations in the town of Vredenburg in the Saldanha Bay area recorded average indoor radon concentrations well below those recommended as threshold levels by international bodies. The average radon concentrations are also significantly below those recorded in Paarl, a town about 100 km southeast of Vredenburg with a similar underlying geology, but different climatological characteristics.

Indoor radon concentrations were measured in 34 homes in Vredenburg, and 62 houses in the west side of Paarl, on or near the granite outcrops. Electret ion chambers (E-PERM™) from Rad-Elec Inc were used to measure indoor radon in the randomly selected houses in each area. For both surveys, the electrets were deployed for periods of between 5 and 20 days. The Paarl survey was conducted between October 2003 and March 2004, while houses in Vredenburg were surveyed during January and February 2019.

In this article, researchers develop a theory to explain the lower than predicted indoor radon concentrations, as well as the difference in results obtained from the Vredenburg and Paarl surveys. They attribute these anomalies to the mitigating effect of the prevailing climatological conditions of the Saldanha Bay area and the generally mild climate experienced at both sites. The research postulates that these conditions can significantly reduce the health hazard associated with elevated indoor radon levels.

1. Introduction

Awareness of the dangers associated with human exposure to elevated radon gas levels in houses became a prominent research focus during the last decade. Numerous studies (IAEA, 2015) on the concentration and impact of radon in inhabited areas have been conducted, with some countries implementing legislation to safeguard people. The World Health Organization ranked radon as the second most important carcinogen causing lung cancer, second only to cigarettes smoke (Pavia et al., 2003). The worldwide average indoor radon concentration is at approximately 39 Bq/m³ (Bochichio et al., 1996).

Both the International Commission for Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) recommend that indoor radon concentrations of dwellings should be below 300 Bq/m³, while some countries recommend radon reduction measures for all houses with radon levels above 100 Bq/m³ (Watson et al., 2017). In this regard, the World Health Organizations states: ‘In view of the latest scientific data, WHO proposes a reference level of 100 Bq/m³ to minimize health hazards due to indoor radon exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m³’ (WHO, 2009).

Granite usually contains high levels of uranium and its progeny, which includes radon. A study by Lindsay et al. (2008) on radon levels in houses of Paarl, South Africa, proved that granite bedrock underneath or near houses results in high indoor radon concentrations. The geology of the West Coast around Saldanha Bay is dominated by granite, but radon has never been measured in the area.

Seasonal variation in indoor radon concentrations is well established by research (Al-Khateeb et al., 2017; Virk & Sharma, 2000; Xie et al., 2015), with the consensus being that winter concentrations are generally higher than summer concentrations. Other relationships between indoor radon and climatological factors are less well established. Kropat et al. (2014) found that higher temperatures lead to lower indoor radon levels, while Botha et al. (2018) concludes that sea breezes mitigate radon levels. Significant for this study, Baeza et al. (2018) allege that architectural style influences
indoor radon concentrations. They found that older houses with more natural openings displayed lower levels of radon than newer, more ‘air-tight’ dwellings. Tchorz-Trzczielkiewicz and Klos (2017) reported that wind can have a beneficial influence in lowering radon levels, while Duggal et al. (2014) concur and state that better ventilation lowers indoor radon levels. Xie et al. (2015) found that higher wind speeds are associated with lower indoor radon levels.

South Africa has been relatively inactive in the field of radon research, apart from a few isolated studies. This might be due to the country’s climate and weather and the resulting lifestyle. These factors may unwittingly mitigate elevated radon concentrations in houses and reduce negative health effects. In this article, the researchers advance a theory to explain how the impact of such potentially high radon levels may be unwittingly mitigated in the towns of the Saldanha Bay area due to meteorological and lifestyle factors.

1.1. The research questions

In order to explain the lower than predicted indoor radon gas concentrations in the Saldanha Bay area, the measurements of Vredenburg were compared to that of an earlier survey of Paarl, a town approximately 100 km south-east of Vredenburg. The same underlying granite geology characterizes the area around Paarl (Kisters & Belcher, 2018; Lindsay et al., 2008), and it was postulated that the average indoor radon concentration for these two towns would not differ significantly. To test the hypothesis, the following research questions had to be answered:

- Is there a significant difference between the average indoor radon gas concentrations of the Saldanha Bay area and those of Paarl?
- Given the similar underlying geology, if a significant difference occurs, what would be the cause of this inconsistency?

To answer these questions, the data from two surveys investigating indoor radon gas concentrations in Vredenburg and Paarl were statistically interrogated, and the climatological differences between the two sites explored.

1.2. Climate of the Saldanha Bay area and Paarl

The Saldanha Bay area is situated on the West Coast of South Africa, about 120 km north of Cape Town, and encompasses the towns of Vredenburg, Saldanha, Langebaan, and the railway station of Langebaan named Langebaanweg. The area has a typical Mediterranean climate with the bulk of the rain falling in winter and with hot and dry summer months (Schulze, 1965). The area is bounded by large open ocean areas to the west and south in the form of the Atlantic Ocean, with the cold Benguela Current flowing northward along the coastline (Visser et al., 2008). Most of the rainfall occur via cold fronts, although significant falls are caused by other systems such as cutoff lows (Reason et al., 2002). Figure 1 depicts average monthly rainfall data for Langebaanweg, inside the Saldanha Bay area, and indicates a mean annual average of 278 mm, with more than 80% occurring between April and September (De Vleeschauwer, 2018a).

![Figure 1](image-url). Average monthly rainfall for Langebaanweg, in the Saldanha Bay area, and Paarl, South Africa. Compiled from De Vleeschauwer (2018a) and the Agricultural Research Council (2020)
The town of Paarl is situated about 100 km southeast of the Saldanha Bay area, and about 50 km from the coast. The area shares a Mediterranean climate with Vredenburg, with the bulk of the rain falling in winter and with hot and dry summer months (Schulze, 1965). As can be seen from Figure 1, the mean annual average rainfall for Paarl is 604 mm, more than twice the Saldanha Bay average. As significantly, Paarl receives substantial amounts of rainfall (equal to or more than 20 mm) for 10 months of the year. Most of the rainfall occur via cold fronts, although significant falls can also be caused by other systems such as cutoff lows (Reason et al., 2002).

The wind regime for the Saldanha Bay area reflect consistent monthly wind speed averages of between 3.1 m/s and 4.8 m/s throughout the year (see Figure 2). Wind gusts of up to 33.4 m/s was recorded but is rare. According to De Vleeschauwer no windless periods of 24 hours were recorded at Langebaanweg since 1973 (De Vleeschauwer, 2018b).

A contributing factor to the consistency of wind experienced in the area is the presence of localized baroclinic fields that develop by day due to differential heating of land and sea surfaces. These baroclinic fields produce sea breezes and their return currents in a closed circulation with convergence and ascent over the land and the opposite out to sea. At night, with the land cooling faster than the ocean, a land breeze with its associated return current develops. These land and sea breezes are common along the coastline of Southern Africa and are strongest along the west coast due to the large horizontal temperature gradient between the cold Benguela Current and the adjacent hot, semi-arid land area (Tyson & Preston-Whyte, 2000).

The wind speed averages for Paarl in Figure 3 indicate monthly wind speed averages of between 1.7 m/s and 3.1 m/s throughout the year. This is substantially less than the active wind regime that is a feature of the Saldanha Bay area. Due to the location of Paarl, about 50 km from the ocean, sea- and land breezes plays no role in the wind regime of Paarl. This leads to much less pronounced and consistent wind movement, in effect lessening the mitigating effect of the winds on the temperature of Paarl.

The average temperatures for Langebaanweg (see Figure 4) indicate average monthly temperatures ranging from 21.2°C in January and February to 12.5°C in mid-winter. The annual temperature range is thus only 9.2°C. Extreme temperatures recorded are 43.1°C for January 2004 and 0.0°C for June 2010 (De Vleeschauwer, 2018a).

The average temperatures for Paarl depicted in Figure 3 indicate average monthly temperatures ranging from 25°C in January to 12.8°C in mid-winter. The annual temperature range is 10.2°C, one degree Celsius more than that of the Saldanha Bay area. While winter temperatures for the two areas are more or less the same, summers in Paarl are noticeably warmer (see Figure 4).

From the discussion above the following picture of the climate of the Saldanha Bay area emerges: The low rainfall, small yearly temperature range, mild winters, and fairly hot summers when temperatures are mitigated by the presence of sea breezes all contribute to make this a region characterized by moderate climatic

![Figure 2. Average wind data for Langebaanweg in the Saldanha Bay area, and Paarl, South Africa. Compiled from De Vleeschauwer (2018a) and the Agricultural Research Council (2020)](image-url)
conditions. Another important aspect of the climate is the consistent presence of moderate winds that further mitigate the climate.

A similar, but subtly different picture of the climate of Paarl can be deduced from the discussion on rainfall, wind, and temperature. When compared to the Saldanha Bay area, it is clear that Paarl has a much higher average annual rainfall, spread over a longer period of time, a slightly higher temperature range and higher summer temperatures, and a less active wind regime with sea-and land breezes playing no role in moderating the climate. However, it must be noted that, if compared to general European climates, both areas experience moderate climatological conditions.

1.3. The geology of Paarl and Vredenburg

The geology of the Paarl and the Saldanha Bay area is dominated by granite rock (see Figure 4) that forms part of the greater Cape Granite Suite underlying a large part of the Western Cape, South Africa (Scheepers & Schoch, 2006; Siegfried et al., 1984). The Cape Granite Suite forms part of the Saldania Belt, which is a fold belt along the southern tip of Africa and a member of the larger system of Pan-African belts. These granitic rocks in the Cape Granite Suite were emplaced between 560 and 520 Ma during the Pan-African orogenic event that led to the amalgamation of Pangea. The western part of the Cape Granite Suite demonstrates three northwest-southeast trending terranes that are separated by tectonic fault zones, one of which is the Colenzo fault that split the West Coast Peninsula and continues through to the Stellenbosch area in the southeast (Kisters & Belcher, 2018). The Colenzo fault zone also separates the two different sub-types of granitic rocks, referred to as I-types and S-types due to their assumed origin through the partial melting of either an igneous or sedimentary crustal source rock, respectively (Chappell & White, 1974).

I-type granite plutons conspicuously dominate the inland terrane, northeast of the Colenzo fault zone. Both the towns of Paarl and Vredenburg developed on exposed I-type granite protrusions within this terrane. Le Roux et al. (2019) found that I-type granite in the Saldanha Bay area contained higher concentrations of uranium resulting in greater radon emanation than other granites. Bezuidenhout (2013) measured relatively high uranium concentrations of 85 (10) Bq/kg in the I-type granite of Vredenburg. This value correlates well with the average concentration of 78 (7) Bq/kg that Lindsay et al. (2008) measured in Paarl. Statistical errors are indicated in brackets. The world average for uranium in soil and rock is 35 Bq/kg (Louw, 2018) which is well below the concentrations that were found in the I-type granite protrusions amongst and on which Vredenburg and the western part of Paarl are situated (Figure 5).

2. Material and methods

Indoor radon concentrations in 34 homes were measured in Vredenburg during the survey period (Le Roux et al., 2019). A total of 62 houses in the west side of Paarl, on or near the granite outcrops, were surveyed by Lindsay et al. (2008). Houses in each area were randomly selected, and electret ion chambers (E-PERM™) from Rad-Elec Inc. distributed

**Figure 3.** Average temperature data for Langebaanweg in the Saldanha Bay area, and Paarl, South Africa. Compiled from De Vleeschauwer, (2018a) and the Agricultural Research Council (2020)
among interested participants. For both surveys, the electrets were deployed for periods of between 5 and 20 days. The Vredenburg survey was done during January and February 2019, and those of Paarl between October 2003 and March 2004. The purpose of the study was explained to each respondent, and each homeowner was asked to complete a form indicating voluntary participation in the

Figure 4. An adapted geological map of the western Saldania Belt using the 1:1 000 000 spatial data provided by the Council for Geoscience indicating the distribution of various I- and S-type granitic intrusions (Kisters & Belcher, 2018; MacHutchon et al., 2020). Vredenburg and Paarl is indicated and the other place name are abbreviated as CT-Cape Town, MB-Malmesbury, RI-Robben Island, SD-Saldanha and SB-Stellenbosch.
Occupants were also instructed to continue with their normal routine to measure their typical exposure to indoor radon.

The chambers were placed in the living area on the lower level of each dwelling, 1 m above the ground and at least one meter clear of any windows, doors or walls. The chambers were left undisturbed for a minimum of three days. The initial and final potential of each electret was measured with a surface potential electret voltage reader (SPER) (also produced by Rad-Elec Inc.), and the final indoor radon concentration calculated after making a standard background gamma correction of 32 Bq/m³. To determine whether the results follow a lognormal distribution, the natural logarithm of the data was determined and plotted (Le Roux et al., 2019). The study by Lindsay et al. (2008) followed the same procedure. Electret ion chambers (E-Perm™) from Rad-Elec Inc. was used and placed in the lower level of houses while they were inhabited.

Indoor radon concentrations are usually higher during winter than during summer (Tchorz-Trzeciakiewicz & Klos, 2017). To make results comparable, both the measurements for Vredenburg and Paarl were taken during the Southern Hemisphere summer.

3. Results and discussion

Results of radon measurements in the built-up areas on the hills in Vredenburg rendered average values of 58.7 (11.7) Bq/m³ (Le Roux et al., 2019), whereas Lindsay et al. (2008) found average values of 132 (11) Bq/m³ in Paarl. Statistical errors are indicated in brackets. The number of houses sampled in Paarl and Vredenburg were 62 and 34, respectively. A graph with the frequency distributions of radon concentrations in Paarl and Vredenburg is shown in Figure 6. Radionuclide concentrations, which include radon, within a geographical region always tend toward a lognormal distribution (Bossew, 2010). Calculating the
natural logarithm of the radon concentrations of the two towns resulted in two sets of data with averages and standard deviations of 4.638 (0.723) and 4.301 (0.759) for Paarl and Vredenburg, respectively. The Shapiro–Wilks test was used to test for normality. In both instances, the log transformed values were found to be not normally distributed.

Since the data is not normally distributed, the non-parametric Wilcoxon rank sum test (for two independent samples) was used to test for significant differences between the raw (not log transformed) radon concentrations of Paarl and Vredenburg. The results indicated that the medians of the two towns differ significantly with a 95% confidence level. The statistical results are listed in Table 1.

The hypothesis that there is no significant difference between indoor radon concentrations in Vredenburg and Paarl can thus be rejected. The lower-than-expected indoor radon levels of Vredenburg can possibly be attributed to the prevailing climatic conditions.

3.1. Climatological factors affecting indoor radon concentrations for Vredenburg and Paarl

Considering the granite bedrock underlying both towns, indoor radon concentrations in both Vredenburg and Paarl should be well above the generally recognized threshold levels for mitigation measures. Although average levels in Paarl are slightly above the threshold levels, those in Vredenburg are significantly less. The explanation for this discrepancy can be found in the difference in climate between the two areas.

In Paarl, there is an absence of sea-breezes due to its location more toward the interior of the Cape Winelands area. This is coupled to a climate that is less mitigated by the influence of the ocean. The average rainfall for Paarl is 604 mm, more than double that of the Saldanha Bay area (Agricultural Research Council, 2020). Rainfall in Paarl is also spread over a longer period of the year than in the Saldanha Bay area. This higher rainfall in Paarl contributes to a more closed lifestyle than that found in the drier Saldanha Bay area. The meso-scale wind regime of Paarl is also much less active than that experienced in the Saldanha Bay area, resulting in a lower potential to flush radon gas from houses.

These slight differences in climatic factors seem to explain the discrepancy between the indoor radon gas concentrations measured in Vredenburg, and those

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Table 1. Statistical results for the Vredenburg and Paarl radon concentrations.

| Variable: Radon | Place      | N  | Median |
|-----------------|------------|----|--------|
| Paarl           | 62         |    | 125.0  |
| Vredenburg      | 34         |    | 48.8   |
| Wilcoxon Two-Sample Test Statistic |            |    | 3379.5 |
| Normal Approximation |            |    |        |
| Z               |            |    | 2.85   |
| Two-Sided Pr > |            |    | 0.0043 |

Z includes a continuity correction of 0.5.

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Figure 6. Normalized Frequency plots of the distributions of indoor radon concentrations in the towns of Paarl and Vredenburg.
recorded in Paarl, even though similar geological structures underlie both towns. This substantiates the theory that the prevailing climatic factors in the Saldanha Bay area lead to a significant lowering of the indoor radon gas concentrations.

**Building practices and lifestyle factors affecting indoor radon concentrations in Vredenburg and Paarl**

However, the real risk to the inhabitants needs to be evaluated using a more comprehensive approach. A thorough and realistic assessment of the associated health risk due to elevated levels of radon gas must include climatic factors such as building practices and prevailing lifestyle characteristics in the region. Both are determined by climate and weather. A consequence of the moderate climatic conditions experienced in the Saldanha Bay region is that people tend to spend many hours outdoors and, especially during the summer, to open their houses to the cooling effect of the sea breezes. Even during the winter period, most people will open their windows during daytime to let fresh air in. An unintentional by-product of this outdoor lifestyle, coupled to the prevailing climatic factors, is the regular ventilation of houses, effectively ‘flushing’ potential radon gas buildup from the houses. This may in effect lead to much lower actual radon gas levels in houses than that predicted for the area.

Houses in the Saldanha Bay area tend to follow general Mediterranean building styles which may serve to further decrease potential indoor radon gas buildup. Houses tend to have plenty of – and relatively large – access doors and windows for ventilation. Most of the houses also have external entertainment areas and outdoor terraces, which enhances the outdoor lifestyle of the region. Few houses have basements, built-in air-conditioning systems, or double windows and insulation of houses are virtually unknown. This results in a general situation in which houses are ‘aired’ on a regular basis, thus frequently dispersing any trapped radon gas.

Lindsay et al. (2008), reports the same type of housing in Paarl. They state: ‘only one house that we surveyed had air-conditioning, and no house had central heating. Most houses had only one level (no basements) ... ’ The higher rainfall, spread over a longer period, coupled to a less active wind regime and the absence of mitigating sea breezes, results in a slightly more ‘closed’ lifestyle in Paarl. Dispersing of trapped indoor radon gas is thus not so effective and sustained than in the Saldanha Bay area, explaining the significant difference in indoor radon concentrations.

To verify the theory discussed above, comprehensive actual radon gas measurements are planned for Vredenburg and other towns in the Saldanha Bay area, as well as for Paarl. More comprehensive measurements will serve to strengthen the theory and to establish if exposure of the population in the town of Vredenburg and the surrounding area are indeed within acceptable norms. If that is the case, it will be possible to further develop the theory that the climate and weather of the Saldanha Bay region is responsible for the mitigation of an otherwise potentially serious health hazard.

### 4. Conclusion

In interpreting indoor radon gas levels holistically, attention must be given to the influence of climatic factors, such as the weather and climate of the area. It is postulated that a typically moderate, maritime climate with an active wind regime, may cause a situation in which the possibly serious consequences of the radon gas concentrations will unwittingly be mitigated by the ensuing lifestyle of the inhabitants of the Saldanha Bay area.

This mitigating effect is further enhanced by the building style of the area with large windows, no basements or heating/cooling systems, and large open-air areas forming an integral part of most houses. People in the area routinely leave their windows open, especially during daytime, for most of the year. Moderate temperatures, and sustained, moderately windy conditions with low rainfall during extended periods of the year facilitate this outdoor lifestyle.

These climatic conditions and the subsequent lifestyle may effectively neutralize the dangers associated with high indoor radon gas concentrations by dispersing the gas trapped inside the houses. This will reduce the actual levels of radon gas in the houses to internationally accepted levels.

To test this hypothesis, the average radon levels obtained in a survey in Vredenburg, a town in the Saldanha Bay area, was compared to those recorded for Paarl, a town in a neighboring area with a similar underlying geology, but not located on the coast. Statistical analysis indicates that the medians of the indoor radon concentrations differ significantly between the two towns. This anomaly can be explained by the difference in the climate of the two towns. While housing styles in the two areas are similar, climatic conditions differ. In Paarl, the absence of an active wind regime and the mitigating effect of sea breezes decrease the sustained removal of indoor radon from houses. Due to the higher rainfall, spread over a longer period of the year, homeowners in Paarl may also keep their windows closed during longer periods of the year, thus further reducing the mitigation of indoor radon concentrations experienced when a more ‘open’ lifestyle is adhered to.

The implication of this finding is that high radon exhalation rates can be effectively mitigated by climatic conditions, the premise of this study. This can have far-reaching implications for the interpretation of
indoor radon levels in communities on the West Coast of South Africa. While lower actual indoor radon levels can be recorded during surveys, radon exhalation rates may be high due to the underlying granite geology. More research to ascertain if this is indeed a fact will have to be done as a matter of urgency.

**Note**

1. Langebaanweg is situated in the Saldanha Bay area and has the only comprehensive set of long-term climate data in the study area, since it is also a military flying school. Weather data is taken as representative for the whole Saldanha Bay municipality that include the towns of Vredenburg, Langebaan, and Saldanha. Langebaanweg, Langebaan, Vredenburg, and Saldanha are all situated within a 30 km radius.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**ORCID**

H.A.P. Smit [http://orcid.org/0000-0003-1684-6337](http://orcid.org/0000-0003-1684-6337)
J. Bezuidenhout [http://orcid.org/0000-0003-2540-0695](http://orcid.org/0000-0003-2540-0695)

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