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# Efficacy of mathematical models in predicting the concentration of indoor radon in areas with high levels of natural background radiation

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► ***Original article***

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## ABSTRACT

***Background***: Indoor levels of $^{222}$Rn in some residential areas in Ramsar are as high as 31,000 Bq/m3, resulting in mean internal exposures up to 71 mSv/y. The main goal of this study was to develop a simple mathematical model for predicting radon concentrationfrom gamma radiation level in dwellings located in high background radiation areas (HBRAs) and a nearby normal background radiation area (NBRA) of Ramsar. ***Materials and Methods:*** The levels of gamma background radiation and indoor radon were measured in 350 dwellings located in normal and high background radiation areas (210 dwellings from HBRAs and 140 dwellings from NBRAs). Moreover, data about the most important environmental factors such as temperature and humidity as well as the inhabitants' nutrition were collected. ***Results:*** The mathematical relationship between the gamma radiation level and indoor radon concentration in NBRAs and HBRAs is introduced in this study. The findings obtained in this study clearly indicate that in normal and high background radiation areas of Ramsar the majority of confounding factors such as the type of building materials and ventilation in different houses are almost identical. Therefore, the level of gamma radiation can be used as a strong predictive tool for radon concentration. ***Conclusion:*** As radon concentration in indoor air strongly varies with time, the simple mathematical methods developed in this study, can help health physicists and environmental scientists have an estimate of the mean radon level in these areas.

***Keywords:*** *Mathematical model, indoor radon, high background radiation areas, Ramsar, prediction.*

## INTRODUCTION

US EPA believes that radon is the 2nd leading cause of lung cancer, after tobacco smoking. It is widely accepted that there is no threshold for lung cancer from radon inhalation. Studies performed in radon prone areas reveal that radon can accumulate in residential places at surprisingly ultra high levels. UNSCEAR in its 2000 report clearly confirmed that Ramsar city in northern Iran, has some inhabited areas with the highest known natural radiation levels in the world [(1)]. The ultra high levels of natural background radiation in Ramsar are caused by high concentrations of radium-226 and its decay products originated from hot springs [(2)]. Indoor radon concentration in some regions of high background radiation areas of Ramsar are up to 31 kBq $m^{-3}$[(3)], a concentration that is much higher thanUS EPA recommended action level of 148 Bq $m^{-3}$ (4 pCi/L). On the other hand, the risk of lung cancer from radon inhalation in smokers is estimated to be 10 to 20 times greater than that of non-smokers. Considering

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high levels of public exposures to ionizing radiation in the residents of HBRAs of Ramsar, some experts have recently suggested that an effective remedial action program is needed [3]. Although some studies showed that individuals residing in the HBRAs of Ramsar have increased frequency of unstable chromosome aberrations, no repeatable detrimental effects caused by high levels of natural radiation in Ramsar have been detected so far [4,5]. We have previously published reports on the health effects of exposure to elevated levels of natural ionizing radiation in Ramsar [6-10] including the first reports on the induction of adaptive response in the residents of these areas [2]. The main goal of this study was developing simple mathematical models for predicting radon concentration from gamma radiation level in dwellings located in NBRAs and HBRAs of Ramsar. The rationale for developing these models was this fact that in contrast with measuring the level of gamma radiation, radon concentration measurements are usually complex, *time-consuming and expensive*. Furthermore, the residents of HBRAs of Ramsar are not cooperative enough to allow long-term measurements in their houses.

## MATERIALS AND METHODS

### *External gamma dose measurements*

The exact levels of gamma background radiation were measured in HBRAs and NBRAs using a calibrated RDS-110 (RADOS Technology, Finland) survey meter. This survey meter was mounted on a tripod approximately 1 meter above the ground inside the 350 houses located in normal and high background radiation areas of Ramsar (140 houses from NBRAs and 210 houses from HBRAs).The readings were recorded every 10 minutes for an hour. Then, the mean of six readings was calculated.

### *Radon concentration*

After the tests were explained to the participants and their informed consent was taken, CR-39 dosimeters (Track Analysis Systems Ltd, UK) were installed in their houses to measure the indoor level of radon gas. After three months of exposure to indoor radon, the detectors were collected and sent back to the dosimetry laboratory of the National Radiation Protection Department (NRPD), Iranian Nuclear Regulatory Authority (INRA).

### *Humidity and temperature measurements*

Humidity and temperature were measured in HBRAs and NBRAs using a multifunction device (Testo410, VANE Technology, Germany)

### *Data analysis*

Microsoft Excel (MS Excel 2013) was used to assess the strength of the relationship between the variables and also to graphically plot the correlations.

## RESULTS

Radon concentration in homes is determined by numerous factors such as uranium concentration in soil and building materials, ventilation, elevation above ground level and living style of the residents. In spite of these confounding factors, we found a statistically significant correlation between the level of gamma exposure and indoor radon concentration in dwellings located in normal and high background radiation areas of Ramsar. Linear least-squares fitting was carried out by using Excel software in this study. The correlation coefficient for normal and high background radiation areas were 0.826. The data for normal and high background radiation areas were fit to the equation Y =0.376x -0.0028 (where Y=radon concentration ($Bq/m^3$), X=Gamma exposure level ($\mu Sv/h$)). The relationship between the gamma radiation level and indoor radon concentration in normal background radiation areas (NBRAs) and high background radiation areas (HBRAs)is shown in figure 1.

### *Relationship between the humidity and indoor radon concentration*

The relationship between the humidity and



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indoor radon concentration in normal background radiation areas (NBRAs) and high background radiation areas (HBRAs) is shown in figure 2.

The correlation coefficient for normal and high background radiation areas were 0.0036.

The data for normal and high background radiation areas were fit to the equation Y = 0.937 × -0.0213 (where Y = radon concentration (Bq/m$^3$), X = Humidity).

### *Relationship between the temperature and indoor radon concentration*

The relationship between the temperature and indoor radon concentration in normal background radiation areas (NBRAs) and high background radiation areas (HBRAs), is shown in figure 3.

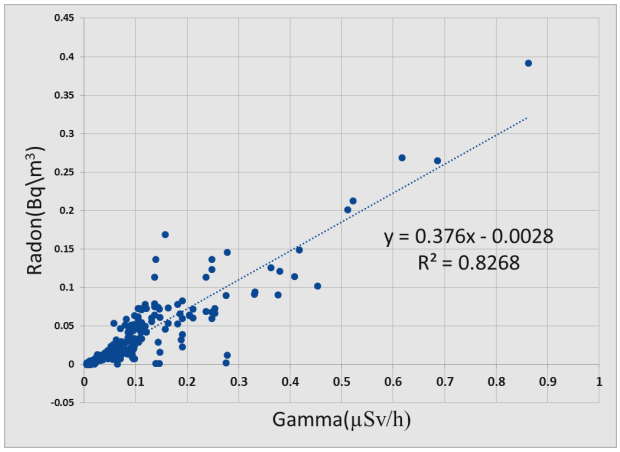



**Figure 1.** Scatterplot shows the relationship between the gamma radiation level (μSv/h) and indoor radon concentration (Bq/m$^3$) in normal background radiation areas (NBRAs) and high background radiation areas (HBRAs).

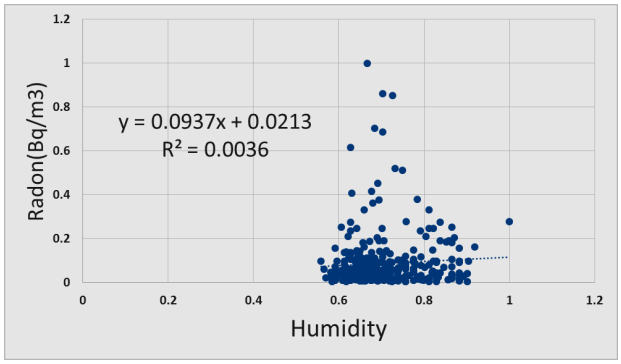



**Figure 2.** Scatterplot shows the relationship between the humidity and indoor radon concentration (Bq/m$^3$) in normal background radiation areas (NBRAs) and high background radiation areas (HBRAs).

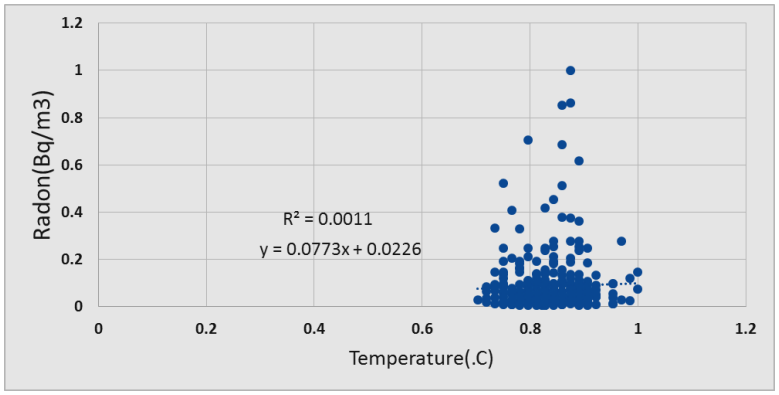



**Figure 3.** Scatterplot shows the relationship between the temperature (°C) and indoor radon concentration (Bq/m$^3$) in normal background radiation areas (NBRAs) and high background radiation areas (HBRAs).

The correlation coefficient for normal and high background radiation areas were 0.0011.The data for normal and high background radiation areas were fit to the equation Y =0.773x +0.0226 (where Y = radon concentration (Bq/m$^3$), X =temperature).

## DISCUSSION

These findings clearly indicate that in normal and high background radiation areas of Ramsar the majority of confounding factors such as the type of building materials and ventilation in



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different houses are so close to each other that gamma radiation can be used as a strong predictive tool for radon concentration. Some studies have shown that the inhabitants of HBRAs of Ramsar receive annual effective doses range between 0.7 and 131 mSv from external indoors and outdoors exposures (with a mean of 6 mSv) [11]. Furthermore, their internal dose due to $^{222}Rn$ has been reported to range from 2.5 to 72 mSv [12]. It is widely believed that the inability of some studies to detect an association between lung cancer and radon can be linked to their weakness in assessing the past radon exposures of the inhabitants [13, 14]. The life was evolved in an environment with much higher background radiation levels than what exist today [15, 16].

The current levels of natural background radiation on Earth vary by at least two orders of magnitude [17]. Moreover, radon measurements play an important role in the studies on HBRAs such as Ramsar that the origin of high background radiation is high concentrations of Ra-226 in soil [5, 18]. In this light, the simple mathematical method developed in this study, can provide an estimate of the mean radon level in large scale screening programs for homes. The main limitation in our study was the relatively small number of radon measurements. Further studies should be performed with a larger number of measurements to verify if this model corresponds well to larger data collected from different areas. As discussed in detail in previous sections, the rationale for developing these models was this fact that in contrast with measuring the level of gamma radiation, radon concentration measurements are usually complex, *time-consuming and expensive*. Furthermore, the residents of HBRAs of Ramsar are not cooperative enough to allow long-term measurements in their houses. We are aware of this fact that the findings of our study cannot simply be extrapolated to other areas. What helped us develop a good mathematical model was the nearly identical socio-economic factors in these small areas (almost all of potential confounding factors such as the type of building materials and the pattern of ventilation in different houses were nearly identical) and hence gamma radiation level could be used as an efficient tool for predictionon of radon concentration. In this light, our data should be used with caution in other HBRAs and NBRAs.

***Conflicts of interest*: *Declared none.***

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