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Developing a method for predicting radon concentrations above a reference level in new montenegrin buildings

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A B S T R A C T

Dependence of indoor radon concentrations (IRCs) in the ground floors of 1200 buildings across Montenegro on 11 factors was analyzed. A group of 734 buildings, for which none of the analyzed factors was missing, was further analyzed using the logistic regression method, in order to develop a prediction model for IRC occurrence above the national reference level for new buildings (200 Bq/m^3). Applying the forward stepwise method, and based on likelihood ratios, five explanatory variables—municipality, type of building, presence of basement, window frames, and period of construction—were selected for including into the final logistic regression model for predicting probability of IRC > 200 Bq/m^3. The final model explained 77.1% of the observed IRCs, while the obtained Area under the Curve of 0.8018 classified the model as having a very high predictive ability. Achieving similar values for both the final prediction model and the validation model, for sensitivity, specificity, and accuracy, confirmed the applicability of the developed model.

1. Introduction

Radon is a naturally occurring noble and radioactive gas. From the radiation protection point of view, the most important radioisotope of radon is ^{222}Rn, commonly known in simple terms as radon. It originates from the naturally occurring ^{238}U chain of decays, more precisely from the alpha-decay of ^{226}Ra, which is present in the environment in rocks, soils, underground and surface waters, and in building materials. Radon is diluted in the outdoor air, where its concentration is typically at a level of 10 Bq/m^3 (UNSCEAR, 2000), while it tends to accumulate in the air of enclosed spaces, such as in buildings, and can reach a concentrations of hundreds, or even thousands, of Bq/m^3.

Indoor radon contributes approximately one half of the average annual effective dose received by the general population from natural sources of ionizing radiation (UNSCEAR, 2008). There is strong evidence that long-term exposure to radon, when its decay products are inhaled, causes an increased incidence of lung cancer in the general population, and that radon is a primary cause of lung cancer in non-smokers, and the second leading cause in smokers (WHO, 2009). Therefore, the World Health Organization (WHO, 2009), the International Atomic Energy Agency (IAEA, 2014), and the Council of the European Union (EURATOM, 2013) recommend measures and safety standards to their member states, to be applied for the protection of people from radon exposure in homes and workplaces.

Many factors affect radon concentrations in a building, and they can be classified into three groups: radon sources, building characteristics and the habits of building occupants (heating and ventilation of the rooms, etc.). The first group of factors depends mostly on geology, because soil and rocks under a building are usually the main source of its indoor radon (building materials are generally the second main source (IAEA, 2015)), while the other two groups are anthropogenic. Thus, it can be said that hazardous radon exposure is largely an anthropogenic environmental health issue (Stanley et al., 2019). This is why it is important to investigate and understand the influence of building factors on indoor radon variations, for prevention from radon exposure (when construction of a new building is being planned), and mitigation of indoor radon levels (when the radon level detected inside a building is too high).

Indoor radon concentration (IRC) is a function of spatial and temporal variability (IAEA, 2013). Generally, geological characteristics of different areas occupied by buildings cause spatial IRC variations, while temporal variations (daily, seasonal, and from year to year) are mainly the result of variations in meteorological conditions. These affect radon transport in the soil and cause temperature (pressure) gradients between

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