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Radon potential, geologic formations, and lung cancer risk

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ABSTRACT

Objective. Exposure to radon is associated with approximately 10% of U.S. lung cancer cases. Geologic rock units have varying concentrations of uranium, producing fluctuating amounts of radon. This exploratory study examined the spatial and statistical associations between radon values and geological formations to illustrate potential population-level lung cancer risk from radon exposure.

Method. This was a secondary data analysis of observed radon values collected in 1987 from homes ($N = 309$) in Kentucky and geologic rock formation data from the Kentucky Geological Survey. Radon value locations were plotted on digital geologic maps using ArcGIS and linked to specific geologic map units. Each map unit represented a package of different types of rock (e.g., limestone and/or shale). Log-transformed radon values and geologic formation categories were compared using one-way analysis of variance.

Results. Observed radon levels varied significantly by geologic formation category. Of the 14 geologic formation categories in north central Kentucky, four were associated with median radon levels, ranging from 8.10 to 2.75 pCi/L.

Conclusion. Radon potential maps that account for geologic factors and observed radon values may be superior to using observed radon values only. Knowing radon-prone areas could help target population-based lung cancer prevention interventions given the inequities that exist related to radon.

Introduction

Lung cancer is the second most commonly diagnosed cancer and has the highest mortality rate of all cancers (National Cancer Institute, 2007). After smoking, radon is the second leading cause of lung cancer (Al-Zoughool and Krewski, 2009; U.S. Department of Health and Services, 2005). It is estimated that 15% of lung cancer cases in men and 53% in women are not caused by firsthand smoking (Sun et al., 2007). Based on residential case control studies in the U.S. and North America (Field, 2001; Field et al., 2006; Krewski et al., 2005), exposure to radon is associated with 15,400 to 21,800 cases, or approximately 10% of lung cancer cases in the U.S. annually (Committee on Health Risks of Exposure to Radon (BEIR VI), N.R.C. (1999)). It is important to note that most of the radon-induced lung cancers are among those also exposed to tobacco smoke (Lantz et al., 2013).

Radon is a colorless, tasteless, odorless radioactive gas derived from the decomposition of uranium in the soil and rock and it is found in every region in the U.S. Different geologic rock units have varying concentrations of uranium, producing fluctuating amounts of radon. Residential radon concentrations vary widely by geographic area (Hystad et al., 2014). Radon risk estimated from geology has been associated with lung cancer cases. In one Canadian case control study, the odds of lung cancer increased by 11% for every 10 years living in areas with geologic formations known to be associated with radon (Hystad et al., 2014).

Radon is typically summarized annually using geographical mapping of radon test values. These values are usually obtained from homeowners who request test kits from state and/or local health departments, and voluntarily test their homes. The data are then analyzed by commercial radon analysis laboratories and made available to state radon programs. In the U.S., political boundaries (i.e., county and zip code) are typically used to summarize the data. However, combining geological and radon survey data may be a better way to map radon potential (Miles and Appleton, 2005; Smethurst et al., 2008; Zhukovsky et al., 2012). Further, with limited resources, having a more accurate way to identify radon prone areas could inform population-based lung

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cancer risk reduction efforts and guide radon policy change (Garcia-Talavera et al., 2013). To date, few studies have considered geological rock formation type in the mapping of radon production potential (Smethurst et al., 2008).

This exploratory study measured environmental risk using geologic units and existing residential radon values to describe the radon production potential in Kentucky. Results are illustrated using geologic map boundaries rather than county borderlines. The objectives were to: (a) examine the spatial and statistical associations between observed radon values and geological formations from which radon is produced; and (b) create a better way to assess potential population-level lung cancer risk from radon exposure using geologic mapping.

Materials and methods

Design and sample

This is a secondary data analysis of observed radon values from Kentucky homes ($N = 309$) and geologic map unit data from the Kentucky Geological Survey. On generalized nationwide maps, most of Kentucky is located in high to moderate radon potential zones (U.S. Environmental Protection Agency, 1993) due to karst, a type of landscape that is formed by the dissolution of soluble rocks. Statewide residential radon data ($N = 938$) from 1987 were obtained from the Kentucky Geological Survey. These data were readily available; acquiring more recent data was beyond the scope of this project. The observed radon values were recorded in picoCuries per Liter (pCi/L), the typical unit of measurement in the U.S. (Field et al., 2006). A geographic subset of 309 radon values in north central Kentucky, an area with high radon concentrations, was used for this study. The remaining data points were not included because they were geographically dispersed, located in more sparsely populated rural areas; results would likely have been unreliable given very few radon values per geological formation category.

Geologic mapping

Radon value locations, reported as geographic coordinates, were plotted on existing digital geologic maps using ArcGIS and associated with specific geologic units. Geologic maps are a cartographic representation of geologic materials present at the earth's surface. Each map unit on a geologic map represents a package of different types of rock (limestone, shale, sandstone, etc.). Complete detailed geologic mapping is available in published and digital GIS formats for the entire state of Kentucky (Kentucky Geologic Map Information Service, 2014). In north central Kentucky, the area of interest with the greatest concentration of data points, the original digital geologic map data set included 35 separate named map units that had radon measurements. Using all 35 would have resulted in an unnecessarily large number of statistical categories and comparisons. For ease of analysis and interpretation, the 35 map units were grouped into 14 categories based on similarities in both rock type and age. This grouping was done by sequentially merging the map units that were the most geologically similar to each other. Not all geologic map units in the study area had identified radon measurements associated with them and they were not included in the study. One benefit of decreasing the number of categories from 35 to 14 rock formation groups was that each of the groups had at least five radon measurements. We investigated both a 14-group and a 7-group solution, but the former was superior in creating a division that was comprised of units that were relatively homogenous within the unit and heterogeneous among them.

Data analysis

Descriptive analysis was used to summarize radon values by geologic formation categories, including medians and ranges. Because the distribution of radon levels was right skewed, the Kruskal–Wallis test, a nonparametric alternative to one-way analysis of variance, was used to compare radon values among the 14 geologic formation categories. Post-hoc pairwise comparisons of radon levels among the formations were based on the Mann–Whitney U procedure with a Bonferroni correction to adjust for multiple comparisons. An alpha level of .0005 was used for this post-hoc test, given the 91 pairwise comparisons among 14 formation categories. To summarize the radon potential categories used to draw the map in Fig. 2, natural log transformation was used to decrease the degree of skewness in the radon values, and geometric means were used to describe each area. This type of transformation has been used previously with radon measurements (Beaubien et al., 2003), since they are typically right-skewed. A small constant value (0.25) was added to the two radon measures equal to zero so that the transformed version would be defined for all observations; this value was chosen as it was one-half the smallest non-zero value obtained. Although the log-transformed values could have been used both to develop the map as well as make quantitative comparisons among the formation categories, we used nonparametric tests for formation comparisons. Given the small sample sizes in some formation categories, this was a more conservative analysis strategy. All analyses were performed using SAS version 9.3 (SAS Institute, 2012).

Results

Description of geologic formation categories

Rock types identified in the study area were sedimentary and mainly included limestone, shale, siltstone, or dolostone. Each of these rock types have specific variations of mineral content, including trace amounts of radioactive materials that generate radon. Fig. 1 summarizes the identified map-unit categories and lists the subsequent dominant rock type and age associated with the geologic map unit. The 14 rock formation categories are labeled A through N.

Rock formation categories A through D are relatively young unconsolidated materials (Quaternary; less than 2.5 million years old) deposited in and near river valleys. These categories were separated based on the variation in their dominant sediment grain size (e.g., clay, silt, sand, gravel). Units E through N are all older bedrock units (Devonian, Silurian, or Ordovician; 350 to 440 million years old) that contain varying amounts of limestone, dolostone, shale, and siltstone.

Radon values and geologic formation categories

The Kruskal–Wallis chi-square test was significant ($\chi_{13,\,295} = 105.4$, $p < .0001$), indicating the radon levels varied significantly by geologic formation category. Post-hoc comparisons based on Mann–Whitney U tests are summarized in the last column of Table 1; formation categories with the same lowercase letter were not significantly different. There were three broad groupings of formation categories as show in the Table 1 and ordered by radon level: K, F, N, and L, with the highest levels, had median radon values ranging from a high of 8.10 to a low of 2.75 pCi/L; M, C, I, and E had median radon values ranging from 2.30 to 1.80; and G, H, J, D, A and B had median radon values ranging from 1.10 to 0.60. These groupings were distinguished by having similar medians within grouping and the two extreme groupings tended to have medians that differed from each other.

While Formation K only differed from Formation G in the pairwise comparisons, this was likely due the small number of observations in K. Formation F, with a lower median radon level than K but a larger number of observations, exhibited significantly higher radon values than Formations G through B. At the bottom of the Table 1, Formations G through B were typically not significantly different from each other, but they were significantly lower than most of the formations in the top group (K through L). The middle group of formations, M through E, had the distinguishing feature of not being significantly different