Original Article

National mapping survey of indoor radon levels in the Maltese Islands (2010-2011)

Christine Baluci, Karen Vincenti, Bhikha Tilluck, Stephen Conchin, Saviour Formosa, Dorianne Grech

Abstract

Aim: To conduct a national geographically based survey to determine the distribution of the mean annual indoor radon gas concentration levels in dwellings in the Maltese Islands and map these levels; to identify any areas with annual mean indoor radon gas concentrations higher than the current proposed WHO reference level of 100 Bq/m^3; to determine an advisory national reference level for radon concentration in buildings.

Method: Radon measurements were carried out in 85 buildings distributed over the Maltese Islands between November 2010 and November 2011 using alpha-track radon detectors. Retrieved detectors were analysed by a Health Protection Agency-accredited laboratory in the UK. The overall annual arithmetic and geometric mean indoor radon gas concentrations for the Maltese Islands were calculated.

Results: The mean annual indoor radon concentration for the Maltese Islands was 32 Bq/m^3, with a geometric mean of 25 Bq/m^3 (standard deviation (SD) 25). The maximum level measured was 92 Bq/m^3 and the minimum 11 Bq/m^3. A radon map of the Maltese Islands was produced using the geographic mean annual indoor radon gas concentration level for each building.

Conclusion: The mean annual indoor radon concentration in Malta was found to be well below the lowest proposed WHO reference levels with no dwellings having a mean annual indoor radon gas concentration above 100 Bq/m^3. This national mapping survey for mean annual indoor radon gas concentration in the Maltese Islands indicates that the current proposed reference level of 100 Bq/m^3 by the WHO may be adopted as the national reference level for the Maltese Islands.

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Introduction

Radon-222 (^{222}Rn) is a naturally occurring radioactive nuclide and is one of the decay products of uranium-238.[1] Uranium is present in variable quantities in the earth's crust and radon therefore occurs in soil, groundwater, natural gas and building materials. The International Agency for Research on Cancer (IARC) classifies radon as a Group 1 human carcinogen.[2] The link between lung cancer deaths in miners exposed to elevated concentrations of radon at work has been confirmed[3], as is the link between residential radon and lung cancer[3-6]. Studies have shown that residential radon is considered to be the second most common cause of lung cancer after cigarette smoking[7] and is responsible for approximately 2% of all deaths from cancer in Europe, particularly in smokers and recent ex-smokers.[8]

Soil, sand, and rock underneath the home are the primary sources of indoor radon gas. Radon permeates into indoor environments from the ground through pressure-driven flows of radon-rich air via cracks in the bottom slabs and cellar walls of buildings. Certain types of bedrock and soil contain higher quantities of uranium. The inflow of radon gas is also dependant on the permeability of ground materials, the pressure difference between soil air and indoor air and the radon exhalation rate of the underlying soil. Building materials made from soil or rock such as alum shale concrete, volcanic tuff, gypsum waste, may also be a source of radon indoors as these may contain low levels of uranium. However, the subsequent levels of radon in the building that are attributable to such sources are not typically high and in general, no action needs to be taken concerning traditional building material.[1] Climatic factors and human behaviours, especially those effecting ventilation of indoor habitats, lead to significant daily and seasonal variations in radon levels. Outdoor radon levels are known to be low and to have no major impact on health.[1,7]

Radon surveys

The aim of radon surveys is to identify areas that are susceptible to high radon levels. This can be achieved by carrying out geographically based surveys, the results of which can be used to develop national radon risk maps and identify radon prone areas.

In 2005, the Institute for Environment and Sustainability of the Joint Research Centre published an overview of radon surveys carried out in Europe.[9] This overview has revealed a lack of harmonization between methodologies, data and mapping at European level that makes it difficult to compare data between Member States.

Radon reference levels

The European Commission recommendation on the protection of the public against indoor exposure to radon (90/143/Euratom)[10] sets reference levels above which remedial action should be taken. These levels correspond to an annual average indoor radon gas concentration of 400 Bq/m^3 for existing buildings and an annual average radon gas concentration of 200 Bq/m^3 for future constructions.

Research has concluded that lung cancer risk increases linearly with long term radon exposure, with no evidence for a threshold below which there is no cancer risk.[8] The increase in risk is statistically significant for annual average indoor radon concentrations even below the recommended level of 200 Bq/m^3.

To minimise the health effects of indoor radon exposure, the World Health Organization (WHO) proposes a reference level of 100 Bq/m^3 where this is possible under prevailing country conditions.[7] A national reference level represents the maximum accepted average annual radon concentration for residential dwellings established by countries at national level above which actions to reduce the radon concentration are recommended.

A WHO survey of 36 countries found that almost all countries have determined national reference levels for their existing housing stock between 200 Bq/m^3 and 400 Bq/m^3.[10] In the UK, the National Radiation Protection Board (NRPB) has recommended an annual average of 200 Bq/m^3 Action Level for radon in homes. It has further defined Radon Affected Areas as those geographic areas with 1% or more homes above the Radon Action Level.[11]

Local studies

Two local studies investigating the levels of indoor radon were conducted between 1994 and 1995, and 1997 and 1998 respectively. In the earlier pilot study carried out by Mifsud et al[12], 24-hour continuous air sampling was carried out using a portable electronic radon monitor (alpha guard) in 68 different localities in Malta and Gozo. Radon measurements were expressed as time weighted averages (over 24 hour periods). The arithmetic mean value for all sites was reported at 55 Bq/m^3 with a geometric mean of 40 Bq/m^3 (SD 2.3).

The second study by Mifsud and Sammut[13] utilised passive etched track detectors placed in 21 dwellings for one year duration (2 consecutive exposure periods between May and October 1997 and November 1997 to April 1998). The computed geometric mean was reported as 32 Bq/m^3 (SD 2).

Method

Radon measurements were carried out in 85 buildings in Malta over a period of 1 year. A 5 x 5 km grid map of the Maltese Islands was supplied by the Information Resources Unit at the Malta Environment and Planning Authority (MEPA). This grid map was based on the local base map sheets alignment and in the local geographical projection known as Truncated UTM ED50. Five buildings, which included one school, one public building and three private residences, were selected from each inhabited 5 x 5 km quadrant on this grid map. The buildings thus selected included 53 private residences, 17 schools, 13 Local Council offices, 1 hotel, 1 restaurant and 1 government office building. Although the focus of the survey was residential dwellings, representing the greatest number of buildings on the island, consideration was also given to radon exposure in workplaces by the inclusion of these schools and public buildings.

The radon monitors used were alpha-track (passive type) detectors using Kodak LR115 film, validated by the UK National Radiation Protection Board (NRPB). Each monitor was identifiable by bar code and number. Such monitors are compact in size (measuring 40 mm x 53 mm x 2.5 mm), causing minimal nuisance effect. They are non-hazardous both in use and in disposal. Other advantages related to the use of such monitors include their relatively low cost, they do not require power to operate, may be safely transported through the mail and are easily deployed by suitably trained personnel. These detectors are also suitable for the long term monitoring as required by this study.

Two radon detectors were placed in different rooms in each identified building by trained Environmental Health Officers (EHOs) and exposed for a period of 6 months (November 2010 to May 2011). The detectors were placed in frequently used rooms on ground floors (e.g. living rooms), with good air circulation. They were positioned at head height or if this was not possible, at least 50 cm above the floor, 10 cm from other objects, 30 cm from an exterior wall and 92 cm from an outside window, in an area with least possible disturbance by inhabitants. The placing of monitors near excessive heat, such as fireplaces or in direct sunlight, and areas of high humidity was also avoided as indicated by the suppliers' directions. EHOs were provided with a checklist to document the monitors and their surrounding environmental conditions.

The detectors were retrieved from each location and replaced by another two monitors for the next consecutive 6 months (June 2011 to November 2011). Retrieved detectors were analysed in the UK by a laboratory accredited by the Radiation Protection Division of the Health Protection Agency (UK).

The monitoring period between November 2010 and May 2011 was considered to be the winter semester while the period May 2011 to November 2011 was considered as the summer semester. The arithmetic and geometric means for the separate winter and summer periods, as well as the arithmetic and geometric mean annual indoor radon gas concentration for each building were calculated.

Each sampling point was plotted in a spatial construct through the use of a Geographic Information System (GIS) software (Mapinfo Professional, 2012, version 11.04, Piney Bowes Inc. USA) where the radon attribute data was subsequently collated to the corresponding sample location point. The use of GIS for such a study enables the analysis of both spatial and attribute (non-spatial) data in an integrated system that allows the analysis of the data based on the location they are found in. Initially, the study sought to carry out a hotspot analysis employing the Nearest Neighbour Analysis (NNA) method to review those highest ranging areas. However, whilst the method depicts a comparative approach based on the highest and lowest registered values, it mainly represents the location of the reading and spreading the value to the nearest point. Since the number of data capture locations is too coarse for a clear understanding of the intervening areas, the outcomes of this method was used as a verification tool of the final map spatial analysis.

Results

By the end of the survey period, 334 out of a total of 340 monitors installed in buildings selected over the Maltese Islands were collected and analysed. Six monitors were lost or damaged and therefore excluded from the analysis. The arithmetic mean annual indoor radon gas concentration for the Maltese Islands (Malta, Gozo and Comino) was 32 Bq/m^3 with a geometric mean of 25 Bq/m^3 (SD 25). If Malta, and Gozo and Comino were to be considered as two separate areas, the mean annual indoor radon gas concentrations are 31 Bq/m^3 (SD 25) for Malta and 36 Bq/m^3 (SD 26) for Gozo and Comino (Table 1).

Analysis of measurements from the first batch of detectors, corresponding to exposure during the winter semester, indicated an arithmetic mean of 37 Bq/m^3 and a geometric mean of 31 Bq/m^3 (SD 27). The arithmetic and geometric mean for the summer semester was 27 Bq/m^3 and 21 Bq/m^3 respectively (SD 22) (Table 2).

The highest annual mean radon levels were registered in Qala, Gozo and Pembroke, Malta (92 and 91 Bq/m^3 respectively) and the lowest at B'Bugia and Luqa, Malta (8 and 10 Bq/m^3 respectively). The lowest annual mean radon concentration recorded in Gozo was 17 Bq/m^3 in Xlendi.

The arithmetic mean annual indoor radon gas concentration in buildings classified as residences was 33 Bq/m^3, while that of schools and public buildings was 31 Bq/m^3 and 30 Bq/m^3 respectively.

Fig. 1 illustrates the location of the selected buildings (sampling points) superimposed on a 5 x 5 km grid map of the Maltese Islands and the geometric mean annual indoor radon gas concentration value range for each sampling point. The resulting thematic map illustrates these findings showing each sampling point colour-ranged according to the relevant geometric mean value. The relevant grids are also colour-coded according to the mean of results obtained from each sampling points falling within the particular grid. Having this data digitally inputted into a GIS system provides the possibility of producing a visual representation of the spatial sampling points spread around the Maltese Islands divided into 5 x 5 km grid map.

Table 1*: Annual Arithmetic and Geometric Mean Indoor Radon Gas Concentration Levels (Bq/m^3)*

	Measurements in Bq/m^3				
	Mean	**Geometric Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Maltese Islands	32	25	25	8	92
Malta	31	24	25	8	91
Gozo & Comino	36	28	26	17	92

Table 2*: Annual Arithmetic and Geometric Mean Indoor Radon Gas Concentration Levels (Bq/m^3) for Summer and Winter periods.*

		Measurements in Bq/m^3		
	Measurement Period	**Arithmetic Mean**	**Geometric Mean**	**Standard Deviation**
Winter semester	November 2010 to May 2011	37	31	27
Summer semester	June to November 2011	27	21	22
Annual	November 2010-November 2011	32	25	25

***Figure 1**: Thematic map output showing the 5x5 km grid map with corresponding geometric mean annual indoor radon gas concentration values for each sampling point*

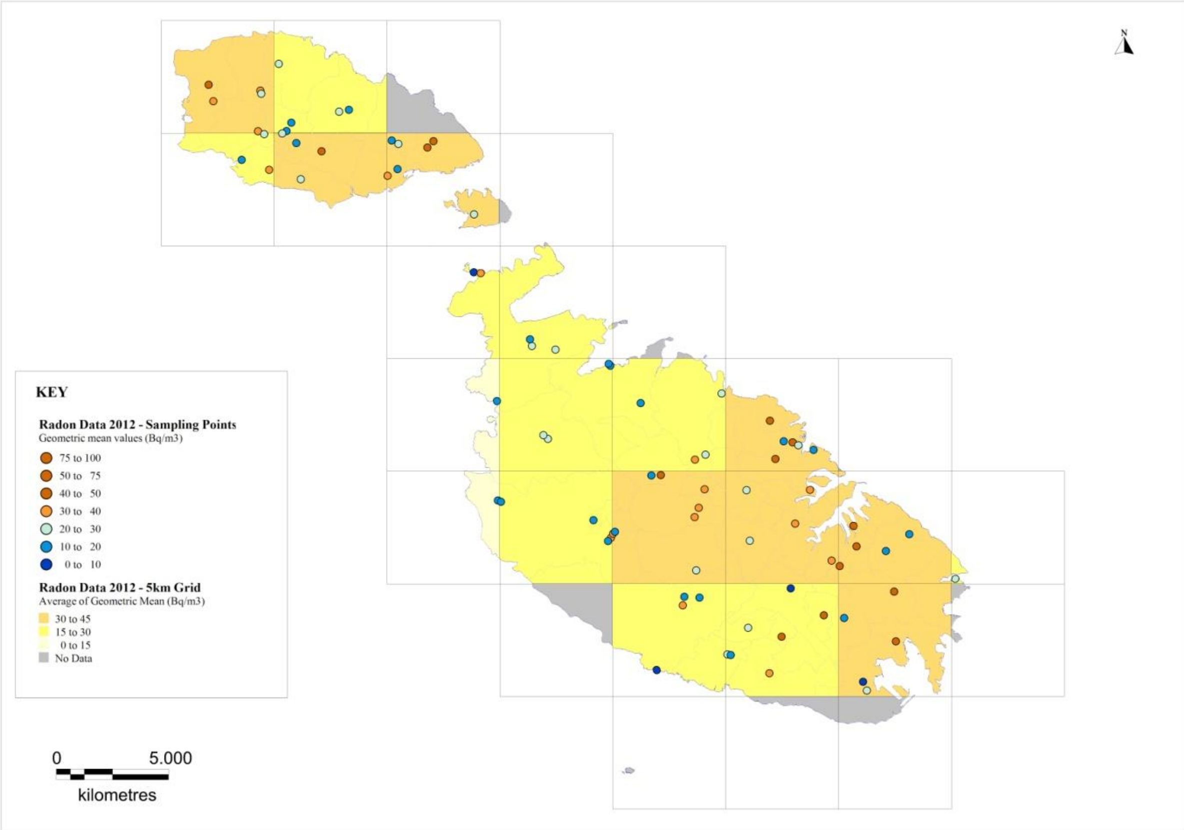
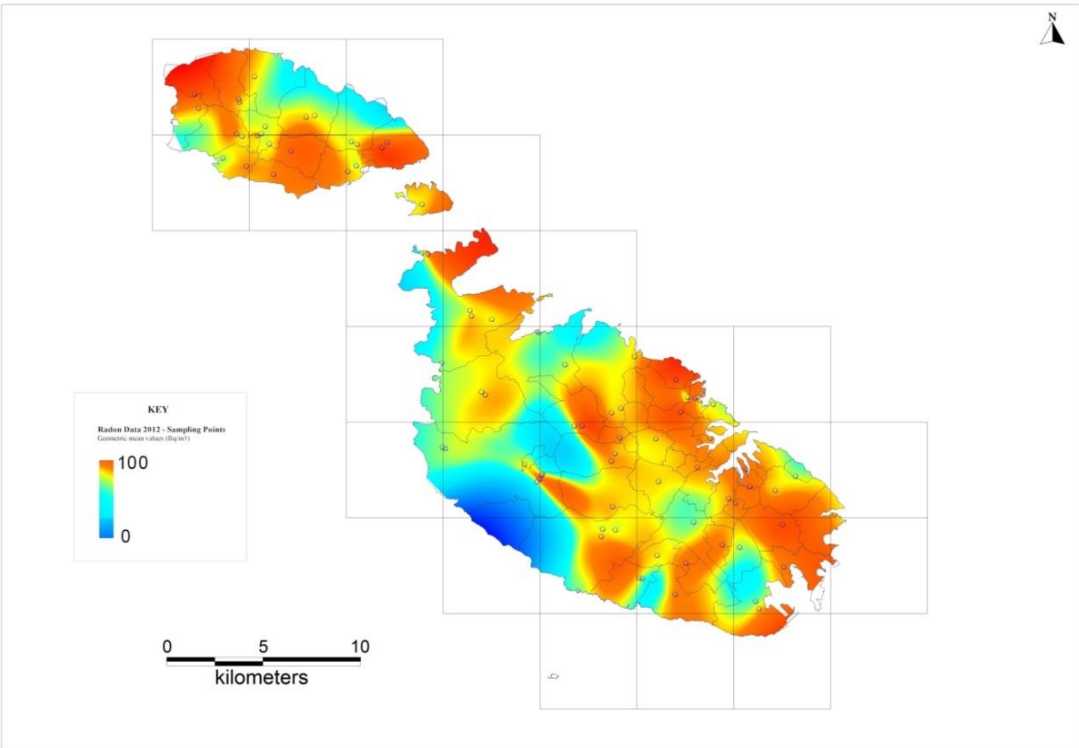


***Figure 2**: Thematic map output showing the Nearest Neighbour Analysis (NNA) radon gas concentration range based on each sampling point*



A Natural Neighbour Interpolation (NNA) map (Fig. 2) was plotted to indicate the highest-lowest range. This method creates natural neighbourhood regions for each data point and each grid cell. Cell values were derived using a point weighting system based on the area of overlap of the grid cells natural neighbourhood region and the regions of surrounding data points. This map gives an indication of the potential levels in between the locations. However, since in some cases the points are located considerable distances apart, such a map calls for further study based on a smaller point distance. This would refine the relationships between the points.

Discussion

Average radon levels vary widely within and between countries. Based on a review of European national radon surveys carried out by the Joint Research Centre (JRC) of the European Commission, the reported levels for mean annual indoor radon gas concentrations in European countries range from around 20 Bq/m^3 to 100 Bq/m^3.[9] Countries with mainly sedimentary soils (e.g. the Netherlands, Poland and the United Kingdom) present lower or equivalent averages, whereas those with old granite soils (e.g. the Czech Republic, Serbia-Montenegro and Finland) are more prone to radon emissions. Since outdoor radon concentrations are known to be low, most countries in the European region have concentrated radon monitoring in dwellings in order to assess human exposure.

Measurements for indoor radon surveys are usually carried out at ground floor level because radon seeps via ground, accumulates inside the building and is heavier than air. Various types of monitors are used for different time intervals in different countries making direct comparisons between country radon levels difficult to interpret. However, large scale surveys are usually carried out using alpha-track monitors for convenience of use.

Considering the linear exposure/response relationship between radon and lung cancer risk, the arithmetic mean annual indoor radon gas concentration is used to estimate the impact on public health[8], while the geometric mean is used to describe the geographical distribution of radon concentrations.[1] The geometric mean annual concentrations of the individual buildings were used in this survey to produce a national radon map in order to identify possible areas with higher than acceptable levels of radon.

The arithmetic mean annual indoor radon gas concentration for the Maltese Islands as established by this study is 32 Bq/m^3 which is below the proposed 100 Bq/m^3 WHO reference level. No single building in the study exceeded this level. Thus, when applying the NRPB criterion for identifying Radon Affected Areas (i.e. where the number of dwellings with concentrations higher then 200 Bq/m^3 exceeds 1%), no area in the Maltese Islands can be classified as radon-prone. Considering local geology and as indicated by the findings of the two previous local studies, this result was expected.

Diurnal and seasonal fluctuations in radon levels are also known to occur, again resulting mainly from the different indoor ventilation patterns one would expect during the everyday use of the site. The use of air-conditioning and fans also lowers the concentration of indoor radon by increasing air exchanges and movement. The division of the monitoring period into two 6-monthly intervals allowed an insight in the seasonal variations of radon concentrations. As expected, the mean annual indoor radon gas concentrations were lower during the summer period than those measured during the winter period (27 Bq/m^3 and 37 Bq/m^3 respectively). This difference is however small in magnitude. The climate in Malta is mild and frequent ventilation of buildings during the colder months is not unusual.

The high standard deviation of the mean values reported can be attributed to the high fluctuations in the mean annual indoor radon gas concentration normally found in inhabited buildings caused by behaviours such as level of ventilation and activity.

Ensuring strict adherence to supplier instructions regarding the placement of the two monitors in each location over each 6 month period was considered to be an important factor in this study, in order to ensure comparable radon exposures both between and within single buildings. However, due to the long exposure period, unwarranted movement of detectors by residents and users of the buildings surveyed could not be excluded.

Reference levels represent the maximum acceptable annual radon concentration in dwellings and are established at a national level. Two reference levels are usually set, one for existing dwellings and a separate one for future dwellings.[11] National authorities need to establish whether measures to reduce the indoor radon levels where these have been exceeded should be statutory or not.

Increasing the ventilation rate of the building or the use of air conditioning are effective ways of lowering radon levels in indoor air. Other mitigation measures include sealing cracks in floors and walls, under-floor sumps and extraction methods. Prevention of radon exposure in new buildings can be implemented through appropriate provisions during the construction phase.

Conclusions and recommendations

The mean annual indoor radon gas concentration for the Maltese Islands was determined by this study at 32 Bq/m^3 which is well below the proposed 100 Bq/m^3 WHO reference level. No single building in this study exceeded this recommended annual mean indoor radon gas concentration level.

This national survey of indoor radon gas concentrations in the Maltese Islands indicates that the proposed reference level of 100 Bq/m^3 currently being recommended by the WHO may be adopted as the national reference level for the Maltese Islands. This reference level may be used for consideration of the application of simple but effective remedial actions as described earlier should radon levels exceed this limit. As mentioned earlier, a reference level does not specify a rigid limit below which there is no cancer risk. Although low level exposures can still lead to lung cancer, the risks at these levels are low and can be reduced further in both new and old buildings by simple mitigation measures aimed at reducing radon levels.

The authors of this study recommend the periodic repetition of an indoor radon national survey using new locations in order to be able to review and ascertain the validity and applicability of the national reference level for the mean indoor radon concentration for the Maltese Islands as proposed by this study.

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