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Analysis of Data Collected in Pilot Study of Residential Radon in DeKalb County in 2015

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Analysis of data collected in pilot study of residential radon in DeKalb County in 2015.

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A Thesis Submitted to the Graduate Faculty of Georgia State University in Partial Fulfillment of the Requirements for the Degree

Master of Public Health

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Abstract

Radon is a colorless, odorless, naturally occurring gas. It is currently the second leading cause of lung cancer and the number one cause of lung cancer to non-smokers in the United States. DeKalb County offers free screening for radon for residents. However, screening rates vary across the county. This pilot study focused on 14 selected tracts within DeKalb County with relatively low levels of radon screening. Over 200 households were recruited and homes were tested for indoor radon concentrations on the lowest livable floor over an 8-week period from March – May 2016. Tract-level characteristics were examined to understand the varitations of race, income, education, and poverty status between the 14 selected tracts and all of DeKalb County. The 14 selected tracts were comparable to all of DeKalb County in most factors besides race. Radon was detected in 73% of the homes sample and 4% had levels above the EPA guideline of 4 pCi/L. Multi-variate linear regression was used to compare all housing construction characteristics with radon concentrations and suggested that having a basement was the strongest predictive factor for detectable and/or hazardous levels of radon. Radon screening can identify problems and spur home owners to remediate but low screening rates may impact the potential health impact of free screening programs. More research should be done to identify why screening rates vary in order to identify ways to enhance screening and reduce radon exposure in DeKalb County.

Analysis of data collected in pilot study of residential radon in DeKalb County in 2015.

By

Sydney Chan

Approved:

Committee Chair : Dr. Christine Stauber

Committee Member: Dr. Dajun Dai

Date

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Curriculum Vitae

Sydney Rachel Chan

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Education

Bachelor of Science, Environmental Science **May 2012**
University of South Carolina

Master of Public Health-Environmental Health **Anticipated 2016**
Georgia State University

Environmental Experience

Eastern Research Group **Atlanta, GA**
Environmental Health Science **September 2015-April 2016**
Contractor to ATSDR

- Reviewed and evaluated environmental data reports for quality assurance and control
- Extracted groundwater data of all organic analytes from over 200 documents
- Coded and entered thousands of lines of environmental data points using Microsoft Excel

Environmental Protection Agency, Region 4 **Atlanta, GA**
Superfund Division, Scientific Support Section **May 2015-August 2015**
Graduate Student Practicum

- Reviewed reports for consistency and technical merit
- Evaluated and interpreted environmental data for human health assessment and decision making at Superfund sites (CERCLA)
- Evaluated data and developed summary statistics and tables for use in Region 10 Regional Methods grant research project
- Assisted in the development of the draft Region 4 XRF Field Operations Guide (FOG)
- Helped to coordinate project activities such as environmental sampling, data collection, and data evaluation for implementation of Region 4 RARE grant
- Collected environmental samples (soil) at an active CERCLA investigation site
- Helped develop risk assessment training program for EPA Superfund Project Managers

Georgia State University **Atlanta, GA**
Graduate Research Assistant **January 2015- August 2016**

- Assisted in research plan development and set priorities for implementation
- Collected environmental data through air sampling of Radon
- Analyzed and interpreted data looking for patterns and correlations

Blue Heron Nature Preserve **Atlanta, GA**
Summer Internship **May 2014-August 2014**

- Wrote, submitted, and awarded grant for "Grants to Green"
- Worked directly under President and Founder to learn leadership and communication skills
- Measured water table level of wetlands and compiled and analyzed data through Excel using graphs and tables

Gamecock Biofuels **Columbia, SC**
Field Curator **January 2012-May 2012**

- Conducted process of converting waste vegetable oil into biodiesel
- Tested product and evaluated data throughout conversion process including pH, Sandy Brae, and 27/3
- Educated campus and community about renewable, reusable energy through fairs and classes

University of Pretoria **South Africa**
Vets-In-The-Wild **June 2011**

- Studied the spread, containment, and cure of wildlife diseases to implement throughout parks and townships
- Helped drive animal vaccination program through townships to stop the spread of rabies
- Communicated health information to the public

Certifications and Training

- EPA Specific Training
  - Scientific Integrity Policy Training
  - Introduction to Environmental Justice
  - Interspecies Extrapolation in the Derivation of Oral Reference Doses
  - Children's Environmental Health Training
- National Environmental Trainers Inc.
  - 40-Hour HAZWOPER and annual refresher
- FEMA
  - National Incident Management System,
    - ICS 100
    - ICS 700
    - ICS 200
- Collaborative Institutional Training Initiative (CITI Program)
  - Conflict of Interest
  - Social Behavioral
  - Social and Behavioral Responsible Conduct of Research
- Board of Regents of the University System of Georgia
  - RTK-Global Harmonized System Training
  - Hazardous Waste Awareness Training

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CHAPTER I
INTRODUCTION

1.1 Background

Radon, the daughter product of uranium, is a naturally occurring, colorless, odorless, tasteless, radioactive gas (American Cancer Society, 2015). Radon has been classified as a known human carcinogen based on human studies (CEE, 2003). It was originally listed in the *Seventh Annual Report on Carcinogens* in 1994 (National Toxicology Program, 2010). Radon is a gaseous substance that easily mobilizes throughout the geosphere, atmosphere, and biosphere (IARC, 2013). The first indoor radon tests were conducted between the years of 1975 and 1978 by the US Department of Energy (George, 2015). After high levels were found throughout Pennsylvania due to mining for uranium, the US Radon Industry was born in 1984 (George, 2015).

Radon is currently the second leading cause of lung cancer, only behind smoking cigarettes (EPA, 2015). The only way to know one's level of exposure is to test their home (EPA, 2015). An interactive map of the United States has been provided by the Environmental Protection Agency (EPA) on a county-level basis to show which "zone" the county you reside in falls. Zones are classified into three different tiers: Zone 1 are counties with predicted average indoor radon screening levels greater than 4 pCi/L, Zone 2 are counties with predicted average indoor radon screening levels between 2 and 4 pCi/L, and Zone 3 are counties with predicted average indoor radon screening levels less than 2 pCi/L (EPA, 2015). Remediation is advised for any concentration over 4.0 pCi/L (EPA, 2015).

There are four Zone 1 counties in Georgia: DeKalb, Fulton, Gwinnett, and Cobb. As seen in Figure 2.2, made by Fredrick Neal, the screening prevalence of radon throughout DeKalb

County is dispersed with some areas of high screening and other tracts with only 1% of homes screened, based upon available data from DeKalb County. Understanding the possible reasons behind the spatial distribution of screening throughout DeKalb County, focusing on the 14 under screened tracts selected, is one of the main gaps to be answered by this pilot study. Another factor not focused on in the overview of the pilot study is the underlying geologic bedrock in DeKalb County. Underling bedrock can be a predictor of high radon concentrations (Demoury et al., 2013). There has been a measured positive association between gamma emissions and indoor radon concentrations (Berens, 2016). Geogenic radon potential maps have been found to be strong predictors of indoor radon concentrations (Demoury et al., 2013). The main focus of this pilot study is to understand radon levels and characteristics of homes in 14 census tracts that have low screening rates.

1.2 Study Objective

The objectives of this study are:

- To describe a pilot study of household recruitment for in home radon measurements
- To analyze radon levels in home and identify:
    - Spatial distribution of radon in sampled homes
    - Associations with housing characteristics and levels of radon in homes using the pilot study data

CHAPTER II
REVIEW OF THE LITERATURE

2.1. Worldwide statistics of radon screening levels

Radon is the second leading cause of lung cancer among smokers and the leading cause of lung cancer among nonsmokers (EPA, 2015). Different exposure pathways have been measured to understand the best predictor to detect indoor radon concentrations. Studies within the United States have shown soil is the most prominent contributing factor to indoor radon (IARC, 2013). When focusing on indoor radon concentrations, the main contributors are due to exhalation from underlying rocks and soils and certain building materials (IARC, 2013). Exposure to radon is primarily through inhalation via vapor intrusion as your home acts as a vacuum for the gaseous substance (EPA, 2015).

Different housing characteristics have been examined to look for associations with hazardous radon concentrations. Building type, foundation type, housing type, construction year, and floor tested have been found to be predictors of indoor radon (Demoury et al, 2013). According to the EPA, the average indoor concentration within the United States is around 1.3 pCi/L. EPA recommends remediation at 4 pCi/L. As seen in Figure 2.1, found on the EPA website, at 4 pCi/L approximately 62/1000 smokers could get lung cancer over their lifetime.

Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO: Stop smoking and...
20 pCi/L	About 260 people could get lung cancer	250 times the risk of drowning	Fix your home
10 pCi/L	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix your home
4 pCi/L	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix your home
2 pCi/L	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 20 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	

Note: If you are a former smoker, your risk may be lower.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Figure 2.1 Risk of cancer due to exposure from radon if you smoke cigarettes (EPA, 2015).

2.2 Country-wide screening promotional programs

Raising awareness throughout the nation will help to reduce to the annual deaths contributed to lung cancer due to radon exposure. Testing a home is the only way to know if you are at risk (EPA, 2015). Raising awareness on a large-scale basis can fall into two main categories: predictive mapping and home screening. Both raise awareness of the potential presence of radon where predictive mapping can show residents if they live in an area that may be prone to higher levels while home screening awareness does not target specific areas due to predisposition.

2.2.1 Mapping to predict potential for radon

Models have been developed using geologic data to predict areas that may have a predisposition for radon exposure due to uranium bedrock (Gagnon et al., 2008). Because radon is the daughter product of uranium (EPA, 2015), mapping areas of underlying uranium bedrock helps to predict where high levels of radon concentrations are more likely to occur (Gagnon et al., 2008). Within the United States, the U.S. Geological Survey (USGS) created a database of soil, geology, and radioactivity that helps to predict where high radon concentrations are more likely to be measured (USGS, 1995). In addition to the USGS database, airborne gamma ray spectrometry (ARGS) mapping is currently being evaluated for its predictive power in presence of radon, results concluding ARGS mapping more predictive than geologic maps produced (Smethurst et al, 2015). ARGS predictive maps, within a study in Norway, produced results suggesting that it was more effective than random sampling strategy in identifying target areas. An amalgamation of three different variables: uranium concentrations from airborne measures, uranium concentrations in sediment, and a combination of bedrock, surficial geology, and basement radon concentrations, were mapped to identify radon-prone areas within Quebec resulting in approximately 98% predictive of detecting radon(Drolet et al., 2013).

2.2.2 Raising awareness of home screening

Radon screening programs within the United States began in the late 1950's when mining for uranium began in the MidWest (George, 2015). Different approaches such as webinars, public forums, and social media outlets have been used in attempt to raise awareness at a national level (Cheng, 2016). The Agency for Toxic Substances and Disease Registry (ATSDR) has partnered with many different states to raise awareness nationally through the education system (Foster, et al., 2015). Surveys conducted have shown three main factors to influence the likelihood of testing: perceived severity, social influence, and if they are current smokers (Rinker et al., 2014).

2.3. Screening programs implementation on the state level

Radon screening at the state level can vary pending on funding, geological predisposition, and awareness of the population. Programs such as Freedom from Radon and Smoking in the Home can help to raise awareness throughout a community to show the synergistic cancer risk effect that occurs with exposure to both indoor radon along with smoking (Hahn et al., 2014). ATSDR is currently working with schools in the state of Georgia to partner screening and awareness at the elementary education level (Foster, et al., 2015). Coloring/activity books have been given to elementary students participating in the educational awareness classes in hopes to incorporate the activities with home assignments. Giving “homework” to the children in the awareness classes is aimed to engage the guardians to raise awareness and understand the dangers of radon in their area (Foster et al., 2015).

Statewide databases can be compiled if regulations are put in place to require all results be reported when tests are conducted (Casey et al, 2015). Using certified testers and laboratories, levels of radon readings are reliable and help to depict areas throughout the state that have a higher risk of exposure. Some states, such as Pennsylvania, have required all radon test results from building and homebuyer’s transactions be reported (Casey et al, 2015). Regulations requiring any radon test conducted to be reported helps to give a better understanding of which areas are lacking testing and which have shown results of “hotspots”.

2.4 Screening and mitigation implementation at the County level

Screening at the county level has been useful in many different studies to understand different approaches to initiate homeowners to test for indoor radon. A pre-post survey comparison showed that participants are more aware of the potential synergistic lung cancer risk when exposed to radon and secondhand smoke (Hahn et al., 2014). Implementing remediation options to reduce exposure to indoor radon increases as awareness of the risk has been revealed on a personal level (Hahn et al., 2014). Currently, there are four counties in the state of Georgia that are ranked U.S. EPA Radon Zone 1, meaning that the predictive average of the area is greater than 4 pCi/L: Cobb, DeKalb, Fulton, and Gwinnett (EPA, 2015). As shown in Figure 2.4, the screening rates throughout DeKalb County are spatially diverse with no true trend.

In order to help mitigate the costs of testing for radon, DeKalb County currently has a free screening program for all DeKalb County homeowners. The link for DeKalb County's website can be found at: http://dekalbhealth.net/envhealth/radon/. Other important information pertaining to radon such as background information, hazards, and mitigation options can all be found at the above website. Programs such as the free screening put in place by DeKalb County can help to raise awareness and screening levels in areas that have been deemed predisposed to high concentrations.

Free screening kits provided to DeKalb County residents can help to advance the knowledge of radon prevalence throughout the area. Free screening programs, such as the one offered by DeKalb County, can also help to raise awareness within communities. Neighbors often communicate with one another, spreading awareness via word-of-mouth. Free testing allows those to test their homes that may not otherwise spend the money.

The pilot study described here not only provided free screening of homes, but added an incentive to get homes tested. The aim of this pilot study is to improve scientific knowledge and understanding of implementation programs that help to raise awareness and screening rates of radon.

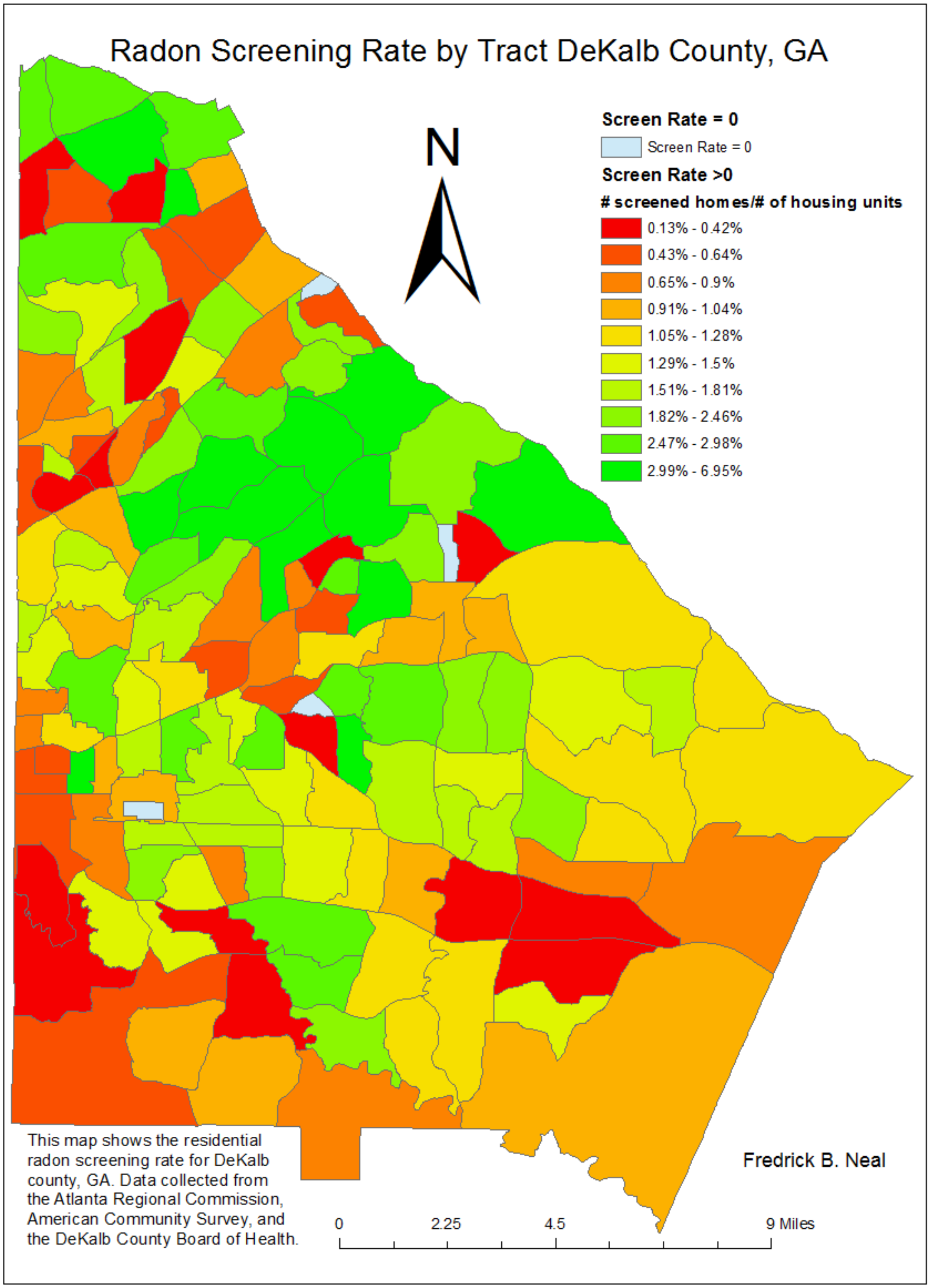

Figure 2.4 Map of radon screening levels by tract in DeKalb County.

Chapter III

METHODOLOGY

3.1 Training and IRB Approval

Georgia State University students from Geosciences Department and the School of Public Health were hired to be involved in the research project. These graduate research assistants recruited volunteer students along with faculty members. All students and faculty members who were involved in the fieldwork completed CITI training. In addition, all volunteers were involved in training about how to recruit households and place the screening tests in the home. Training took place in March 2015 and recruitment took place in March through May 2015. Each volunteer was taught how to properly express the hazards of indoor radon, fill out the questionnaire, hang the test kit, and the proper communication strategies with participants. Because this pilot study had interaction with human subjects, institutional review board (IRB) approval was required. The Georgia State University IRB approved this project (IRB No.H14542). Funding was awarded from the National Institute of Minority Health and Health Disparities.

3.2 Study Recruitment Procedures

Fourteen tracts within DeKalb County were selected based on estimated low percentage of dwellings screened for radon. The recruitment goal for the project was to collect 200 indoor air samples on the bottom livable floor of the house. Recruitment of homes began on March 28th 2015 with recruitment occurring every Saturday until May 16th 2015. Groups of two trained employees and/or volunteers were partnered and traveled to one or two of the census tracts each Saturday. Randomly selected addresses were provided for initial approach. If the household did not respond, a household on the same street within three to five households was contacted. When the owner of the house answered the door, he was provided details on the goals of the project and asked if they were willing to participate. If he agreed to participate, he provided informed consent, a survey was performed, and a radon test kit was installed in the home. Between 72 to 148 hours later, two trained volunteers/employees would return to the home to collect the radon kits.

3.3 Data collection

Once the homeowner agreed to participate in the study, the questionnaire was administered. See Appendix A for sample questionnaire form. In the survey, the following data was reported or observed about the housing characteristics: age of home, foundation, building type, and housing type. In addition, the primary respondent was asked to answer questions about the following: the presence of any children under 18 years of age, presence of smoking and any prior knowledge of radon. After the questionnaire was complete, the kits were hung eye level on any interior wall of the lowest livable floor. Basic facts were collected such as start time, date, and average temperature of the home. One main requirement of the test to help to ensure validity of the result was that all windows and doors remain closed to capture the highest possible levels of indoor radon, yet it is unknown whether a homeowner strictly followed the rule. For every 20 homes sampled, a duplicate test kit was placed on the same floor for quality assurance/quality control. Test kits were products of Air Chek, Inc. More information on the kits can be found at www.radon.com.

For successful completion of the radon test, the resident would receive a $15 Walmart gift card during pick up of the test kit. Each kit was sealed and immediately dropped in the mail for analysis by Air Chek laboratories. Results were emailed to Dr. Dajun Dai, the project lead, and shared with one designated project staff for analysis.

3.4 Data analysis

The questionnaires were entered into Microsoft excel along with the results from the radon screening assays. The questionnaire data were then analyzed using descriptive statistics to describe the sample. In addition, radon levels in homes were examined and an analysis of association between measured radon levels and households characteristics was performed using two-sample t-tests and one-way ANOVA. Two different chi-squared tests were run to compare level of home tested to detection of radon. The first test compared level of home tested versus detection of radon and the second chi-squared test compared level of home tested versus hazardous levels of radon and those below. All tests were run using Stata version 13.0.

3.5 American Community Survey Data

In addition to the data collected in the pilot study, data from the American Community Survey (ACS) was also examined. The following variables were extracted from the 2014 5-year ACS database for the fourteen census tracts**:** Educational attainment, income, race, and poverty status. For these, the fourteen census tracts were compared to the rest of the county to determine whether or not the census tracts were different when comparing the pilot sample to the rest of DeKalb County.

Chapter IV

RESULTS

4.1 Description of results

Based on an analysis of ACS data regarding income, education, poverty, and race, all fourteen census tracts in which samples were drawn were compared to the entire county. This comparison is provided in Table 4.1. Table 4.1 was generated to compare the 14 sampled tracts to all of DeKalb County.

Table 4.1 ACS data comparing the 14 selected tracts to all of DeKalb County

		14 Sampled Tracts	**All of DeKalb County**
Race			
Population		89,172	722,161
	White	8.61%	35.30%
	Black/African American	85.70%	53.70%
	American Indian/Alaska Native	0.127%	0.26%
	Asian	3.21%	5.75%
	Native Hawaiian & Other Pacific Islander	0.00%	0.02%
	Other	0.58%	2.75%
	Two or more	1.81%	2.24%
Education (25 yrs old +)			
Population		56,607	484,408
	Less than HS	9.25%	11.60%

	HS Graduate (includes equivalency)	27.44%	21.00%
	Some college/associate degree	33.03%	25.70%
	Bachelor's degree or higher	30.28%	41.80%
Average income at household level (2014 inflation adjusted)			
		$68,277	$73,744
Poverty Status			
Population		86,913	692,359
	Below poverty level	19.83%	19.60%

As shown in Table 4.1, there are some differences between the 14 tracts samples and the overall distribution when examining race. The most prominent difference between our 14 sampled tracts and all of DeKalb county shows that there is a higher proportion of African Americans present in the 14 census tracts from the pilot study compared to the entire county (83% versus 53% respectively). Educational attainment comparisons for the pilot census tracts and the rest of the county suggest somewhat lower levels of population with a bachelor's degree compared to the rest of the county. Average household income was with roughly $5,000 lower in the pilot study census tracts.

Household recruitment survey:

A total of approximately 269 man-hours of recruiting were invested in the pilot study. The hours calculated do not reflect the time it took to retrieve each test kit, preparation time of the packets, nor time spent organizing and filing data. Recruitment logs of houses visited were kept to represent houses that 1) were approached and allowed testing 2) were approached but nobody was home or 3) were approached but did not want to participate in the study. Of the 471 recorded visitor logs, the willingness to participate were 127 (26.96%) yes, 259 (54.99%) unanswered, and 85 (18.05%) unwilling to participate. (Note that not all visitor logs were accounted for.) After all recruitment was completed, a total of 217 homes participated in the pilot study. Of the 217 tested households, 16 results came back invalid.

A summary of the characteristics of the households participating in the survey is provided in Table 4.2. Construction year of homes ranged from 1950 through 2014, with the median year of home built in 1997. Housing type of homes tested was dominated by multi-story homes, 113 (52%) out of 217 tested. Approximately 28% were split-level homes tested and 1/5th were ranch-style homes. Homes were identified to be mostly frame construction (64%) followed by brick (19%) and then some combination of frame, brick and/or block. The majority of foundations were slab (61%) with 27% with basements and 11% with crawl spaces. Over 75% of the screening tests were conducted on the 1st floor of the home.

Approximately ¾ of the homes tested did not have smokers present or living in the house. There were 49 (23%) of homes tests that reported smoking in the house. Knowledge of radon was assessed, with 115 (53%) out of 217 having previous knowledge of radon and approximately half had children residing in the home.

4.2 Radon Results

Of the 201 radon screening tests that came back with a valid test result, 154 (78.12%) were collected from the 1st floor with the remaining collected from the basement. Of the valid 201 results, approximately 26% of the samples resulted in no detection of radon. The detection limit of the sample was 0.3 pCi/L. A histogram of the results is provided in Figure 4.2.1. As demonstrated in the histogram, the distribution of radon results does not appear to be normally distributed and the values ranged from <0.3 pCi/L to 10.8 pCi/L. For analytical purposes, all non-detects were assigned a value of 0.15 pCi/L. Figure 4.2.2 shows all radon results from the 14 selected census tracts, showing no spatial trend of radon concentrations.

Table 4.2. Descriptive results of the 217 homes tested in DeKalb County in 2015

		N	%
Smokers		217	
	Yes	49	22.58
	No	167	76.96
	Missing	1	0.46
Children living in home			
	Yes	109	50.23
Heard of Radon			
	No	115	53
Floor tested			
	1st	171	78.8
	Basement	45	20.74
	Missing	1	0.46
Housing Type			
	Split-level	61	28.11
	Ranch	45	20.74
	Multi-story	113	52.07
Building Type			
	Block	3	1.4
	Brick	41	18.89
	Frame	140	64.52
	Other	32	14.75
	Missing	1	0.46
Foundation Type			
	Basement	59	27.19
	Crawl Space	25	11.52
	Slab	133	61.29

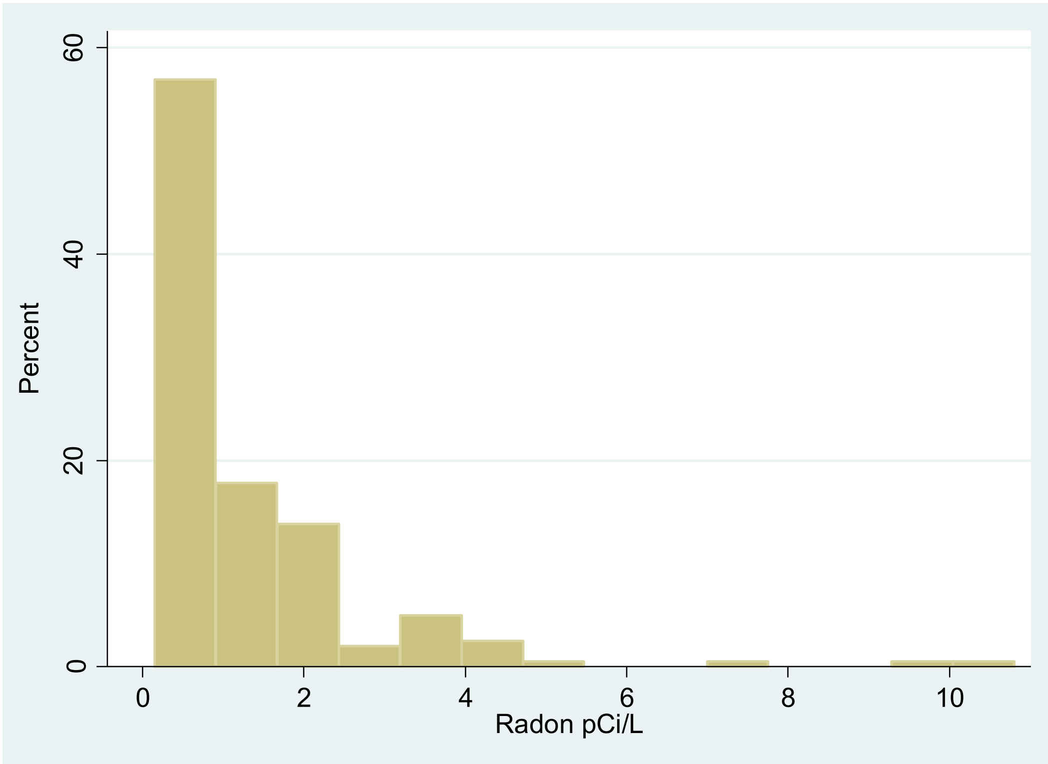

Figure 4.2.1 Histogram of radon results from 201 homes tested in DeKalb County.

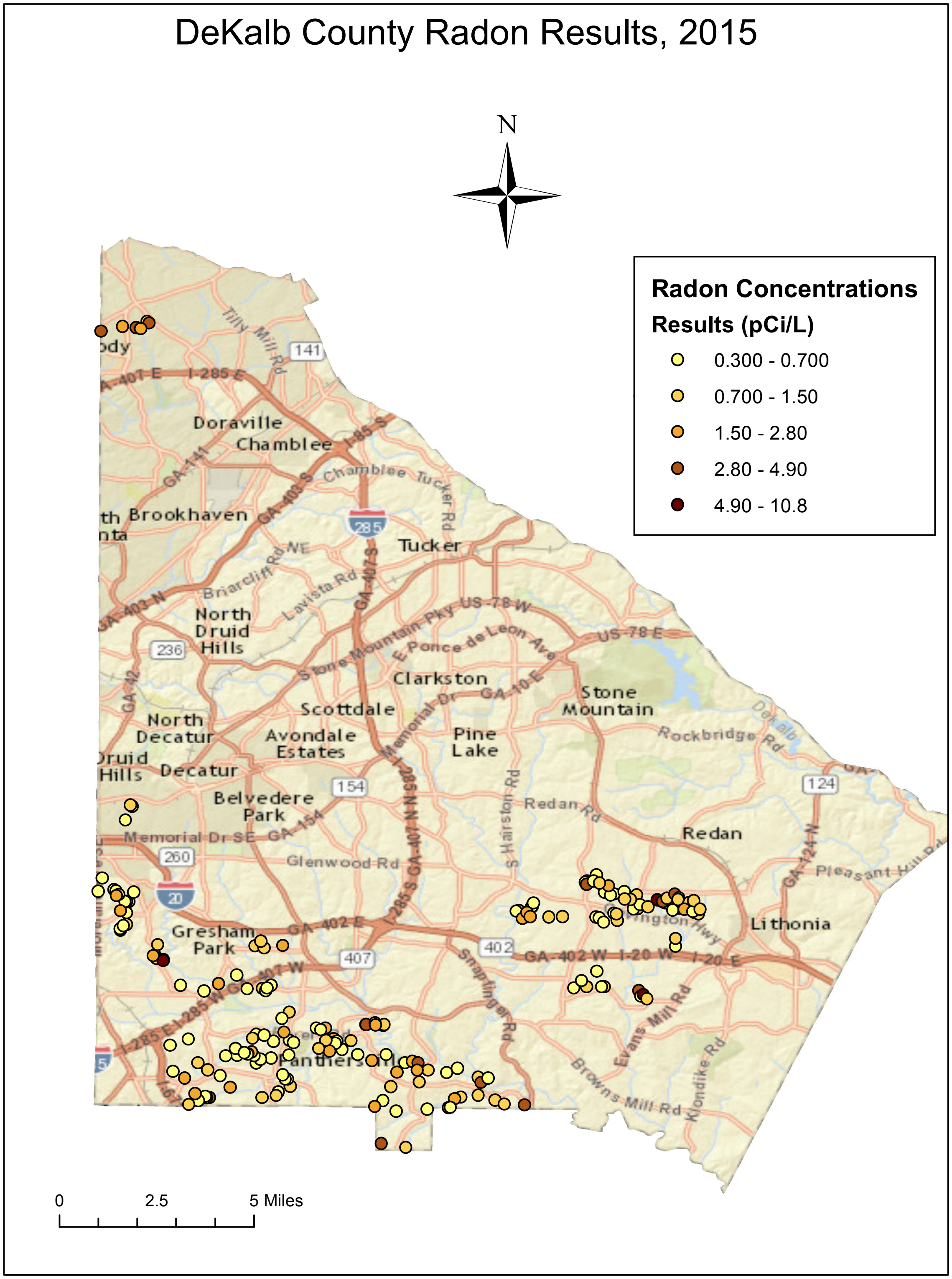

Figure 4.2.2 Map representing radon results within the 14 sampled tracts of DeKalb County (2015).

4.3 Association of radon and variables

In an attempt to determine which housing characteristics had the biggest impact on radon in our sample, we examined the results graphically and with both linear and binary logistic regression. All tests were set to p-value of 0.05. As shown in Figure 4.3.1, the box-and-whisker plots comparing radon values over housing type do not suggest large variations for radon concentration. Average concentration for ranch homes was the highest at 1.53 pCi/L, with multi-story and split-level homes at 1.15 pCi/L and 1.17 pCi/L, respectively. An analysis of variance (ANOVA) found no statistically significant differences across housing type (p-value = 0.35).

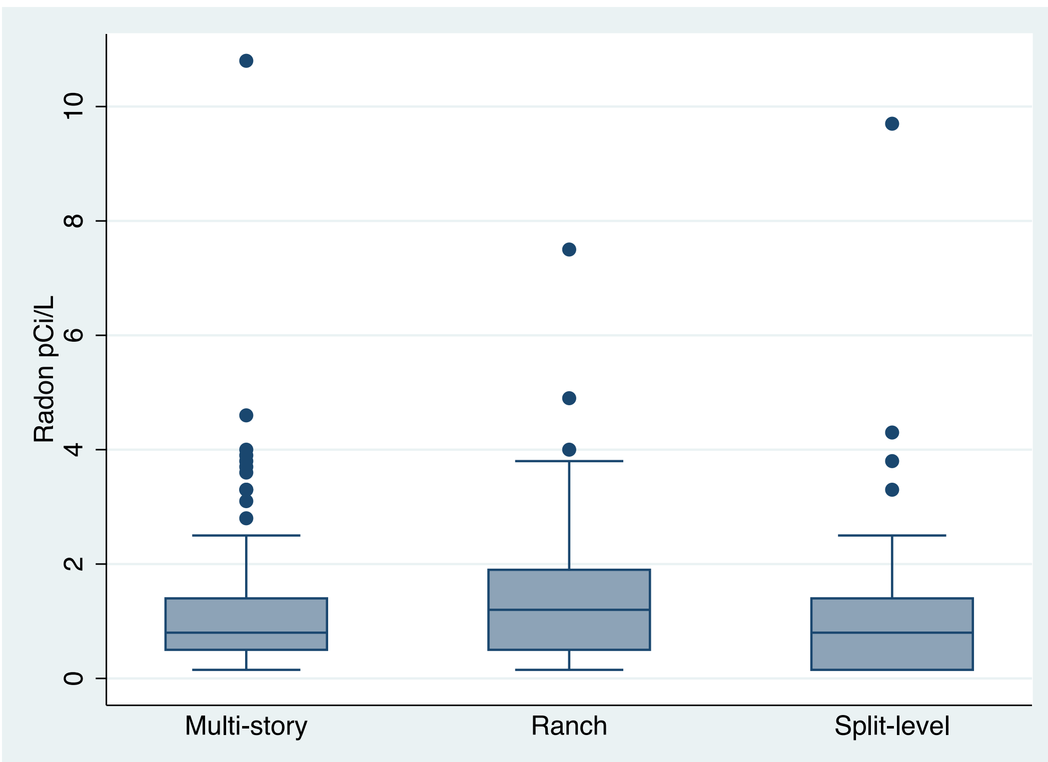

Figure 4.3.1 Box-and-whiskers plot of radon results and housing type of 217 sampled homes in association with radon results.

Foundation type was examined for an association to radon. Results are presented in Figure 4.3.2 and suggest that basement had the highest interquartile range (IQR), with a statistically significant difference between the three foundation types, p-value = 0.0001. Houses with basements as their foundation type had the highest average radon concentration of 1.92 pCi/L with slab and crawl space averages to follow, 0.98 pCi/L and 0.81 pCi/L, respectively.

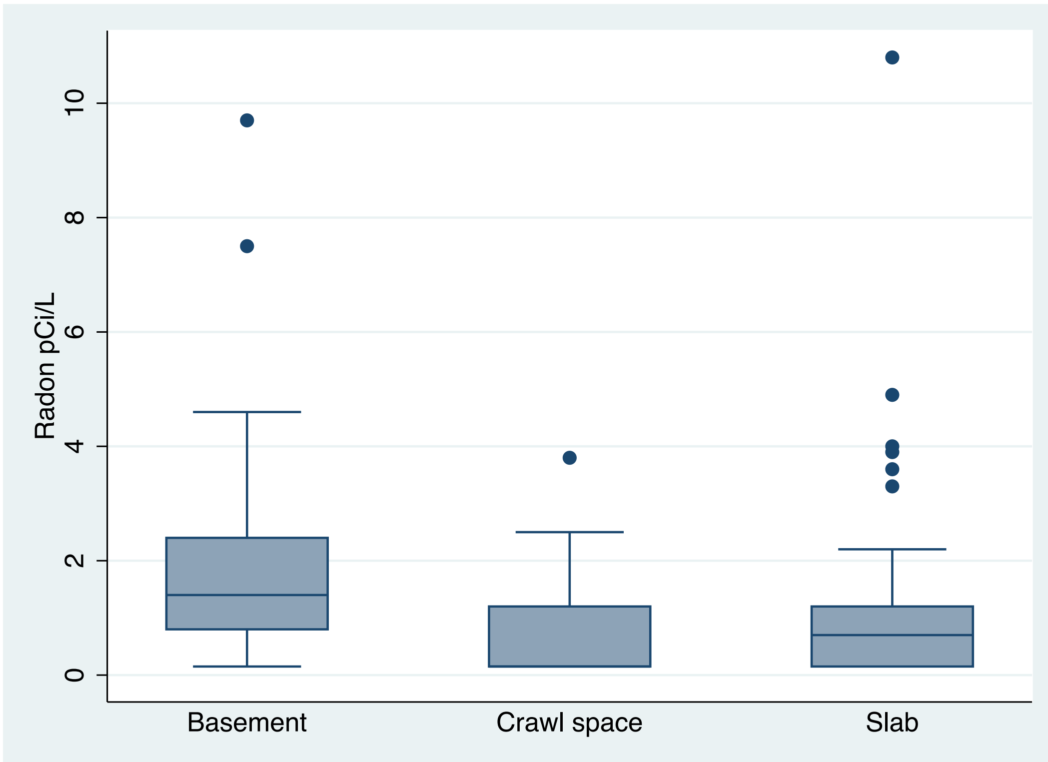

Figure 4.3.2 Box-and-whiskers plot of radon results and foundation type of 217 sampled homes in association with radon results.

Building type and the association with indoor radon concentration was also examined. The average concentration of radon for brick building types was 1.35 pCi/L. Frame building type resulted in the highest radon results, 10.8 pCi/L, but the average concentration was 1.29 pCi/L. For homes with building type categorized as “Other” the average radon concentration was 0.92 pCi/L. The three block homes had the lowest average concentration of 0.72 pCi/L. After comparing 50th percentiles across the four different building types: block, brick, frame, other, the results supported that brick had the highest radon concentrations with a 50th percentile of 1 pCi/L. As shown in Figure 4.3.3, the box-and-whiskers plot reveals no statistically significant different between the building types and detecting radon, p-value = 0.5344.

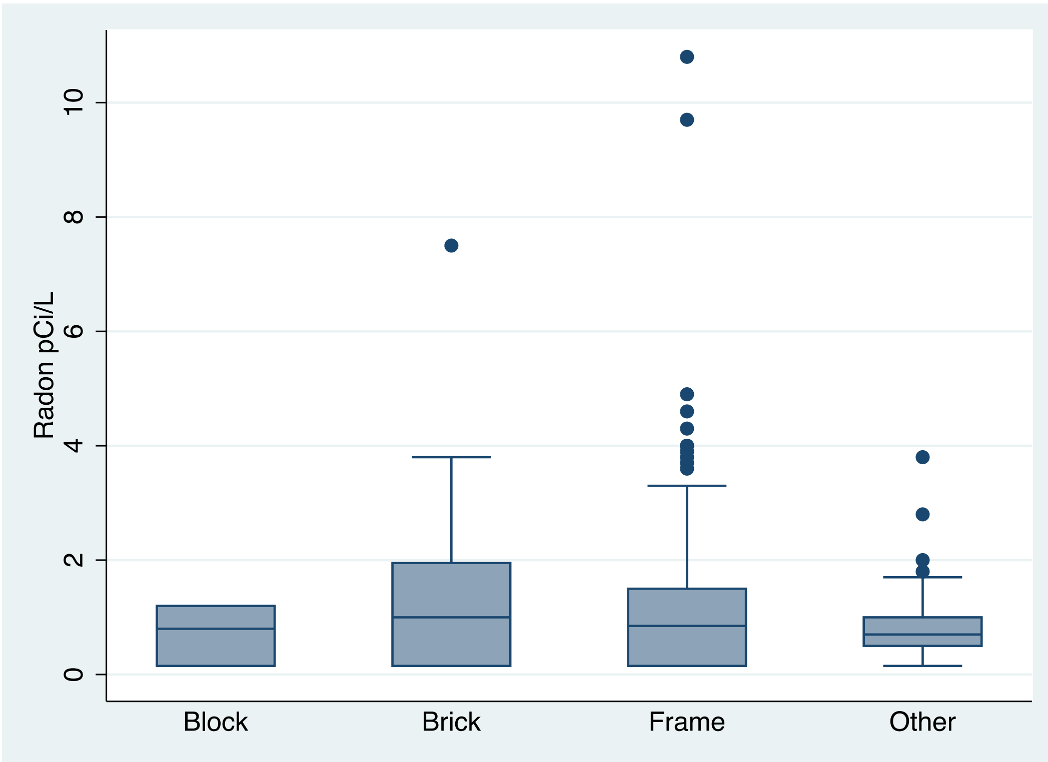

Figure 4.3.3 Box-and-whiskers plot of radon results and building type of 217 sampled homes in association with radon results.

A two-sample t-test was performed to look differences in mean radon concentration by the location of the sample test (1st floor or basement). . The average concentration for tests performed on the 1st floor was 0.98 pCi/L (95% CI [0.79, 1.17]) and the average concentration for tests performed in basements was 2.08 pCi/L (95% CI [1.02, 1.43]), a statistically significant difference as indicated by two-sample t-test ($p < 0.001$). As shown in Figure 4.3.4, the box-and-whiskers plot revealed there appears to be a difference in average radon concentrations between the two floors sampled.

Both raw radon concentrations and log transformed concentrations were found to have this statistically significant difference concluding that floor of home tested was associated with a difference in radon concentrations with basement resulting in higher concentrations.

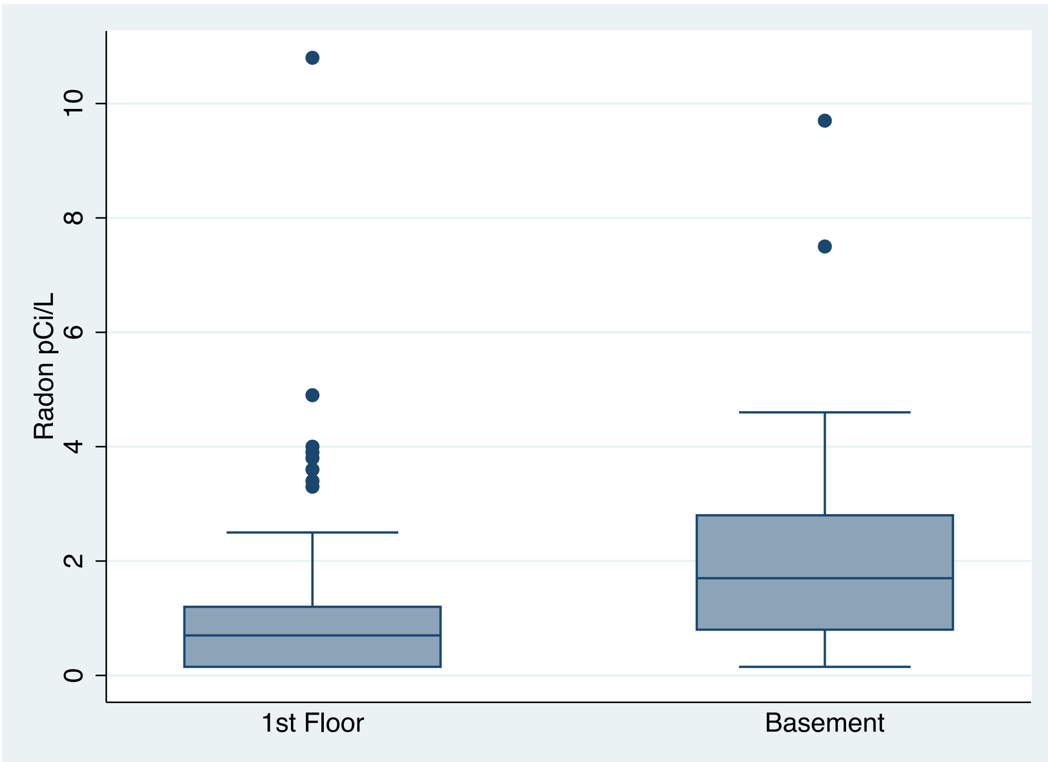

Figure 4.3.4. Box-and-whiskers plot of radon results and floor of home tested of 217 sampled homes in association with radon results.

After coding radon results into a binary variable of presence versus absence of radon, as detected with the screening test, a chi-squared test was performed to examine the various household and sample characteristics that might be associated with detection of radon. There was no statistically significance difference between the two floors of home tested when looked at detection versus not, p-value = 0.065.

In addition, we examined radon results which resulted in hazardous levels (above EPA guidelines) to determine if there was any association with sample location. There was a statistically significant difference of radon results and floor of home tested when separating into hazardous levels versus not, p = 0.005, with basement samples resulting in more hazardous detections.

Three different one-way ANOVA tests were run to look at the individual relationship of housing type to radon concentrations, construction year to radon concentrations, and building type to radon concentrations. As seen in the Table 4.3, all three did not reveal a result of statistical significance. P-values resulting in 0.3499, 0.3048, and 0.5344, respectively. A final one-way ANOVA was run to examine the relationship of foundation type to radon concentrations. Foundation type was found to be a significant predictor of radon concentrations (p-value of 0.0001).

In addition to one-way ANOVA, a multi-variate linear regression was preformed to examine all housing factors at once and to identify the strongest predictor of radon in the home. The results suggested that foundation type is the strongest predictor in observing a detection of radon in the home, p-value = <0.001 while all other housing characteristic variables were no longer statistically significantly associated with radon concentrations.

Table 4.3 Summary table of associations of housing characteristics and radon from one-way ANOVA testing.

Housing Characteristic	**P-Value**	**Statistically Significant**	**Application**
Housing Type	0.3499	No	Not a strong predictor of radon concentration
Construction Year	0.3048	No	Not a strong predictor of radon concentration
Building Type	0.5344	No	Not a strong predictor of radon concentration
Foundation Type	0.0001	Yes	Predictor of detecting radon
Floor of home sampled	0.065	No	Not a strong predictor of radon concentration

Chapter V

DISCUSSION AND CONCLUSION

5.1 Discussion

Indoor radon exposure due to vapor intrusion can lead to 22,000 deaths annually (WHO, 2015). The only way to know the presence of the naturally occurring, odorless, tasteless, and colorless gas is the test your home (EPA, 2015). In our pilot study in 14 census tracts with relatively low screening rates, we found that of the homes tested in the pilot study, 73% resulted in detection of radon with only 4% above the recommended remediation limit (4 pCi/L). Of the housing characteristics assessed, the presence of a basement was the strongest predictor of both the presence and concentration of radon.

Other researches have conducted free radon testing kits to help raise awareness of radon screening (Bain et al., 2016). The Iowa Cancer Consortium funded a study conducted in Iowa with a single event hosted by a local physician resulting in over 350 new homes screened (Bain et al., 2016). Screening was not random as in our pilot study, but awareness was raised among the community through one event hosted by a local physician. A pilot study conducted in Bulgaria had similar findings to our pilot study revealing differences in radon concentrations of homes with and without basements (Ivanova et al., 2013). Construction year and housing type was also examined in a study conducted in Israel. This study found that apartments and newer homes had higher average levels of radon (Epstein et al., 2013). The findings of the Israeli study may differ from ours due to “residential secure spaces” now built in newer homes. These spaces can act as a vacuum and storage area for radon to build in concentration since the purposes of the rooms are to be air-tight (Epstein et al., 2013).

When comparing our 14 census tracts to the rest of the county, we found a higher proportion of African Americans compared to the rest of the county, 83% versus 53% respectively. Educational attainment, poverty status, and average annual income were similar between the 14 tracts and all of DeKalb County. These 14 census tracts were selected because of their comparatively low screening rates based on an analysis of screening data. Whether or not this difference would result in increased exposure to radon to these populations is not clear. However, it is important to understand how and why people take advantage of screening programs such as this one and how it could be enhanced in areas where it is not currently being used.

5.2 Study Limitations

This pilot study aimed to understand the spatial distribution of screening within DeKalb County along with associations of housing characteristics and concentrations of radon in the home. The sample size of 201 valid results was a limitation to the study, limiting the power of our results when running statistical tests. Another challenge experienced during the pilot study was the willingness to participate. Many homeowners did not want the faculty/volunteers to enter the home and leave a sampler on their walls. Trust between the homeowners and researchers was low causing recruitment to be a harder process than anticipated.

Seasonal variation was also a limitation to this study. The screening and recruitment process was conducted during the spring months in Georgia. A requirement for accurate testing requires that all windows and doors remain shut with no fans or air conditioning blowing on the tests, allowing maximum concentrations of radon to be observed. It is possible that this could have reduced detection and concentrations of radon in the home during screening tests.

5.3 Recommendations

For future studies, raising awareness in the community before knocking on individual homeowners doors could help to save time and resources. As seen an Iowa study conducted by Bain et al. (2016), building a network of trust within the community could help to advance the willingness to participate in the study. If time permitted, repetitive testing of participating homes should be examined to understand and identify seasonal variations of radon concentrations in the home.

5.4 Conclusion

Radon is the second leading cause of lung cancer and its presence remains unknown unless tested for. In the 14 tracts selected throughout DeKalb County, 4% of the homes tested resulted in levels above 4 pCi/L. Houses with a basement were more likely to have radon detected in the home.

Housing characteristics along with descriptive statistics may help to identify areas to increase screening and potentially reduce exposure. Increasing screening will be an important step in that effort and targeting screening in areas that may have both high potential exposure and low screening could be beneficial.

APPENDIX A

Georgia State University Radon Test Information Sheet

Home Owner ID____________________

Research Staff Name____________________Panther ID ____________________

Sampling Address____________________________________City_________State/Zip____

Homeowner Address (if different) _____________________City_________State/Zip____

House Type:
Ranch () Split-Level () Multi-Story () Other___________ Construction Year______

Building:
Frame () Brick () Block () Other__________

Foundation:
Slab () Crawl Space () Basement () Other______________

Number of Smokers ______ Number of Children (under 18) _____________

Homeowner Awareness: Newspaper () T.V. () Radio () Family () Friends () Neighbors () Other________

Monitor ID______________Date Placed _________ Time Placed _____________
Date Removed_________ Time Removed ___________
Floor: _____________

Test Methods: Charcoal () Continuous Monitor ()

Room Tested: Living () Bedroom () Den () Hallway () Office () Basement () Other_____

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