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Geographic Information System Application to the Problem of Predicting Indoor Radon Concentrations

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GEOGRAPHIC INFORMATION SYSTEM APPLICATION TO THE PROBLEM OF PREDICTING INDOOR RADON CONCENTRATIONS

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ABSTRACT

It would be extremely useful to determine if, on a county-size scale, there might be some predictability to indoor radon. One approach is to make an application of GIS and 3D visualization to explore the radon problem in Fairfax County in northern Virginia, to evaluate correlations between indoor radon and geology, elevation, slope, and aeroradioactivity. It was found that there is a tendency for indoor radon to be greater in some parts of Fairfax County in homes on some geological units, in homes constructed on lower slopes, on sites at lower elevations, and in areas of higher aeroradioactivity. However, none of these physical variables exhibits a strong enough control on indoor radon to be used to construct radon potential maps that carry a high confidence of accuracy.

1.   INTRODUCTION

Exposure to natural sources of radon has become a significant issue in terms of radiological protection. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) reports that nearly half of the total natural background dose received from natural sources can be attributed to inhaling radon and its progenies present in dwellings. It is estimated that nearly 1 out of every 15 homes in the U.S. has excessive elevated radon levels (USEPA, 2007). Moreover, it is recognized that very significant amounts of radon accumulates in some homes in the Appalachian Mountain System (Mose et al., 1992).

The American Association of Radon Scientists and Technologists (AARST) estimates 10 million homes in America have indoor radon in excess of 4 pCi/L, the USEPA's recommended maximum when buying a home. This estimate is growing by about 75,000 homes per year, since new homes are built constantly. Concerns about indoor radon emanation from soil have led to an increased focus on comparisons between radon concentrations in the soil and in dwellings constructed on these soils (USEPA, 2007).

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Soil-to-indoor comparisons have been made in attempts to create radon potential maps. These maps seek to reduce the lung cancer hazard by alerting concerned homeowners. Some radon potential maps show that very high indoor radon concentrations may be correlated with uranium found in soil over uranium enriched crystalline rock units or over locally fractured rocks (Oliver and Kharyat, 1999, 2001; Swako et al., 2004; Krivoruchko, 2005; Mose et al., 1992), but sometimes the high radon homes are simply over soils that have higher permeability. To verify these determinations, GIS comparisons of geotechnical factors with the spatial variation of indoor radon is essential (Oliver and Kharyat, 1999; Lacan et al., 2006).

The primary goal of the following study was to evaluate the radon risk potential of all of Fairfax County in northern Virginia. Fairfax County has a large land area (over 250,000 acres) and a large number of homes (population is over 1,000,000 people), and over 1,000 homes have already been sampled for indoor radon, using a series of four 3-month measurement intervals.

1.1   Causes of Indoor Radon

Many regional studies have examined the temporal variation of indoor radon (Denman et al., 2007; McNeary and Baskaran, 2007; Magalhaes et al., 2003). Studies have addressed the decreased health risk obtained from using radon reduction methods (Kitto, 2007). Others examined the association between some geological units and indoor radon (Mose et al., 2006b; Siaway et al., 2006), and the association between indoor radon and surficial gamma radiation (Kline and Mose, 1990; Mose et al., 2005).

Other recent studies have successfully quantified radon levels in dwellings (Ioannides et al., 2000). Others have focused on the spatial distribution of residential radon (Franco-Marina et al., 2003; Lacan et al., 2006), on the exhalation rates of radon levels in prevailing building materials (Jong et al., 2006), and on quantifying seasonal variations and depth dependence of soil radon concentration levels in different geological formations (Al-Shereideh et al., 2006; Lu and Zhang, 2006; Magalhaes et al., 2003). Some investigators have focused on quantifying the amount of natural radioactivity in building materials (Ahmad, 2007), on evaluating radon emanation from soil gas (Malczewski and Zaba, 2007; Zunic et al., 2006), and on assessing factors that underlie radon emission (Barros-Dios et al., 2002). Still other investigators have evaluated radon concentrations in soil and groundwater (Mose et al., 2006a), examined seasonal indoor radon variations related to precipitation (Mose, et al., 2006b), and assessed differences in indoor radon emanation due to soil chemistry, home heating systems and precipitation (Siaway et al., 2006; McNeary and Baskaran, 2007).

2. RESEARCH OVERVIEW

2.1 Hypotheses to Test:

2.1.1 Radon verses Geology

Geostatistical techniques are commonly used to map a range of environmental variables, particularly to generate probability maps that delineate areas that exceed a health-based threshold value. However, very few case studies in which indoor radon measurements have been investigated using geostatistical techniques have been published (Dubois et al., 2007). In northen Virginia, due to the numerous universities and to the numerous state and federal geological survey scientists in the area, abundant geotechnical data and radon data are available, and might be used to make radon potential maps. It has been suggested that soils above some particular geologic units in northern Virginia may be associated with elevated indoor radon concentrations (Mose and Mushrush, 1997; Mose et al., 2005; Siaway et al., 2006; Mose et al., 2006a, b, c).

2.1.2 Radon verses Slope and Elevation

The location of a home may also be important. It seems likely that homes constructed on hillsides (homes on greater slopes) and hilltops (homes with higher elevations) might tend to have more indoor radon because these soils are more permeable, allowing greater movement of radon in soil gas (Mose and Mushrush, 1997; Siaway et al., 2006). This could be attributed to the permeability of the soils. Factors that could contribute to high radon concentrations in high slope and high elevation areas include the possibility that uranium-rich rocks underlie these areas. It may also be that these areas have thin soils and bedrock close to the surface, and may have permeable fractured rocks (Otton and Gunderson, 1991). Shashikumar et al. (2008) found variations of radon concentrations in the soil-gas under dry and wet conditions at different depths, so perhaps high slope and high elevation homes more often have dry-soil conditions which could allow greater and faster transport of soil-gas radon into homes.

2.1.3 Radon verses Soil Radioactivity

Appleton (2007) suggested that on-the-ground direct sampling of soil radioactivity (as opposed to airplane measured radioactivity) could be used to map radon potential maps. However, on-the-ground sampling of soil and making radioactivity measurements of each sample is expensive, so the measurements are often not numerous. Aerial radiometric data have been used to quickly quantify the radioactivity of large areas of rocks and soils (Schumann, 1995; Appleton, 2007). Uranium and radon soil measurements are estimated by measuring the gamma-ray emission of Bi^{214}, a radioactive decay product of radon. Consequently, it seems reasonable that an aeroradioactivity map could be a good indicator for homes with radon.

2.2   Radon Measurements and Geotechnical Database

Most new homes in Fairfax County have no pre-occupancy radon test, and most older homes have never been tested. For this investigation, data were obtained from over 1,000 homes that were tested for indoor radon using winter, spring, summer and fall 3-month intervals. The measurements were examined to see if they exhibit a non-homogeneous pattern. If they did, this pattern could possibly be related to non-homogeneous geotechnical parameters, such as the distribution of geological units, the slope under homes, the elevation of homesites, and the distribution of high- and low-aeroradioactivity soil.

The variation in indoor radon was visually examined, and from this examination a non-homogeneous pattern appeared likely, so a hypothesis was advanced that indoor radon in the central part of Fairfax County is higher than indoor radon in the western and eastern sides. To evaluate this hypothesis, indoor radon data were subjected to a directional distribution analysis (i.e., standard deviational ellipse and trend tools).

A standard deviational ellipse was calculated, which describes the distribution of the indoor radon measurements in homes in northern Virginia. It measures the distribution of data values around the statistical mean. The ellipse method allows one to see if the distribution of indoor radon measurements is not uniform throughout Fairfax County, but instead, if contoured as in topographic mapping, has a particular orientation.

A trend analysis was also used to provide a three-dimensional perspective of the data. In the case of this radon study, home locations were plotted on an x, y plane. Above each home location, the indoor radon measurement was given by the height of a "stick" in the z dimension. In this fashion, new data were created, which are points above a plot of the study site, at a height of the z values. The tops of the "sticks" are then projected onto the x, z plane and the y, z plane to form scatter plots. If the surface defined by the projected points is flat, no trend exists. If the curve through the projected points is not flat, it suggests a trend in the data. In this fashion, the standard deviational ellipse (also referred to as a "directional distribution") measures whether a distribution of features exhibits a directional trend. In Fairfax County, the ellipse showed that indoor radon decreases from the center of the county to the northeast and to the southwest.

2.3   Spatial Autocorrelation

Spatial autocorrelation is a method that can be used to measure the magnitude of trends. Spatial autocorrelation can show the extent to which the value of one attribute (i.e., indoor radon measurements) changes when the value of another attribute (i.e., slope, elevation, aeroradioactivity) changes. If we can correctly identify some attribute that influences indoor radon, we might get a better understanding of how to predict indoor radon. This might be done by using the null hypothesis method for spatial autocorrelation analysis. For example, we can use a null hypothesis which states that comparisons we can measure occur randomly across the study area.

It also allows for the detection of clusters of similar radon measurements and quantifies the extent to which clusters are clustered. In this case, a cluster refers to a grouping of similar indoor radon at homesites that are close together. A "cluster of

clusters" could come from a study area which has clusters of radon measurements, and many similar clusters occur near each other. Departures from randomness happen when clusters have geographic trends. If we are studying the distribution patterns for indoor radon at homesites, groups of similar clusters ("clustering of clusters") in the distribution pattern occur when there is some broad area that has higher than average seasonal indoor radon and some other area with lower than average radon. This is called a positive spatial autocorrelation. That is, positive spatial autocorrelation has similar radon values appearing together, while negative spatial autocorrelation has dissimilar radon values appearing in close association.

The special autocorrelation investigation using special autocorrelation on winter indoor radon measurements showed that with 99 percent certainty, the clustered distribution pattern for indoor radon at homesites could not be the result of random chance. This means there is less than one percent likelihood that the cluster pattern could be the result of a random chance. Said still another way, based on the pattern of winter indoor radon measurements, it is possible to reject the null hypothesis that winter indoor radon measurements are evenly distributed and have a random pattern across the study area. A similar conclusion was found for the spring, summer and fall indoor radon measurements. By inference, there must be some cause for this trend. To make predictive maps, tests were made to determine if indoor radon concentrations are dependent on any or all of these four available and well documented geotechnical factors: geology, slope, elevation and aeroradioactivity.

2.4   Indoor Radon Verses Geology

The first goal of the research was to compare, by using a Geographic Information System (GIS), the distribution patterns of indoor radon verses geology. In nature, some geological units and the soils produced over these units are richer than others in uranium, which produces the radon. Similarly, the soils of some types of rocks are more permeable (more sandy) and allow more rapid radon movement through soil and facilitate faster and greater entry into homes. Therefore, it was hypothesized that the homes constructed over some geological units would have significantly higher indoor radon than homes over other units.

Most of the rock units present in Fairfax County are also found in counties north and south of this area. They often have different names, but they are geologic units of similar age and composition, found from Maine to Georgia, much like the sand of the modern Coastal Plain. A digitized geologic map of Fairfax County was used because the precise locations of homes could be placed on this map.

The eastern part of the study area is called the Coastal Plain, and the dominant geologic unit is a thick and wide series of sedimentary strata. The central portion of the study area is part of the Appalachian Piedmont Province. These rocks are part of the ancient Appalachain Mountains. Piedmont rocks are recrystallized sedimentary and volcanic rocks, plus large now-crystallized chambers of formerly molten rock. They were uplifted and subsequently worn down, and are now covered along the east side of the Piedmont by the modern beach sands of the Coastal Plain and the Atlantic Ocean. The Piedmont extends far west of Fairfax County, and as with the Coastal Plain, extends from

New England to Georgia. Several chambers of formerly molten rock are in the Piedmont in Fairfax County, the largest of which is the Occoquan granite. One of the widespread now-recrystallized but formerly sedimentary rock layers in the Piedmont Terrane is the Sykesville Formation, a metamorphic rock that formed from a small-to-medium grained mixture of clay and sand layers, and now has a quartzofeldspathic matrix that contains quartz "eyes" and a heterogeneous suite of pebble-to-boulder size fragments. Another large Piedmont unit is the Pope's Head Formation, a metamorphosed light-gray to pinkish- and greenish-gray fine-to-coarse quartzo-feldspathic sandstone. A third major metasedimentary unit, only slightly different from the Popes Head Formaaion, is the Mather Gorge Formation. The other units in the Piedmont are much less widespread and have fewer measurements. In the western part of the Fairfax County Piedmont, there is a fault bounded valley called the Culpeper Basin. It contains unmetarmophosed sedimentary strata that were deposited after the metamorphic events that shaped the Piedmont. Also present in the Culpeper Basin are unmetamorphosed volcanic strata.

3.   RESULTS

3.1   Distribution of Indoor Radon Measurements for the Geological Units

The following sections examine the indoor radon measurements in homes that are built in the soil of the three geological units with the largest number of measured homes. These are homes over the Sykesville Formation (143 measured homes), the Pope's Head Formation (135 measured homes), and the Mather Gorge Formation (372 measured homes). Figures 1-4 are the radon measurements in the Sykesville Formation as histograms, 5-8 are the Pope's Head Formation histograms, and 9-12 are the Mather Gorge Formation histograms.
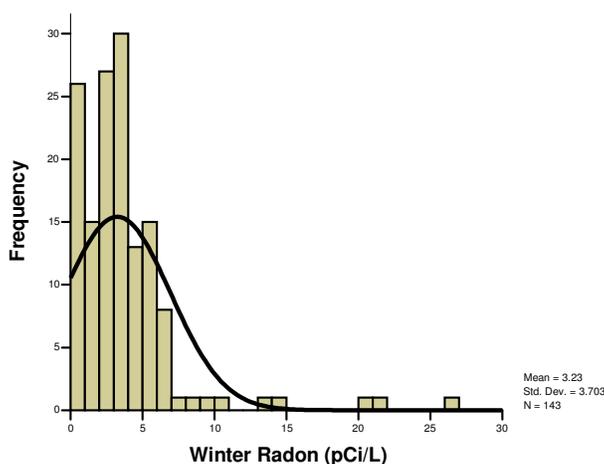

Figure 1. Histogram of Winter Indoor Radon in the Sykesville Formation Homes
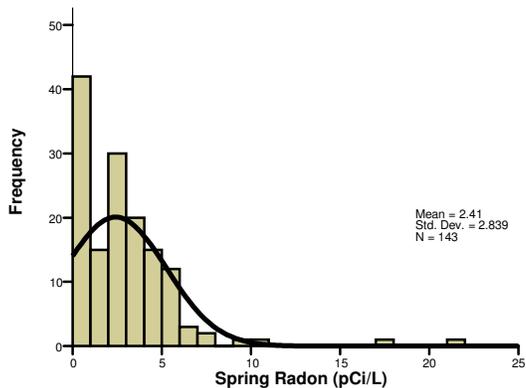
Figure 2. Histogram of Spring Indoor Radon in the Sykesville Formation Homes

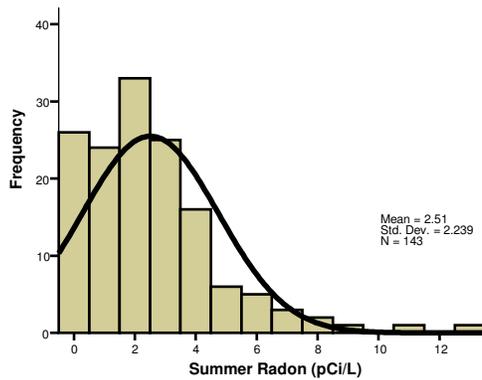*Figure 3*. Histogram of Summer Indoor Radon in the Sykesville Formation Homes

Figure 4. Histogram of Fall Indoor Radon in the Sykesville Formation Homes

Figure 5. Histogram of Winter Indoor Radon in the Pope's Head Formation Homes

Figure 6. Histogram of Spring Indoor Radon in the Pope's Head Formation Homes

Figure 7. Histogram of Summer Indoor Radon in the Pope's Head Formation Homes
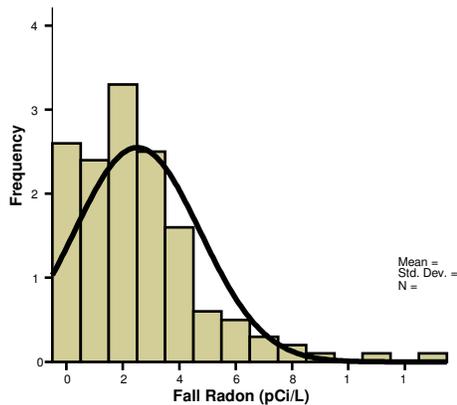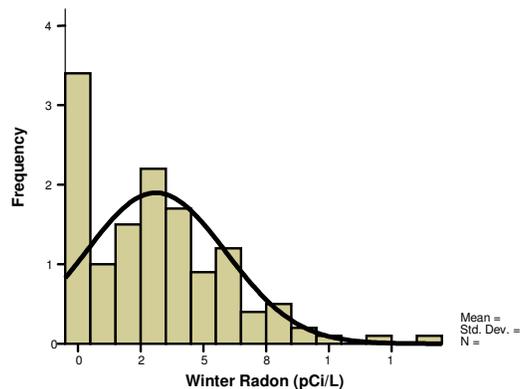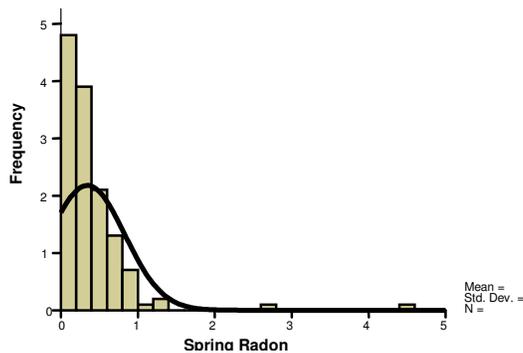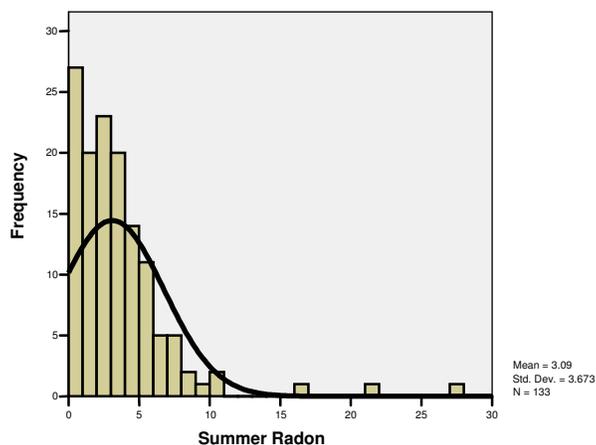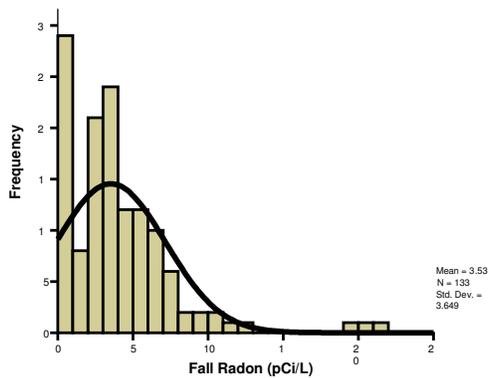
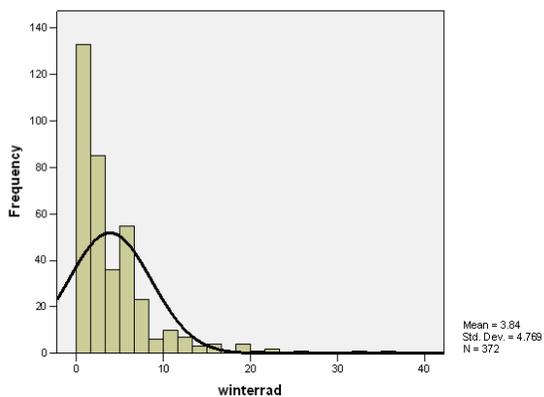*Figure* 8. Histogram of Fall Indoor Radon in the Pope's Head Formation Homes

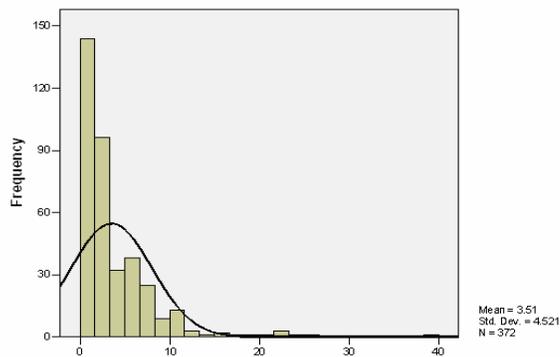*Figure 9.* Histogram of Winter Indoor Radon in the Mather Gorge Formation Homes

Figure 10. Histogram of Spring Indoor Radon in the Mather Gorge Formation Homes
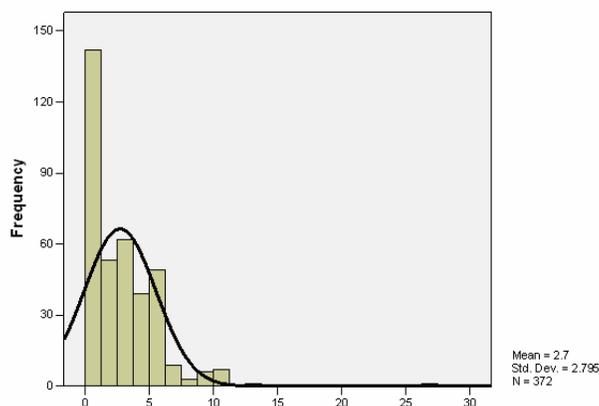
Figure 11. Histogram of Summer Indoor Radon in the Mather Gorge Formation Homes
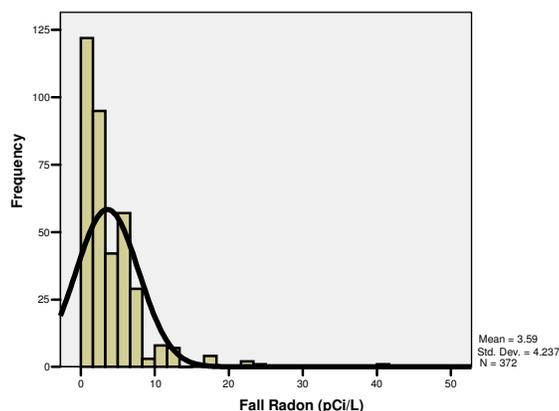
Figure 12. Histogram of Fall Indoor Radon in the Mather Gorge Formation Homes

3.2 Statistical Analysis of Indoor Radon in Homes on Different Geological Units

Summaries by season of the three geological units for which many measurements of indoor radon are available are shown in Tables 1-4. The radon values (mean, median and trimmed mean) when evaluated (standard deviation, 95% C.I., 5% trimmed mean and IQR) were found to be so close as to be essentially identical (all are about 3 pCi/L at the 95% C.L.). It can be concluded that indoor radon risk maps that carry a high confidence level cannot be created based on the delineation of these particular geological units. This seems to contrast with studies that suggest that geological knowledge is useful in predicting and mapping residential radon concentrations (Shi et al., 2006), and that sound predictions can be made with a reasonable level of uncertainty (Andersen et al., 2007).

It is anticipated that when more measurements become available, it may be found that some geological units for which we now have few data might be found to have very high or very low indoor radon. Unfortunately, at this time, many of these units have only a few available measurements. It is important that additional work be done on this possibility, because if units making high indoor radon exist, it could encourage the constructor using high-risk soils to use radon-gas resistant construction methods.

Table 1. Winter Indoor Radon

Geologic Unit	# of Homes	Mean Radon (pCi/L)	Median Radon (pCi/L)	Standard Deviation (pCi/L)	95% C.L.	5% Trimmed Mean.	IQR
Sykesville Formation	143	3.2	3.0	3.7	2.5 – 3.8	2.7	3
Pope's Head Formation	133	3.1	3.0	2.8	2.6 -3.6	2.9	5
Mather Gorge Formation	372	3.8	3.0	4.8	3.4 – 4.3	2.3	5

Table 2. Spring Indoor Radon

Geologic Unit	# of Homes	Mean Radon (pCi/L)	Median Radon (pCi/L)	Standard Deviation (pCi/L)	95% C.L.	5% Trimmed Mean.	IQR
Sykesville Formation	143	2.4	2.0	2.4	1.9 – 2.1	2.1	4
Pope's Head Formation	133	3.4	3.0	4.9	2.6 – 4.3	2.8	3
Mather Gorge Formation	372	3.5	2.0	4.5	3.1 – 4.0	2.9	5

Table 3. Summer Indoor Radon

Geologic Unit	# of Homes	Mean Radon (pCi/L)	Median Radon (pCi/L)	Standard Deviation (pCi/L)	95% C.L.	5% Trimmed Mean.	IQR
Sykesville Formation	143	2.5	2.0	2.2	2.5 – 2.9	2.3	2
Pope's Head Formation	133	3.1	2.0	3.7	2.5 – 3.7	2.6	3
Mather Gorge Formation	372	2.7	2.0	2.8	2.4 – 3.0	2.4	4

Table 4. Fall Indoor Radon

Geologic Unit	# of Homes	Mean Radon (pCi/L)	Median Radon (pCi/L)	Standard Deviation (pCi/L)	95% C.L.	5% Trimmed Mean.	IQR
Sykesville Formation	143	3.0	3.0	2.5	2.6 – 3.4	2.8	2
Pope's Head Formation	133	3.5	3.0	3.6	2.9 – 4.2	3.1	4
Mather Gorge Formation	372	3.6	3.0	4.2	3.2 – 4.0	3.1	5

3.3   Indoor Radon Compared to Slope

Soils on land in northern Virginia with greater slope tend to be more permeable because they have a higher sand content, and therefore might have a higher probability of greater gas flow (Fairfax County GIS, 2006). Consequently, the second hypothesis was advanced, that homes with more indoor radon are those that are constructed on land with greater slope. In order to investigate this hypothesis, a three-dimensional visualization

was prepared of seasonal indoor radon and slope. Since it was found the variation in the distributions of indoor radon is about the same for all four seasons, the winter indoor radon values are used to visualize the relationship (Figure 13). All the comparisons seasonal show that there is a weak tendency for indoor radon to be less in areas with higher slope. Consequently, based on these comparisons, the hypothesis that homes with more indoor radon are on a surface with higher slope is rejected. In fact, lower indoor radon levels tend to occur more often in areas with higher slopes.This "tendency" is not strong enough correlation to use in making a high confidence radon potential map, but could be used to make a low confidence map.

Figure 13. Scatter Plot of Slope and Winter Indoor Radon Measurements

3.4   Indoor Radon Compared to Elevation

Areas of high elevation also tend to have more permeable and sandier soils, and gas and liquids move faster through such soils (Mose et al., 2006c; Shi et al., 2006) Consequently, the third hypothesis was advanced, that homes with more indoor radon tend to be on land of higher elevation.

This observation was tested with data from all four seasons, and as an example the comparison between elevation and winter indoor radon is shown in Figure 14. This comparison, and all the other comparisons show that there is a tendency for indoor radon to be less in areas with higher elevation.
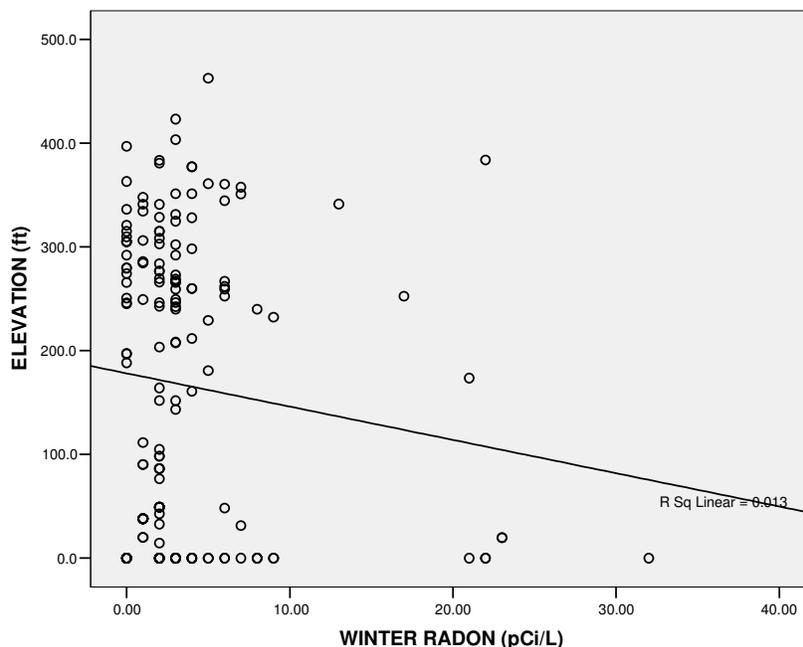
Figure 14. Scatter Plot of Elevation and Winter Indoor Radon Measurements

Although it appears that indoor radon tends to be less in homes of higher elevation, this is another weak correlation, and like the discussion about slope, it is a tendency and is not a strong enough correlation to use in creating a high confidence radon potential map. The lower radon-higher elevation can only be used to create a low confidence radon potential map.

3.5   Indoor Radon Compared to Aeroradioactivity

It has been theorized that aeroradioactivity (i.e. airplane measured soil aeroradioactivity) maps might be a useful way to create indoor radon potential maps (Li et al., 1995; Smith and Cowles, 2007; Mose et al., 1992). During the 1970s, airborne gamma-ray spectral data were collected throughout the United States along a grid of east-west and north-south flight lines as part of the National Uranium Resource Evaluation project (NURE) (Duval et al., 1989). Because radon-222 is followed closely in the decay path by bismuth-214, NURE data are also useful in identifying areas more likely to have elevated radon levels in soil and rock.

To collect the NURE aeroradioactivity data, the east-west flight lines were typically 3-6 miles apart and north-south lines were typically 12 miles apart. The NURE project used low and slow flying aircraft with special analytical equipment to detect and record the intensity of gamma-ray energy from the decay of bismuth-214 from the uppermost 20 to 30 cm of the surface of soil and rocks at regular locations along each flight line. The aircraft flew several hundred feet above the surface and measurements were collected, on average, a little more than 100 feet apart along the flight lines. Estimates of the soil and rock uranium content at each location, in parts per million, were calculated using the gamma-ray data that were collected. This technique assumes that uranium and its decay products are in secular equilibrium. These estimates are designated by the abbreviation eU (equivalent uranium) to distinguish them from a conventional chemical analysis of

uranium. The estimates are possible because bismuth-214 is one of the radioactive decay products for uranium-238, and the amount of bismuth-214 is proportional to the amount of uranium-238 (and total uranium) present in the rock or soil. Detailed compilation of aeroradioactivity data is addressed in USGS Open File Report/OFR 02-0361 (USGS, 2001).

As the aircraft flew over the initial checkpoint, the Doppler navigation system recorded the aircraft positions in terms of along-track and across-track distances relative to the initial checkpoint and the predetermined heading. The ground data consisted of longitude and latitude of initial checkpoint, longitude and latitude of the end or the closure point, and the recorded across-track values associated with each point. The ground data (radiation-channel observation) was then associated with its measurement site (longitude and latitude) so they can be plotted together on a map. In theory, areas with soils showing above average radioactivity will probably be areas with above average indoor radon (Mose, 2005). The fourth hypothesis was advanced, that high aeroradioactivity could be used to locate homes with high indoor radon. The homesites where seasonal indoor radon was measured were plotted on an aeroradioactivity map to test this hypothesis.

The pattern of comparisons between aeroradioactivity and indoor radon for all of the three geological units was similar for all four seasons, so only comparisons for the winter data are shown. Figure 15 presents the comparison for the Sykesville Formation homes, Figure 16 is for the Pope's Head Formation homes, and Figures 17 is for the for Mather Gorge Formation homes. All show that in homes located where the aeroradioactivity is between about 200-350 cps, indoor radon was usually less than 5 pCi/L in all the measured homes. However, between about 350-600 cps, some radon measurements exceeded 5 pCi/L.

In summary, these comparisons all suggest that indoor radon tends slightly to increase with aeroradioactivity. However, aeroradioactivity cannot be used to identify areas of high (or low) indoor radon potential sufficiently well to be used to create high confidence radon potential maps. It could, at best, be used as a trend in predicting indoor radon.

4. DISCUSSION

GIS is used to digitize, process and integrate a variety of data, such as geological maps, radon concentrations and aeroradioactivity values associated with house locations. Geostatistical techniques are commonly used to map a range of environmental variables, particularly to generate probability maps that show where variables exceed a given threshold. The approach taken in this research was to examine comparisons between indoor radon data and location, and with geotechnical data. The results were used to determine if there is a relationship between indoor radon and geology, slope, elevation, and aeroradioactivity, and to determine if these geotechnical data could be used to create indoor risk maps.
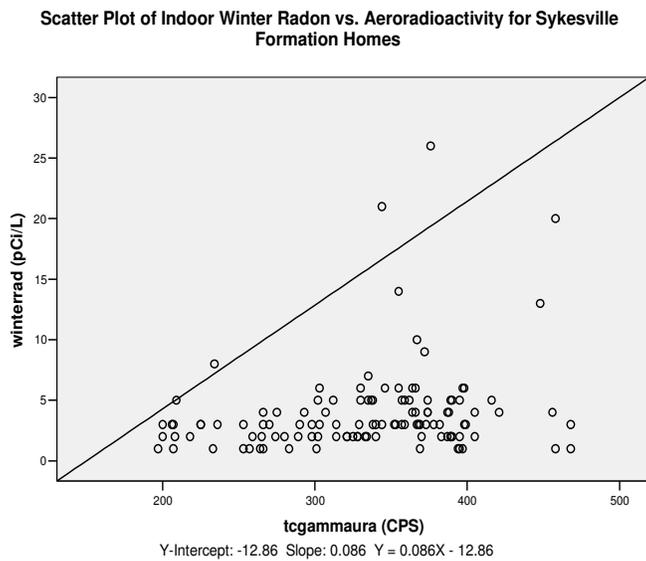
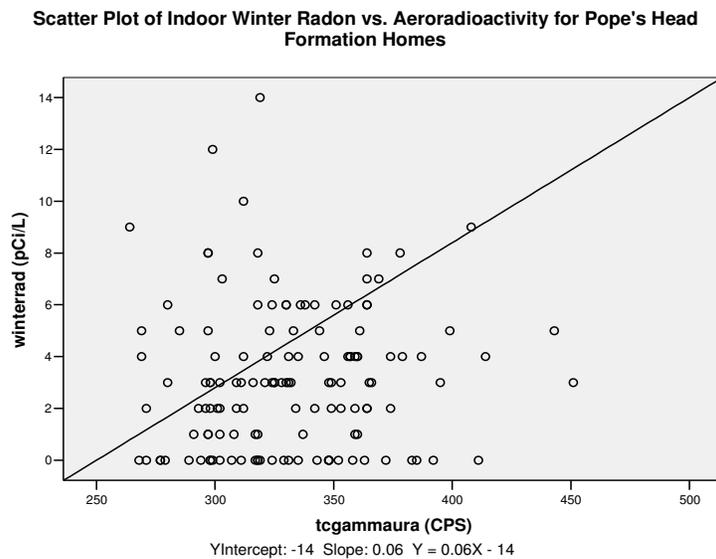*Figure 15*. Scatter Plot of Indoor Winter Radon and Aeroradioactivity for Sykesville Formation Homes

Figure 16. Scatter Plot of Indoor Winter Radon and Aeroradioactivity for Pope's Head Formation Homes

Scatter Plot of Indoor Spring Radon vs. Aeroradioactivity for Pope's Head Formation Homes

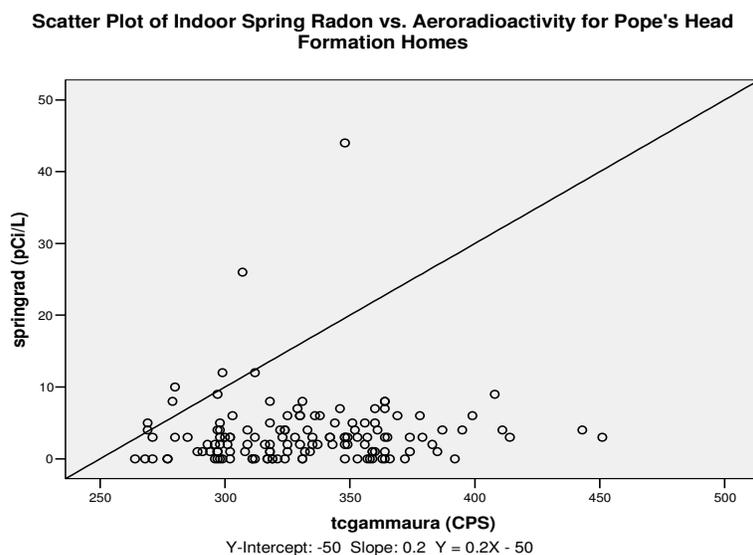Y-Intercept: -50 Slope: 0.2 Y = 0.2X - 50

Figure 17. Scatter Plot of Indoor Winter Radon and Aeroradioactivity for Mather Gorge Formation Homes

A standard ellipse and trend analysis of all the measured homes in Fairfax County revealed a trend in indoor radon measurements, best described as a tendency for indoor radon measurements to be highest in the center of the county (the Piedmont area). This tendency for indoor radon to be greater in the center of Fairfax County was investigated by comparing indoor radon in homes on three different geological units in the Piedmont, on different slopes, at different elevations, and over areas of different aeroradioactivity.

The radon verses geology study focused on examining the indoor radon concentrations in homes constructed over the Piedmont's Sykesville Formation, Pope's Head Formation and Mather Gorge Formation, selected because they have many indoor radon measurements. A statistical analysis of the distribution of measurements in these units showed that there is considerable overlap, and that a radon risk map of high confidence could not be based on the location of these geological units.

The next study was made to evaluate the possibility that slope and elevation influence indoor radon. It was found that indoor radon levels tend to be higher in homes built on lower slope and in homes at lower elevations. Unfortunately, these were weak correlations and a radon risk map of high confidence could not be based on the homesite slope or elevation.

The fourth study was made to evaluate the possibility that aeroradioactivity could be correlated with indoor radon. It was found that aeroradioactivity tends to be only slightly greater in areas with greater indoor radon, so a radon risk map of high confidence could not be based on aeroradioactivity. Indoor radon only has a weak positive correlation with aeroradioactivity.

5. CONCLUSION

The relationships between indoor radon concentrations and geology, slope, elevation and aeroradioactivity were made to target resources into high-risk areas and to encourage builders of new homes to avoid areas with high radon potential. Conversely, if it is necessary to build new homes in areas of high indoor radon potential, it is hoped that the results of this study would encourage builders to use radon resistant building methods. This is becoming an established practice in many countries (Synnott and Fenton, 2005).

The body of techniques embodied in geostatistics (Johnston et al., 2001, Mitchell, 2005) that were used in this study provided the tools requisite to determining the structure of the spatial variation and to evaluate geotechnical information to estimate indoor radon concentrations. This research sought to evaluate the possibility that on a county-size scale, there might be some predictability to indoor radon. In northern Virginia, Fairfax County was used, because there are more radon measurements available for one county than in any other county in North America.

Exposure to indoor radon as a result of soil gas ingress into buildings is the most significant contributor of radiation dose to members of the public (Baixeras et al., 2001). Many countries have carried out radon surveys to establish the extent of this problem. In some cases, these resulted in radon potential maps, but in the present study, it did not.

The investigation showed that there is only a tendency for indoor radon to be greater in some parts of Fairfax County in homes on some geological units, in homes constructed on lower slopes, on sites at lower elevations, and in areas of higher aeroradioactivity. However, none of these physical variables exhibits a strong enough control on indoor radon to be used to construct radon potential maps that carry a high confidence of accuracy. That is, results showed that indoor radon only has a weak positive correlation with geology, slope, elevation and aeroradioactivity.

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